AIRCRAFT ACCIDENT REPORT 7/88

Air Accidents Investigation Branch

Department of Transport

Report on the accident to Fokker F27 Friendship G-BMAU 2 nm west of East Midlands Airport on 18 January 1987

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

21 November 1988

The Right Honourable Paul Channon
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr M M Charles, an Inspector of Accidents, on the circumstances of the accident to Fokker F27 Friendship G-BMAU, which occurred 2 nm west of East Midlands Airport on 18 January 1987.

I have the honour to be
Sir
Your obedient servant

D A COOPER
Chief Inspector of Accidents

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5. APPENDICES

Air Accidents Investigation Branch

Aircraft Accident Report No: 7/88
(EW/C998)

Registered owner:		British Midlands Airways Ltd
Operator:		British Midlands Airways Ltd
Aircraft	*Type:*	Fokker F27 Friendship
	Model:	Series 200
	Nationality:	British
	Registration:	G-BMAU
Place of Accident:		2 nm west of East Midlands Airport
		Latitude: 52° 49' 55" N
		Longitude: 001° 22' 50" W
Date and Time:		18 January 1987 at 1415 hrs
		All times in this report are UTC

SYNOPSIS

The accident was notified at 1424 hrs on 18 January and the investigation commenced that day. The AAIB team consisted of Mr M M Charles (Investigator in Charge), Mr J D Payling (Operations), Mr A H Robinson (Engineering) and Mr P F Sheppard and Mr R J Vance (Flight Recorders).

The aircraft was engaged on crew training and crashed during the final stages of a simulated asymmetric instrument approach to land at East Midlands Airport. After the accident one inch of ice was found on the leading edges of the aircraft's wings and tail surfaces.

The report concludes that the probable cause of the accident was that the aircraft became uncontrollable at an airspeed well above both its stalling speed and minimum control speed because its flying and handling characteristics were degraded by an accumulation of ice. The decision by the training captain not to operate the airframe de-icing system was an underlying cause but he could not have been expected to foresee this at the time. A contributory factor was that the operating crew allowed the airspeed to fall below the normal approach speed during the latter stages of the approach.

1. FACTUAL INFORMATION

1.1 History of the flight

The aircraft was engaged on crew training. The commander, who was an experienced training captain, occupied the right pilot's seat and a first officer undergoing training for conversion to captaincy occupied the left seat as handling pilot. Another captain refreshing on type sat on the jump seat behind the pilots' seats, the intention being that he should move into the left seat after the first officer's training period. The weather was: wind velocity 150°/7 kt, visibility 4 km and cloud 7 oktas stratus, base 1000 feet. The surface temperature was –2 °C and the QNH 1030*.

The training session began with a practice abandoned take-off after which the aircraft took off at 1308 hrs and flew 3 practice instrument landing system (ILS) approaches followed by touch-and-go landings on runway 09, climbing to 2000 feet above mean sea level (amsl) after each take-off. The runway in use was then changed and the aircraft flew a simulated asymmetric ILS approach to runway 27 followed by a missed approach (go-around) with the left engine throttled back. The runway was then changed again and an ILS approach to runway 09 was flown with the left engine still throttled back. This approach was followed by a touch-and-go landing during which both engines were brought up to full power. Very soon after becoming airborne the training captain again simulated failure of the left engine and the aircraft was climbed to 2000 feet amsl. Soon after the aircraft levelled off, the handling pilot commented on the large amount of rudder required to counteract the simulated failure of the left engine after take-off. The training captain then said that he was deliberately putting more drag on the left side than would have been the case if the propeller had auto-feathered so that the climb performance corresponded better with that of an aircraft with passengers on board. He went on to say that if the handling pilot could cope with that extra drag, he could expect to control the aircraft if the failed engine auto-feathered because the rudder pedal force would then not be quite so great. The crew then began a procedural non-directional beacon (NDB) approach to runway 09, for which instrument screens were fitted in front of the handling pilot. It was intended that the aircraft should be landed after the NDB approach for the pilot in the jump seat to take over as handling pilot. Decision altitiude for the approach was 740 feet and touchdown altitude was 305 feet. It was company practice for beacon passage to be identified by the movement of the radio compass needle and, as the aircraft passed about one third of a mile north of the marker beacon inbound,

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* QNH is the corrected mean sea level pressure at an airfield or for a specific area. When set on an aircraft altimeter it causes the altimeter to read the height of the aircraft above mean sea level.

descending through approximately 1300 feet amsl, the handling pilot said 'OVER THE BEACON NOW'. No audio signal from the marker beacon was heard on the cockpit voice recorder (CVR). The landing checklist was completed during the following 20 seconds, including confirmation that the undercarriage was down, fuel heaters were off, two blue propeller lights were illuminated and fuel was trimmed up.

48 seconds after passing the beacon the aircraft reached decision altitude, and the training captain asked the handling pilot "HOW LONG AND WHERE IS IT?", to which the handling pilot replied "GOT ABOUT A MINUTE AND TEN SECONDS TO GO - SHOULD BE STRAIGHT IN FRONT". 22 seconds later and some 36 seconds before impact the training captain said "WHY ARE WE AT 650 FEET?" and pointed out that the handling pilot had allowed the aircraft to descend below decision altitude when he was, for training purposes, still in instrument meteorological conditions (IMC). The handling pilot responded by saying "INTEND GOING AROUND THEN", or words to that effect. The training captain then said "YES, WELL I'LL LET YOU SEE IT NOW. THERE IT IS". As the training captain was saying this the sound of an engine power increase was heard on the CVR, and frequency analysis of this sound indicated that at this stage, about 25 seconds before impact, the rpm of one engine was increased to 14,800 revolutions per minute (rpm), a setting 200 rpm below maximum continuous power. 10 seconds later the training captain was heard to say "HANG ON, THAT'S THE - THAT'S THE FIELD THERE. SEE IT?" The handling pilot then said "HOLD TIGHT", at which point, some 13 seconds before impact, the CVR recorded the sound of another engine increasing power to 14,800 rpm. A moment later the handling pilot said "HAVEN'T GOT IT", and the training captain said "I'VE GOT IT". The CVR provided no other evidence of how the handover of control was accomplished but considerable sounds of effort were heard for the next 6 seconds until, 5 seconds before the impact, the sound of both engines running down rapidly was heard. During the next 4 seconds both engines were heard to reduce to about 10,500 rpm and then accelerate again very rapidly before falling back again as the impact took place.

On the CVR, 106 seconds elapsed between the handling pilot stating that he was over the beacon and the sound of the impact. The impact occurred 2.66 nm from the beacon, showing that the mean groundspeed over this period was no more than 90 kt, equivalent to an indicated airspeed (IAS) of 97 kt when corrected for temperature, pressure and wind component. The aircraft was seen by eye-witnesses shortly before the accident. All agreed that it was lower than usual for an aircraft on the final approach path. Some witnesses thought it was trying to climb and described the engines as being at high power. Typical eye-witness statements were that the aircraft was 'behaving erratically', was 'wobbling' and that 'the wings were dropping from side to side'. Most witnesses described large and rapid banks to both right and left. The right bank was described as very steep and most agreed that the aircraft had recovered from this steep bank before it disappeared from view.

One witness described how he helped to carry to an ambulance a stretcher on which lay the supernumerary pilot. He stated that this pilot asked if he had seen the crash and if he had seen the aircraft "dip left". When the witness replied that he thought it had dipped to the right, the pilot said that that was after the dip to the left. Since that time the crew have been unable to recollect the details of their own actions or the behaviour of the aircraft immediately before the accident.

The pilot on the jump seat remembers being aware that both pilots in the front seats were regularly checking the wings for ice build-up but he was not able to see the wings himself. He saw the runway lights when the aircraft reached decision altitude and then removed his headset and turned round on his seat to stow some loose articles on the galley shelf before landing. He felt an unusual motion and looked back into the cockpit in time to see the aircraft recover from a yaw to the left before banking steeply to the right. At this time he believes he saw the training captain's hand on the throttle levers and that he saw him momentarily close the throttles and then open them up again. The handling pilot recollected that he was flying a single-engined approach and is sure that he would not himself have opened up the left engine, believing that any such action would have been the prerogative of the training captain. No record was obtained from the flight data recorder (FDR) (see paragraph 1.11.1).

The aircraft struck the ground on the northern side of the Castle Donington motor racing circuit. The marks on the ground indicated that it struck the ground in a nose-down attitude, banked to the left and with considerable left sideslip. After the accident an accumulation of mixed rime and glaze ice was found on the leading edges of the wings and tail surfaces which had formed rough-surfaced horns one inch high above and below the airflow stagnation point. No ice was found on the flaps or landing gear. In the sub-zero temperature, and in the absence of precipitation, this ice remained unchanged for 24 hours after the accident. Photographs of the ice accumulation are at Appendix 1.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	3	-	-
Minor/None	-	-	

1.3 Damage to aircraft

The aircraft suffered extensive damage in the ground impact. The left wing was fragmented outboard of the engine, with the structural integrity of the root attachment being destroyed. The right wing remained attached to the fuselage only by electrical looms and engine control cables. All the landing gear assemblies were torn off and the underside of the forward fuselage, including the flight deck floor, was substantially damaged by impact with a pile of concrete slabs, several of which had entered the cabin. The horizontal stabiliser attachment to the rear fuselage was damaged as a result of the right tailplane tip having scraped along a concrete wall. Both propellers struck the ground causing the right one to become detached.

1.4 Other damage

A small section of concrete walling and a metal gate on the perimeter of the Castle Donington racing circuit were destroyed.

1.5 Personnel information

1.5.1 *Commander:* Male, aged 39 years

Licence: Airline Transport Pilot's Licence valid until 2 June 1987

Aircraft ratings: PA28, Cessna 150/185, Cessna 200/210, Cessna 400 series, Herald, Viscount, DC9, Fokker F27

Last medical examination: 6 November 1986, Class 1, no limitations, valid until 31 May 1987

Instrument rating: Valid until 26 March 1987.

Last company base check: 27 September 1986

Flying experience:

Total flying hours:	8345
Total hours on type:	2983
Hours in preceding 28 days:	11
Hours in preceding 24 hours:	6½
Rest period before duty on day of accident flight:	16 hours

1.5.2 *Co-pilot:* Male, aged 31 years

Licence: Airline Transport Pilot's Licence valid until 1 March 1994

Aircraft ratings: PA28/32, PA23 series (except 200T and 250T), PA34 series, PA44 series, Fokker F27, DC9

Last medical examination: 10 November 1986, Class 1, no limitations, valid until 31 May 1987

Instrument rating: Valid until 6 March 1987

Last company base check: 7 September 1986

Flying experience:

Total flying hours:	5220
Total hours on type:	572
Hours in preceding 28 days:	11
Hours in preceding 24 hrs:	nil
Rest period before duty on day of accident flight:	16 hours

1.5.3 *Supernumerary pilot:* Male, aged 35 years

Licence: Airline Transport Pilot's Licence valid until 4 February 1990

Aircraft ratings: Cessna 150/172/182, Fokker F27, Islander, Viscount, DC9, Shorts 330/360

Last medical examination: November 1986, Class 1, no limitations, valid until 30 November 1987

Instrument rating: Valid until 4 September 1987

Last company base check: 5 August 1986 (on Viscount)

Flying experience:

Total flying hours:	7117
Total hours on type:	176
Hours in preceding 28 days:	7
Hours in preceding 24 hrs:	nil
Rest period before duty on day of accident flight:	20 hours

1.6 Aircraft information

1.6.1 Leading particulars

Type:	Fokker F27 Friendship Series 200
Constructor's number:	10241
Date of manufacture:	1964
Certificate of Registration:	Registered in the name of British Midland Airways Ltd
Certificate of Airworthiness:	Issued on 9 March 1984 in the Transport Category (Passenger), last renewed on 16 March 1986 and valid until 8 March 1987
Total airframe hours:	38,487
Engines (2):	Rolls-Royce Dart 528D-7E
Maximum weight authorised for take-off:	18,999 kg (41,798 lb)
Actual take-off weight:	15,998 kg (35,196 lb)
Maximum weight authorised for landing:	18,144 kg (39,917 lb)
Estimated weight at the time of the accident:	15,000 kg (33,000 lb)
Estimated fuel remaining at the time of the accident:	2,950 kg (6490 lb)
Centre of gravity (CG) limits at accident weight:	24 - 36% mean aerodynamic chord (MAC)
CG at time of accident:	26.3% MAC
Target threshold speed at accident weight:	90 kt with 40° flap (A company limitation specified a minimum of 95 kt for single-engined landings)

Stalling speed at accident weight and configuration:	73 kt (power off)
*Minimum control speed in the air V_{mca}:**	78.5 kt at sea level

1.6.2 *Flight characteristics*

The following information from the aircraft flight manual is relevant. The aircraft has positive lateral stability in all flight conditions except at very low speed in the landing configuration, when it is neutrally stable. Directional stability is positive in all flight conditions and configurations, and ample directional control with rudder is available under all normal flight conditions. The ailerons remain effective down to and below the stall. Aileron and rudder control forces are reduced by balance tabs.

During single-engined operation at second segment climb speed (V_2: approximately 89 kt at the accident weight with 16° flap), full rudder and half aileron are required to keep the aircraft straight.

1.6.3 *Aircraft ice protection*

Electrically heated elements protect the engine and oil cooler air intakes, the propeller spinner and blades, the windshield and the pitot heads from ice formation. Power unit ice protection should be switched on in ambient temperatures below 10° C.

Airframe de-icing is accomplished by the inflation of pneumatic boots. The boots are sequenced by an electronic timer that can be selected to heavy or light/moderate icing conditions; they can also be operated manually. The normal operation of the system is described in the flight manual as follows:

> 'If flight conditions permit, most satisfactory de-icing will be obtained as follows:
>
> > allow a build-up of ice about ¼ inch; select HEAVY ICING for one or two cycles.
>
> If continuous (automatic) operation is preferred: initially select LIGHT/MODERATE ICING.'

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* The minimum control speed in the air (V_{mca}) is the lowest speed at which control of the aircraft may be maintained with a failed engine with the remaining engine(s) at full power and the aircraft in a take-off configuration.

A note in the flight manual states that ice accretion of more than 1 inch on the leading edge should be avoided.

1.6.4 *Torque pressure indicating system*

When the engine is producing torque, an axial thrust is produced between the helical teeth of the 3 reduction gear layshaft driven gears and the high speed pinion, and between the helical teeth of the layshaft driving gears and the propeller shaft annulus gear. The resulting forward thrust is proportional to the torque transmitted through the gear train. This thrust is opposed by oil pressure acting on a piston face at the forward end of each layshaft. A dessyn transmitter is tapped into the line that interconnects each pressure cylinder, and this registers the balancing pressure. The indicator is a DC ratio indicator and is calibrated to read torque pressure over the range 0 to 600 psi.

Rolls Royce have stated that production tolerances can result in a spread of up to 100 psi, measured at take-off power; a specified torque pressure reading can thus correspond to different power settings for different engines. Each engine has a torque declaration attached to the log book which is updated on installation and on each overhaul. Also, the torque indication system has a tolerance of plus or minus 28 psi.

1.7 Meteorological information

1.7.1 *General situation.*

A near stationary warm front lay across the United Kingdom from west Scotland to Cornwall. The area of the accident was affected by a cold, continental airstream.

1.7.2 *Actual weather conditions*

An aftercast of the weather conditions described 3 to 6 oktas of stratus, base 900 to 1300 feet, 6 to 8 oktas of stratus/stratocumulus, base 1300 feet to 1700 feet, tops 2500 to 3500 feet, with further layers up to 10,000 feet. The weather was cloudy and hazy with surface visibility 3500 to 4000 metres. The freezing level was on the surface and the icing index was moderate to severe. The wind velocity on the surface was 150°/7 kt, and at 2000 feet was 190°/12 kt. The weather recorded at East Midlands airport at 1420 hrs was: surface wind 150°/7 kt, visibility 4000 metres in haze, 7 oktas stratus cloud, base 1000 feet, and temperature -2° C. The QNH was 1030.

1.8 Aids to navigation

The only relevant aid to navigation was the non-directional radio beacon (NDB) for runway 09. This was a locator beacon situated 3.9 nm from the touchdown point of the runway on a bearing of 274° M from the runway, radiating on 393 kHz and coding 'EMW'. The height of the 3° glideslope at the beacon was 1600 feet amsl. The beacon was checked immediately after the accident and found to be operating normally. Pilot reports from other aircraft using East Midlands Airport that day confirmed the satisfactory operation of this beacon.

1.9 Communications

VHF communications were satisfactory. Tape recordings were available of transmissions on the East Midlands approach, radar and tower frequencies.

1.10 Aerodrome information

Runway 09 had a landing direction of 094° M, a threshold elevation of 305 feet amsl and a landing distance available of 2280 metres. It had high intensity approach lights extending for 420 metres from the landing threshold, with two crossbars. Precision approach path indicators were installed for a 3° glidepath. All these lights were illuminated at the time of the accident. There were no significant obstructions on the approach path to runway 09. Two large power stations were located close to the airfield, one was 1.7 nm to the north-west and the other 3.3 nm to the north-east. On the day of the accident the wind was from the south-east and the efflux from these power stations could not have affected the approach to runway 09 (see AIB Report No 6/87).

1.11 Flight recorders

1.11.1 Flight Data Recorder

The aircraft was fitted with a Sundstrand Universal Digital FDR, part number 980-4100-EWXN, serial number 1598, which was recovered from the aircraft in an apparently undamaged state. However, when replay was attempted, the recorder indicated that it was not running. Subsequent investigation revealed that it had in fact been running at normal replay speed but the erase head for the most recently recorded track had been continuously energised and had been erasing recorded data. As a result, the most recent recorded data had been deleted. The fault appeared to be in the recording system control board and, when this was replaced with a serviceable unit, the recorder could be replayed. It was found that only the first part of the accident flight had been recorded, and this was followed by an erased area which included the rest of the flight. No information useful to the investigation was obtained from the recorder.

The unit was returned to the manufacturer where the fault was confirmed but was intermittent. It was eventually traced to the transport interface board where it was found to be associated with a loss of signal between the processor and the transport interface board connector. Because of its intermittency, the precise nature of the fault could not be established.

1.11.2 Cockpit Voice Recorder

A Fairchild A100 CVR was installed in the aircraft, which recorded on a 4–track endless loop with a duration of 30 minutes. The following information was recorded on each track:

Track 1 - Commander's headset (audio)

Track 2 - Cockpit area microphone

Track 3 - Crew microphones (summed)

Track 4 - Co-pilot's headset (audio)

The recorder was recovered intact from the aircraft and a successful replay was obtained.

1.11.3 Analysis of CVR

A spectrum analysis of the sounds from the cockpit area microphone was undertaken. Frequencies associated with the propeller speed and the engine centrifugal compressor blade passing frequencies were identified. A measure of engine and propeller speeds was thus obtained and a time history of the engine speeds was derived, estimated to be accurate to within ±100 rpm. This time history is shown in Appendix 2.

1.12 Wreckage and impact information

1.12.1 On site examination (See Appendix 3)

The aircraft had struck level, snow covered ground some 1.3nm short of the threshold of runway 09. The groundmarks indicated that the track on impact was 105° M, and the wreckage trail was approximately 300 feet long. Towards the end of the groundslide the right hand side of the forward fuselage had struck a glancing blow on a wall, which ran roughly east-west at that point. The wall was constructed from substantial concrete sections, additional supplies of which were stacked in piles 2 to 3 feet high in the area of the initial impact point.

The only evidence of the attitude of the aircraft at impact was provided by the marks in the snow made by the left wing tip (which were positively identified by the marks of the aileron-mounted static wicks), the landing gear and fuselage. The marks ascribed to the nose landing gear and right main landing gear were 5 feet apart laterally, and immediately forward of these was a substantial excavation made by the fuselage. The twin wheel assemblies of the main landing gear had each made a single gash in the snow. The aircraft manufacturer advised that previous F27 accidents had shown that impact of the forward fuselage with the ground caused the wings to sweep forward. However, in this case, no propeller slashes were found on the fuselage, as would have been the case if the wings had swept forward by more than 10°, whilst still being nominally attached to the fuselage.

The initial left wingtip and left landing gear marks were of relatively light contacts, indicating minimal structural disruption of the outer wing at initial impact. Assuming no movement of the wing relative to the fuselage, these marks indicated a bank angle on impact of 18°. The distance between the two marks was considerably less than the 'on aircraft' dimension and showed a left sideslip of 40° on impact. There was a similar compression of the distance between the main landing gear marks, which were separated by only 17 feet, compared with the main landing gear track of 23.6 feet., which also indicated a left sideslip of 40°.

The pitch angle was estimated from the damage sustained by the underside of the nose and forward fuselage,which suggested a nose down attitude in excess of 10°. The damage was more severe on the left side than on the right, which provided additional evidence of the left bank at impact.

It was clear that the forward fuselage had borne the major part of the impact, as considerable debris from this area was found on the ground close to the impact point. The right main and nose landing gear marks were on the rearmost edge of the fuselage impact area. A few feet further forward, however, the ground-marks became more confused as considerable quantities of snow had been displaced by the fuselage and left hand propeller. The snow had been lying quite thickly over the stacked concrete slabs and in the impact area of the left engine and propeller. However, on the right side of the wreckage trail, the wind had blown away the lying snow, leaving a hard, icy surface. No groundmarks could be discerned in this area, although it was probable that any such marks had been obscured by vehicles of the emergency services immediately after the accident. No marks could positively be identified as having been made by the aircraft in this area. In particular, no marks were identified from the right propeller, and it was concluded that a high sideslip angle may have caused this propeller to strike the ground in the confused area of groundmarks left by the forward fuselage.

All the landing gear assemblies had become detached during the impact: the direction of bending failure at the top of the nose leg indicated that failure had been to the right, which again suggested left sideslip. A similar indication was obtained from the top of the right landing gear oleo.

The underside of the wing centre section torsion box had four fittings attaching it to the fuselage. Both right hand fittings had failed in tensile overload as a result of upward and forward deflection of the right wing. It was thus apparent that this wing had behaved in a similar manner to that noted in other F27 accidents. The left attachments had remained intact, acting as a hinge about which the inner part of the left wing had rotated downwards during the final part of the groundslide. The right wing had been lifted high enough initially to clear the concrete wall (although it remained loosely attached to the fuselage by engine control cables and electrical looms) and, unimpeded by ground contact, had overtaken the fuselage, with the trailing edge scraping along the top of the wall and the tip subsequently striking and sliding along the ground. The outermost 12 feet of this wing became detached during the process and was found close to the rear of the fuselage. The left wing outboard of the engine disintegrated during the impact sequence, and the aircraft came to rest with the wing root section still tenuously attached to the fuselage but with the left engine and nacelle lying on the ground.

The right tailplane tip had scraped along the wall during the final stages of the groundslide, causing the entire tailplane to become skewed on its mountings. The glancing blow struck by the forward fuselage against the wall probably did little to deflect the aircraft from its path, although it may have contributed to the head injuries suffered by the training captain. The underside of the forward fuselage was severely disrupted by impact with the piles of concrete slabs, several of which were found in the forward area of the passenger cabin, where the floor had been ripped out and the first few rows of seats torn from their mountings.

1.12.2 The flight deck

The positions of the engine control levers yielded no positive evidence because of the structural disruption of the forward fuselage and the cable runs. It was also clear from their random indications that many of the instruments had been damaged in the impact. The following pertinent control positions and indications were noted:

airframe de-icing:	OFF
windshield de-icing:	High power
power unit de-icing:	FAST cycle
rudder trim:	3/8 right
aileron trim:	fractionally right wing low
landing gear:	DOWN
fuel filter heaters:	OFF
pitot heaters:	ON
left airspeed indicator:	63 kt
right airspeed indicator:	66 kt

1.12.3 *Subsequent examination of the wreckage*

The wreckage was taken to the AAIB at Farnborough for detailed examination. When the aircraft was dismantled for tranportation it was established that the elevator and rudder control cables were still attached.

1.12.3.1 *Structures*

It was established that the aircraft had been structurally complete at impact, with no fragments having detached in flight. The wing and undercarriage structural failures described in paragraph 1.12.1 were all consistent with impact features and it was concluded that no pre-impact structural failure had occurred.

1.12.3.2 *Flying controls*

The operating cables of the primary flying controls had suffered a number of failures during the impact sequence, particularly under the floor aft of the flight deck, and both the rods that connected the ailerons with their operating bellcranks had fractured. All the failures were consistent with overloads and no evidence of a pre-impact failure was found. The trim, balance and spring tabs were still attached. The drive nuts on the threaded spindles of the flap operating mechanism were found in the position corresponding to 16° flap on all flap sections.

1.12.3.3 *Airspeed indicators*

The airspeed indicators were examined to establish whether their respective readings of 63 kt and 66 kt could be indicative of the impact speed. On both instruments application of air pressure and its subsequent removal caused the needles to move away from and return to the as-found readings, thus establishing these as off-set zeros. No visible damage had occurred to the internal mechanisms and it was considered that the most likely reason for the off-set zero readings was a permanent set caused by impact forces acting on the balance weights.

1.12.3.4 Engines

The impact characteristics of each engine were different: the left propeller had had a comparatively gentle impact into soft snow before the tips struck a concrete slab, whereas the right propeller had suffered a sharp impact which had caused the propeller to detach from the engine.

Prior to removing the engines from the wreckage, it was established that no disconnect had occurred in the engine or propeller controls. The engines were taken to the Rolls Royce facility at East Kilbride where they were subjected to a strip examination in the presence of an Inspector of Accidents.

(i) Left engine: serial no. 17599

No foreign object damage was observed on either of the impellers. The quill drive shaft from the turbine to the reduction gear assembly at the front of the engine had suffered a torsional failure typical of an engine that had been rotating at impact. The engine was difficult to rotate by hand until the accessory gearbox was removed, when it was discovered that one of the gearwheels was out of alignment on its bearing. The lack of distress on the other gearbox components indicated that this could not have been a running condition and was thus likely to have been an impact feature. There were some minor rub marks on the turbine shrouds caused by slight flexing of the turbine shaft, which was attributed to impact forces. With the exception of the above features, which were consistent with ground impact, there was no evidence of any fault or failure which could have contributed to the accident.

(ii) Right engine: serial no. 8216

A small amount of foreign object damage was apparent on some of the first stage impeller blades, most probably caused by fragments of the reduction gear casing that were released when the propeller became detached. The quill drive shaft to the reduction gearbox had suffered a torsional failure similar to that on the left engine, thereby showing that the right engine also had been rotating at impact. A small amount of rubbing damage was evident on the forward faces of the shrouds of all three turbine stages where they had contacted the rear faces of the nozzle guide vane (ngv) shroud/sealing lands. The ngv damage was confined to an arc on the underside of the engine such as would have been the case if the turbine shaft had flexed downwards when the aircraft struck the ground. Considerable quantities of charred and semi-charred vegetation were found on the turbine blades, predominantly in the high pressure (hp) stage. These deposits were concentrated on the underside of the shrouds and had clearly been centrifuged to this position when the turbine was still rotating. More semi-charred vegetation was found on the nozzle box heat shield. There were thus no defects found in the right engine other than those attributable to impact forces, although the presence of the vegetation in the turbine section necessitated some additional research (see paragraph 1.16.2).

1.12 3 5 *Engine fuel system*

The fuel pumps and fuel control units were removed from both engines and found to be free from physical damage. Satisfactory functioning was demonstrated on a test rig at Lucas Aerospace under the supervision of an Inspector of Accidents and there were no significant excursions from the test schedule. The units were then stripped and examined. The fuel control units were found to be in good condition apart from a slight indentation on the metering edge of a plunger attached to the shut-off cock on the unit from the left engine, which was consistent with a blow on the shut-off cock operating lever, which could have occurred during the impact.

Each fuel pump had a quill driven rotor carrying seven variable-stroke, spring-loaded operating pistons, each of which was fitted with a silver-plated slipper running in contact with a non-rotating camplate. Sulphiding had occurred on the piston slipper tops, which, in the pump from the right engine, was sufficiently advanced to have started to lift the silver. Such sulphiding occurs when fuel with a high sulphur content is used. If pumps so affected are allowed to remain in service, the slipper tops will eventually smear onto the camplate face, causing the quill drive to shear. This is a known problem which can be rectified by a modification which changes the plating material on the slippers and camplate. In the opinion of the manufacturer, the pump from the right engine was in a condition of imminent failure. Nevertheless, failure had not occurred and the observed condition of the pump was not relevant to this accident

The fuel datum control (fuel trimmer) provides a means of varying the fuel flow to meet ambient temperature variations, thereby preventing turbine temperature limits being exceeded. The datum shift is effected by means of electric actuators located in the engine nacelles. Although there had been some distortion as a result of the impact, the actuator rams of both engines were found close to the fully retracted ("full increase") position.

1.12.3.6 Propellers

The propeller assemblies, together with the controller units and the feathering pumps were taken to the manufacturer, Dowty Rotol Ltd., for strip examination and bench testing. Apart from the feathering pump test, these operations were witnessed by an Inspector of Accidents. The propeller variable pitch mechanism consisted of a hydraulically operated piston which moved in a cylinder secured to the front of the hub. The piston was connected via operating linkages to pins on the base of each blade such that aft movement of the piston coarsened the blade pitch. Hydraulic pressure was supplied from the engine high pressure oil system, boosted by an engine driven pump in the propeller control unit (PCU). The piston moved on a sleeve which housed a spring collet and lock piston assembly. Flanged steel rings attached to the front and rear faces of the piston formed pitch stops. The entire assembly was called the pitch lock unit.

Following the accident the propeller blades were generally in a very coarse position. The blades of the left propeller were severely damaged, mainly at the tips and particularly at the leading edge corners. Inboard from the tips the blades exhibited gentle bending. On the right propeller one blade had a 10 inch portion torn off, with the next blade in the passing sequence having suffered severe tip damage. The remaining two blades were less severely damaged, which suggested that the majority of the rotational energy had been dissipated by two blades striking the ground in an impact that was sharp enough to cause an immediate propeller shaft failure.

When the propeller assemblies were stripped, it was apparent that the pitch operating linkages had been pulled due to the blades twisting in a coarsening direction, suggesting that the engines were powering the propellers at impact. One blade linkage in each propeller had failed in tensile overload during this process. A series of impact marks was observed on each of the transfer (collet) sleeve outer diameters. As this component was the central locating diameter for the propeller operating piston and the blades were twisting towards coarse pitch during the impact, the primary impact mark was identified as the one in the finest pitch position. In each propeller, the position of the primary impact mark corresponded to a blade pitch angle of 35°, expressed at 0.7 of blade radius. No pre-existing defect was observed in any of the propeller components during the strip examination. Functional testing of the pitch lock units, the PCU's and the feathering pumps showed that all these components were capable of normal operation.

1.12.3.7 Power plant de-icing

Electrically heated mats provided ice protection for the propeller blade leading edges, the spinner and the power unit intakes. The leading edge lip of each intake was continuously heated. Cyclically heated elements were located inside and outside this lip, with FAST or SLOW cycle times selectable from the flight deck. Although the intakes had suffered severe physical damage during the impact, electrical continuity checks showed the unit from the left engine to be functional. Similar checks on the right engine intake showed that the cyclic elements were satisfactory but there were three breaks in the continuously heated areas. X-ray photography showed that two of these breaks were associated with areas of impact damage. The third break had occurred beneath a sharp cut in the rubber caused by small, sharp object. There was, however, no evidence of electrical arcing, and it was concluded that this too was an impact feature.

It was noted that two pairs of electrical leads supplying the heater mats had been crossed over within the plug that connected the right intake with the airframe. The intake manufacturer stated, however, that this would not have adversely affected the operation of the system.

1.12.3.8 Engine ancillary equipment

The engine torque transmitters, together with their indicators, the low torque switches which signal the auto-feathering system, and the fuel filter heater valves were returned to their respective manufacturers for functional testing and inspection. The fuel filter heater valves were in the closed position, to which they are normally set during the before-landing checks. All the components operated satisfactorily with the exception of the fuel filter heater valve from the left engine. Whilst on the test rig the valve would only open partially, and subsequently would not close again. When the unit was disassembled, it was found that valve movement was impeded by corrosion products within the valve body. These deposits were of fresh appearance and it was concluded that they had arisen from post accident corrosion. Additionally, the left torque indicator displayed an error of + 6 psi over the 60 to 100 psi range against a maximum permitted tolerance of ± 4 psi.

1.12.3.9 Fuel

Fuel samples from the bowser from which G-BMAU had last refuelled were analysed; no significant departures from the specification were found. Samples taken from the engine fuel filters were also satisfactory apart from a small amount of sediment. No water was found, indicating that the filters had not been affected by ice. The refuelling records showed that there should have been adequate fuel on board the aircraft at the time of the accident but the degree of airframe disruption was such that this could not be verified, although there was evidence of considerable fuel spillage on the accident site. During the engine strip the engine-mounted fuel components were found to be primed with fuel.

1.13 Medical and pathological information

The three pilots on board the aircraft were all seriously injured when the lower front part of the fuselage was damaged by impact with the ground.

1.14 Fire

Up to 3000 kg of fuel was released from the aircraft when the wing fuel tanks were ruptured. The emergency services blanketed the fuel spillage with foam and there was no fire.

1.15 Survival aspects

The crew restraint harnesses appeared to have held on impact. Although the pilot in the jump-seat had been thrown forward over the centre console, he had not suffered significant chest injuries and appeared to have been partially restrained by the lap strap and diagonal upper-torso restraint strap fitted to this seat. The damage to the lower forward fuselage caused very serious leg injuries to the pilots in the left seat and the jump seat. The pilot in the right seat suffered a severe head injury and injury to his left arm and leg.

Close to the site of the accident the Donington Park Emergency Services Team of the British Motor Racing Marshalls' Club were holding a training day and reached the aircraft a very short time after the accident. The doctor in this team was able to give immediate medical attention to the 3 seriously injured pilots. The team gained access to the aircraft through the left forward passenger door and, after removing the galley cabinet, were quickly able to rescue the pilot in the jump-seat. Approximately 30 minutes elapsed before the team, with the help of the East Midlands Airport and local authority fire services, were able to rescue the other two pilots. Paramedics in the team rendered first aid to the injured pilots until ambulances arrived some 30 minutes after the accident. Fire vehicles from East Midlands Airport reached the accident site 14 minutes after the accident and were followed a short time later by local authority fire vehicles. Concrete wall sections from the pile on which the aircraft landed, each weighing approximately 500 kg (1100 lb) penetrated the fuselage and caused extensive damage to the floor and passenger seats in the forward cabin. The accident would have been survivable for passengers in the rear of the cabin but some serious injuries and possibly fatalities could have been expected among passengers in the forward cabin.

1.16 Tests and research

1.16.1 Flight assessment

A flight was carried out to assess the effect on lateral control of rapid throttle movements. The aircraft was flown in the same configuration and with similar engine power settings as pertained immediately before the accident ie with undercarriage down, flaps set to 16°, maximum continuous power on the right engine and the left engine set to 80 psi torque. At speeds as low as 90 kt it was found that rapidly opening the left engine to maximum power produced no more than a slight yaw to the right and in no test was more than 5° of right roll induced. The aircraft remained stable laterally and responded normally to control inputs. It was also established that a high rate of climb could be obtained even at 90 kt as soon as the left engine was opened up.

1.16.2 Engine grass ingestion test

The presence of charred pieces of grass in the turbine section of the right engine prompted the question of whether a degree of cooling had occurred, indicative of the engine having flamed out prior to impact. This question was asked in the light of the absence of similar debris in the left engine, and against an intuitive expectation that any vegetation ingested immediately after flame-out would have been incinerated, leaving little or no deposit in the turbine. To resolve this question, Rolls Royce ran a Dart engine on the test bed and then shut it down by closing the high pressure fuel cock. At this point a handful of grass was introduced to the intake. When the engine was disassembled it was found that semi-charred remnants of grass had become lodged in the turbine section in a similar manner to but in greater quantities than found in the accident engine. Some grass was also found in the compressor, although this was probably due to the greater length of the grass used in the test.

1.16.3 Propeller time history

In an attempt to interpret the propeller blade pitch angle setting of 35° at impact in terms of engine handling, Dowty Rotol produced a simulated time history of the propeller parameters over the last 10 seconds of flight. The engine and propeller speeds were derived from the CVR, which allowed the derivation of the likely throttle lever movements and consequent fuel flows. The simulation then calculated the propeller blade angles for sea level pressure and a temperature of -2°C.

The aim of the study was to account for the reduction from the 14,800 engine rpm peak over the final .75 seconds of the CVR trace. If the throttles had been left fully open for this period the rpm reduction must have been caused by the propellers striking the ground, with the CVR trace ceasing after a further .75 seconds as a result of disruption to the airframe. However, the simulation showed that the propeller blade angle would have been less than 27° if the impact had occurred at full throttle. On the other hand, if the throttles had been closed at the rpm peak, then the rpm reduction would have occurred as a result of reduced fuel flow as well as ground contact. The simulation (which could not allow for ground contact) then showed a marked blade angle increase, due to the control unit sensing an overspeed relative to the selected rpm. In fact, such a momentary over-coarsening would be expected to occur following any throttle closure.

1.17 Additional information

1.17.1 Analysis of radar recordings

Recordings of secondary radar returns from the aircraft were available from air traffic control radars at Clee Hill and Claxby, both of which were more than 50 nm from the site of the accident. Two difficulties were encountered in the analysis of these recordings. First, the positions given by the Clee Hill radar were consistently north of those given by the Claxby radar, and this was attributed to either distortion due to terrain and low altitude or to some fixed aximuth or range error in one or both radars. Secondly, when the times on the radar recordings were compared with those obtained from correlation of the CVR and ATC tapes, the radar position relating to the time when the handling pilot said he was over the beacon (referred to subsequently as 'beacon passage'), was 16 seconds short of the beacon.

Accordingly, two separate analyses were made of the radar data. The first assumed that the aircraft was close to the beacon at beacon passage and used only the data from Claxby, which showed returns from the aircraft to within 0.6 nm of the accident site and accorded more closely in latitude with the centreline of the approach and the known impact point. This analysis made no attempt to reconcile the inherent radar azimuth errors, and accepted that reasonably accurate groundspeeds could be obtained only over track lengths of more than one mile. It showed that the groundspeed of the aircraft was 104 kt as it approached beacon passage and an average of 101 kt from the beacon to a point

0.6 nm from the impact point. When corrected for temperature, pressure and wind component, these figures represented rectified airspeeds (RAS) of 111 kt and 108 kt respectively. The limits of accuracy of these figures was ±6 kt. There was no evidence from the radar trace of any significant loss of airspeed in the period immediately before the end of the trace.

The second analysis was more complex, using smoothed data from both radar heads and assuming that the times on the radar recording were correct ie that the aircraft was 16 seconds short of the beacon at beacon passage. It showed the aircraft passing the beacon at 104 kt RAS, flying at between 104 kt and 110 kt for the next 70 seconds and then decelerating to 86 kt at a point 16 seconds from impact. The second analysis indicated that only 16 seconds elapsed between the last radar paint and the impact. The discrepancies between the two analyses of the radar data could not be reconciled.

Recordings were also available of the final stages of the ILS approach flown by the aircraft some 14 minutes before the accident and provided a comparison of transponded altitudes between that approach and the final NDB approach. Altitudes on the ILS approach were found to be within 50 feet of the glidepath and confirmed that, when corrected by 440 feet to allow for the local pressure and temperature, the transponded altitudes measured could be treated as accurate to within 50 feet. It was found that, on the final NDB approach, the aircraft completed the procedure turn at an altitude of 2000 feet and commenced a slow descent when approximately 3.2 nm short of the beacon. It maintained a rate of descent of between 320 and 370 feet per minute (fpm) until reaching the beacon at an altitude of 1300 ±50 feet. The rate of descent then increased to about 1,100 fpm until the aircraft levelled off at an altitude transmitted by the transponder as 100 feet, equivalent to a true altitude of 540 ±50 feet. The radar height then remained unchanged until the end of the radar trace. Terrain height beneath the final stage of the flight path varied around 250 feet.

1.17.2 Engine performance

1.17.2.1 Evidence from the CVR

The frequency spectrum analysis of the background noise on the CVR provided evidence of the engine power changes during the last 25 seconds before impact. It showed that, whilst during the previous ILS approach, the speed of the idling (left) engine remained constant at 10,800 rpm, it dipped below this figure several times during the final NDB approach and, from a point some 70 seconds before the impact, it fell steadily. This decline in rpm showed that the propeller was no longer constant-speeding and was on the flight fine pitch stop. Such an rpm reduction could have occurred only if power or airspeed, or both, were reduced below the levels maintained during the ILS approach.

1.17.2.2 *The relationship between engine torque and propeller blade angle*

Figures were supplied by Rolls Royce and Dowty Rotol of the interaction between airspeed and a variety of engine parameters. However, most of this data pertained to the high power end of the performance spectrum, with little available for power settings below the constant speed range.

The CVR-derived engine rpm on the ILS approach showed that the left engine was constant-speeding at 10,800 rpm. This figure was used by Dowty Rotol in a computer prediction which calculated the propeller blade angle, thrust and shp for a variety of airspeeds and fuel flows. The pertinent data was as follows:

TAS (kt)	Engine rpm	Propeller Thrust (lb)	Shp	Blade Angle (degrees)
600 lb/hr Fuel Flow				
100	10,800	1,261	465	25.66
90	10,800	1,375	464	24.58
80	10,800	1,475	463	23.50
500 lb/hr Fuel Flow				
100	10,800	675	262	23.03
90	10,800	730	262	21.77
80	10,800	813	261	20,63
400 lb/hr Fuel Flow				
100	10,645	-129	62	20,00
90	10,250	119	99	20.00
80	9,904	351	127	20.00

Notes:

1. Idle fuel flow is of the order of 280 lb/hr.

2. The engine falls below the constant speed range somewhere between 400 and 500 lb/hr fuel flow.

3. The apparent increase in power with reducing airspeed at 400 lb/hr is due mainly to reducing windmilling drag.

An idea of how torque pressures equated to power settings below the constant speed range was given by the results of a ground test conducted by Rolls Royce. Although these figures could not be truly representative of behaviour in the air, they showed that the torque pressure reading over the constant speed range was from 20 to 150 psi. The corresponding spread of power was from 80 to 600 shp. Below the lower limit of the constant speed range engine rpm dropped rapidly. These conclusions were confirmed during a number of flights when torque, fuel flow and engine rpm were recorded at different airspeeds. Different aircraft were involved in these flights and the results were not consistent. However, on one flight engine rpm fell to 9,500 at 110 kt when torque was reduced to 20 psi; on another, engine rpm fell to 8,200 at 100 kt when torque was reduced to zero.

1.17.2.3 *Interpretation of the CVR analysis*

Before the engine rpm derived from the CVR analysis could be related to airspeed it was necessary to determine the airspeed at the time the left propeller ceased to constant-speed. The rpm fluctuations showed that this had occurred by the time the aircraft passed the marker beacon (see Appendix 2), when its speed according to the raw data analysis of the radar traces was between 105 and 117 kt RAS. A further computer prediction by Dowty Rotol giving theoretical engine rpm against airspeed for low fuel flows showed that the propeller would reach its fine pitch stop in this range of airspeed with fuel flows between 345 and 395 lb/hr. Within this range, the prediction showed that engine rpm declined with airspeed at 1,000 rpm for each 24 kt lost. Using these figures, the following theoretical airspeeds were calculated for the last 75 seconds of the radar trace:

Time to Impact (seconds)	Mean Engine Rpm	Mean Airspeed (kt RAS)
100 to 75	10,560	105±6
75 to 50	10,460	103±6
50 to 25	9,970	91±6

Soon after power was increased on the right engine, the left engine rpm dipped to 9,800, equivalent to a theoretical airspeed of 87±6 kt.

1.17.3. *Aerodynamic effects of ice*

The aerodynamic effects of ice depend upon the nature of the ice accreted on the aircraft. Rime ice, which forms at low temperatures, has been shown to have less effect than glaze ice. Glaze ice generally forms in temperatures just below freezing point and produces a rougher shape than rime ice, often forming ridge above and below the leading edges that act as spoilers, reducing lift and great inceasing drag. Studies have shown that the aerodynamic effects of rime ice ca be fairly successfully predicted but the effects of glaze ice are more difficult predict because of the large areas of separated airflow that can be caused by such accretions at high angles of attack.

During natural icing trials conducted on a specially instrumented Twin Otter by the United States National Aeronautical and Space Administration (NASA) in 1983/4, one icing encounter lasting 25 minutes resulted in the formation of a mixture of glaze and rime ice similar in appearance to that found on G-BMAU. This accumulation caused an increase in drag coefficient for the whole aircraft of 75% and, for the wing section alone, of 120%. At an angle of attack of 6°, the lift coefficient was reduced by 16%. A very large increase in the power required for level flight on one engine was also measured, but the report specifically excluded reference to handling problems. A further report by NASA on stability and control stated that a moderate accumulation of glaze ice was found to have caused a reduction of 16% in elevator effectiveness and a reduction of 23% in the pitch damping coefficient when partial flap was lowered.

1.17.4 *F27 icing flight trials*

Certification flight tests were conducted on the F27 in natural icing conditions in 1957/8. During these tests up to 1 inch of ice was allowed to accumulate on the leading edges of the flying surfaces, and it was demonstrated that controllability and handling characteristics remained satisfactory. During the trials low speed handling was assessed but the effect of ice on stalling speed was not determined. It was found that with undercarriage and flaps up and about ¼ inch of ice on the leading edges, buffeting started at 108 kt, but when the speed was further reduced to 100 kt the aircraft behaved normally. In a further test what was described as a thin layer of very rough glaze ice was found to have caused a reduction of airspeed from 209 kt to 183 kt at high cruise power settings. Low speed asymmetric flight tests in icing conditions were not required for certification purposes and were not carried out.

1.17.4 *Previous accidents*

Records for all aircraft show that 90 accidents and 23 incidents involving loss of control in icing conditions were reported to ICAO in the 10 years to 1987. In most cases the reason why control was lost was not stated. In 17 occurrences there was evidence that lateral control of the aircraft was affected, and in 18 others the aircraft was described as having stalled during take-off or landing.

Investigation of an accident that occurred to a Viscount near Bromma Airport, Sweden, on 15 January 1977 attributed the accident to stabiliser stall due to ice. It was concluded that a layer of ice on the leading edge caused the airflow to break away from the underside of the stabiliser when landing flap was lowered. The trim force of the stabiliser was lost and the aircraft pitched down into a steep dive. After the accident it was shown that the elevators had a large downward deflection on impact and it was concluded that they had been sucked down into the low pressure area beneath the stabiliser when the airflow broke away, resulting in excessive stick forces that the pilot could not overcome.

Another accident involved an F27 engaged on pilot training at Ronnë Airport, Denmark, on 27 December 1969. An engine failure after take-off was simulated and, at a height of 120 feet above the runway, the aircraft was seen to bank first to the left and then to the right and lose height. From the FDR the investigators identified a small change of heading to the left when the aircraft was 45 feet above the runway at a speed of 98 kt and presumed that this indicated the point at which power was reduced on the left engine. At 60 feet above the runway the speed had fallen to 92 kt and the aircraft was climbing at 800 fpm on a steady heading. At 120 feet above runway level the speed had dropped to 87-88 kt and the climb had stopped. A rapid heading change of 6° to the left was seen. The speed further declined to 85 kt and the aircraft began to descend and simultaneously turn slowly to the right. The aircraft then descended at 1000 fpm until it hit the surface 29 seconds after lift-off. After the accident, 25 mm of ice was found on the leading edges of the flying surfaces. The commander had noticed the build-up of ice on the wings but had considered that the quantity of ice was insufficient for de-icing to be effective. In their analysis of the accident the investigators were unable to determine whether or not the aircraft could have maintained a climb on one engine with that quantity of ice but thought its climb capability would probably have been marginal. They also considered that there would have been a 'deterioration in performance in connection with roll and yaw' and that 'it must be taken for granted that the stalling speed was increased, perhaps as much as up to 85-90 kt'. Their findings included the statement that '. . the pupil (ie handling pilot) attempted such a rate of climb that the airspeed fell below that desired, causing the aircraft to stall or at least to be in a condition approaching the stall.'

A third relevant accident occurred to a Shorts SD360 near East Midlands Airport on 31 January 1986. In this accident the aircraft crashed after a severe, diverging, rolling oscillation that could not be controlled by normal pilot recovery action. The probable cause of the accident was considered to be a significant accumulation of airframe ice which so degraded the aircraft's stability and control characteristics that the crew were unable to maintain control. The first two recommendations of the AAIB report No 6/87 on this accident, together with the response of the Civil Aviation Authority, were :

4.1 The Civil Aviation Authority should give consideration to the continued design philosophy of inflatable boot de-icing as opposed to other airframe ice protection systems on aircraft cleared for all known types of icing.

Response : CAA accepts this recommendation and will continue to consider the design philosophy of such widely used systems in order to be satisfied that in each case it can be demonstrated that the system can satisfactorily protect the aircraft within the defined certification icing atmosphere. CAA is, however, reviewing the certification icing atmosphere to assess whether it should be expanded to cover the effects of freezing rain and other conditions likely to be encountered close to 0 °C OAT.

4.2 Pneumatically inflated wing and tail de-icing systems be exercised during the final approach to land, when an aircraft is flying, or has flown in conditions conducive to the accretion of ice.

Response : CAA accepts this recommendation and will consider the need for any additional instructions.

2. Analysis

2.1 General

The accident occurred during an exercise regularly flown during flight crew training ie a simulated single-engined missed approach. Eye witness evidence indicates that control of the aircraft was lost during a late stage of the approach. Neither engine had failed and no pre-existing defect was found in the aircraft's systems or flying controls that could have contributed to the accident. The only circumstance in which the conditions of flight were not normal for a single-engined approach was that one inch of rough ice had accumulated on the leading edges of the wings and tail surfaces.

The investigation of the accident was hampered severely by lack of evidence from the FDR and the inability of the operating crew to recall much of their own actions or the behaviour of the aircraft before the accident.

2.2 Impact attitude

The damage to the forward fuselage was consistent with a bank angle of 18° to the left and a nose down pitch attitude of 10°. There was also clear evidence from the direction of bending of the nose and right main gear legs, which were torn off to the right, that the aircraft was sideslipping to the left on impact. This evidence was supported by the fact that each pair of main wheels had made a single gash in the snow instead of the twin tracks that would have been expected if no significant sideslip or bank angle had been present at impact.

The assessments of bank angle of 18° to the left and of sideslip angle of 40° described in paragraph 1.12.1 are valid only if there was no significant structural disruption or distortion of the airframe during the impact sequence. However, according to the aircraft manufacturer, the initial impact of the forward fuselage would have caused a tendency for the wings to fail at the centre section and sweep forward. Such a failure was evident on the right wing in this accident but the left wing root attachments to the fuselage, whilst showing some evidence of forward bending, had remained intact throughout. Forward deflection of the left wing would have moved the ground contact points of the left wingtip and left main landing gear forwards and inwards, whilst downwards bending of the wings would also have deflected the main landing gear marks inwards. These effects would have given exaggerated indications of bank and sideslip at impact. The errors arising from these effects were limited by the fact that there was no evidence of propeller strikes on the fuselage, indicating that. the left wing could not have deflected forwards by more than about 10°

Thus, whilst the degree of structural deflection that occurred during the initial impact cannot be known, there is little doubt that the aircraft struck the ground with a significant angle of sideslip. The bank angle could have been up to 18° to the left, depending on the amount of downward bending of the wing. It is probable that the subsequent major impact of the left outboard wing with the ground then caused the yaw angle to reduce during the groundslide.

2.3 The final flight path

The raw radar data indicates that the aircraft was low throughout its final descent, passing the beacon some 300 feet below the 3° glideslope and then markedly increasing its rate of descent until it reached decision altitude at 740 feet amsl some 3 nm from touchdown. However, instead of flying level, the handling pilot allowed the descent to continue. The training captain called decision altitude and gave a further warning when the aircraft reached 650 feet. The aircraft was finally levelled off at a height given by secondary radar as between 490 and 590 feet, with some 2½ nm to go to touchdown. The handling pilot probably still had his view obscured by screens but the pilot on the jump-seat saw the runway lights before the aircraft levelled off, and it is reasonable to assume that the training captain also had the runway in sight. It is clear from the training captain's comments at this time and from the fact that he did not take control of the aircraft that he did not consider that the aircraft was in an emergency situation.

It was some 36 seconds before the impact that the training captain pointed out to the handling pilot that the aircraft was below decision altitude, and, soon afterwards, the handling pilot said that he intended 'going around'. The training captain's remark "HANG ON, THAT'S THE - THAT'S THE FIELD THERE. SEE IT?", made some 10 seconds after power was increased on the right engine, indicates that by this time the instrument screens had been removed. It is unlikely that this remark would have been made if the aircraft had not been turning away from the centreline of the approach, and may have coincided with the left roll observed by the eye witnesses. As this roll caused the aircraft to depart from its intended flight path, it could not have been deliberate and must have occurred despite the efforts of the handling pilot to keep the aircraft straight. The strongest indication that the bank was involuntary was that power on the left engine was rapidly increased 12 seconds after the missed approach was initiated, suggesting that, with high power on the right engine, directional control could not be maintained.

The aircraft was then observed to roll rapidly and steeply to the right. It should have been possible in normal circumstances for the pilot to recover from this right bank and, unless the airspeed was very low indeed, the aircraft should have climbed quite rapidly as soon as power was increased on both engines. Instead, however, the aircraft appears to have lost about 300 feet in the short distance between the last radar return and the impact. The pattern of the impact showed that the aircraft had recovered from the steep right bank and had both rolled and sideslipped to the left before impact. The behaviour of the aircraft, therefore, in terms of both lateral control and rate of descent indicates that in the last few seconds of flight it was either stalled or very close to being stalled.

2.4 The power setting on the left engine

Evidence that the left propeller was on the flight fine pitch stop during the final approach indicates that the left engine was at an abnormally low power setting. The falling rpm may be attributed to loss of airspeed rather than reducing power for it is most unlikely that power was reduced deliberately on that engine during the approach. After the previous take-off it was the training captain's declared intention to simulate the single-engined climb performance of a more heavily loaded aircraft and there appears to be no reason why he should not have done this for training purposes. No minimum safe setting for simulating power on a failed engine was specified in operating manuals, although the aircraft manufacturer specified a minimum setting of 40 psi torque for descent power, and the aircraft operator recommended a setting of 80 psi for simulated single-engined training. It is reasonable to suppose, however, that whatever power was set on the left engine it was sufficient for level flight with landing gear down and flaps set to 16° because considerably less than full power was used on the right engine during the period of level flight preceding the loss of control, and only a slow deceleration was seen during this level phase. It is unlikely therefore that low power on the left engine contributed to the accident.

The power actually set on the left engine cannot be determined precisely from the data available. From the behaviour of the engine rpm, the fuel flow appears to have been between 345 and 395 lb/hr , equivalent, according to the Rolls Royce figures, to just below 20 psi torque but the actual reading seen by the training captain on the left torque gauge cannot be known. Taking account of the tolerance of ±28 psi in the torque indicating system, and the fact that the left torque gauge was found to be overreading when tested after the accident, there is no evidence to show that the training captain deliberately reduced left engine power below the specified minimum of 40 psi. Nevertheless, the behaviour of the left propeller clearly shows that the left engine was operating below this setting and the left propeller may have been producing a small amount of negative thrust which might have affected the airflow over the tail empennage. This factor is further discussed in paragraph 2.8.

2.5 The airspeed on the final approach

The behaviour of the aircraft would have been influenced by its speed but, in the absence of FDR evidence, the only information about airspeed has had to be derived from the radar plot. Of the two separate analyses, the first appeared to give the more consistent results. The results of the second analysis relating to the final portion of the flight path were anomalous for they gave a time of only 16 seconds from the last radar position to the point of impact, which, if it were true, would indicate that the airspeed between these two points must have been about 120 kt, unless all three of the last radar positions were grossly in error. Also, by moving the point of beacon passage back by 16 seconds, this analysis increased the distance travelled in the 107 seconds known to have elapsed between this point and the impact, indicating a mean airspeed of 112 kt or more for this period, a figure that could not be reconciled with the airspeeds calculated from the behaviour of the left propeller. These anomalies clearly show the problems of trying to produce precise solutions from data that has large and random errors. The argument in this section is therefore based on the first analysis of the radar plot, using unsmoothed data.

The radar plot showed the RAS to have averaged approximately 108 ±6 kt from the beacon to the point where the aircraft descended below radar cover about .6 nm short of the impact point, and this is close to the normal approach speed of 110 kt. Yet the 106 seconds that elapsed between the time the handling pilot said 'OVER THE BEACON NOW' and the impact gave a mean RAS of 97 kt for the last 2.6 nm of the flight. Even if the handling pilot anticipated the beacon by 5 seconds, the RAS derived from the CVR would still be only 102 kt. This discrepancy appears to indicate that the aircraft lost considerable speed shortly before the impact. The reducing rpm of the left engine also showed that airspeed was lost during the latter stages of the approach. The rpm analysis showed that the airspeed declined to between 85 and 97 kt just before the radar trace ended.

It is difficult, however, to accept the speeds at the lower end of this bracket in view of what was occurring in the cockpit at the time. The aircraft was flying level about 300 feet above the ground and there was ample additional power available on the right engine that could have been used to maintain airspeed or to combat the effects of any particularly low power that might have been set on the left engine. There were 3 experienced pilots on the flight deck, at least two of whom might have been expected to notice and remark upon any unusual loss of airspeed, yet no such remark was made. The training captain said 'THAT'S DECISION ALTITUDE' some 58 seconds before the impact and he was likely at that time to have been aware of the airspeed as well as the height. He said

'WHY ARE WE AT 650 FEET?' just 35 seconds before the impact, and again it is reasonable to suppose that he was still aware of the airspeed. Yet at this time the left engine rpm was only 10,000, equivalent to an airspeed of about 91 kt on the theoretical calculation. It is unlikely that such a serious loss of airspeed could have passed unnoticed by both front seat pilots. The first possibility of significant distraction from the flight instruments seems to have been 23 seconds before impact when the training captain said 'YES, WELL I'LL LET YOU SEE IT NOW - THERE IT IS', indicating, perhaps, that he removed the instrument screens at that time. It is hard to believe that the training captain would not have taken control at this time if the airspeed had been dangerously low, instead of devoting his attention to removing the instrument screens.

It seems likely, therefore, that although the speed of the aircraft may have been close to or on the lower limit of the speeds calculated from the radar trace it could not have been lower. It may be concluded, therefore, that the speed of the aircraft declined to not less than 94 kt at a point .6 nm from impact and to not less than 92 kt before power was increased on the right engine for the go-around.

2.6 Non-operation of the airframe de-icing equipment

One of the few recollections of the pilot on the jump seat was that throughout the flight both pilots in the front seats were visually checking the wings for ice, but the ice found on the aircraft after the accident indicated that the airframe de-icing boots had not been operated regularly during the flight.

Many pilots are concerned that if pneumatic ice boots are operated too early, before the ice is thick and brittle enough to be broken, the ice may not be shed fully, and channels may be formed beneath any remaining ice which render the boots ineffective beneath that ice. During the investigation this view was heard from several of the training captains of the operating company and seems also to have been held by the training captain involved in the similar accident in Denmark in 1969 (see paragraph 1.17.4).

The aircraft flight manual states that ¼ inch of ice should be allowed to accumulate before the boots are operated. It also states that the aircraft should not be flown with more than one inch of ice. The training captain stated after the accident that when training he did not normally operate the boots until he thought it was necessary, in order to avoid the risk of an uneven shedding of ice making control of the aircraft under asymmetric power more difficult. It appears, therefore, that he was aware of the ice accumulation and, at some time not long before the crash, he considered it to be less than one inch thick and made a conscious decision not to operate the de-icing boots.

The photographs at Appendix 1 were taken at fairly close range and show that one inch of rough glaze ice had accumulated on the leading edges. However, a good deal of this ice formation was on the upper surface of the leading edge and may not have been apparent to the pilots who could see the leading edge of the wing only at a distance of about 20 feet. In the light, therefore, of the guidance in the flight manual, the training captain's own experience and the lack of specific data on the aerodynamic effects of ice accumulations on engine-out operations, his decision not to operate the boots was understandable. Nevertheless, it is unlikely that this accident would have occurred if the de-icing boots had been operated before the final approach.

2.7 The handover/takeover of control

The evidence indicates that it was the training captain who advanced the left throttle. It seems likely, therefore, that he took control of the aircraft when it appeared to him that the handling pilot was not maintaining directional control. This appears to have occurred some 2 seconds before the handling pilot said "HAVEN'T GOT IT". It is possible, but unlikely, that the training captain reached for the left throttle without taking over the flying controls and that the rapid acceleration of the left engine produced a roll to the right that the handling pilot did not expect and could not correct. The behaviour of the aircraft during the flight assessment, however, showed that, even if this had occurred, in normal circumstances the handling pilot could have corrected such a roll even down to a speed as low as 90 kt. There seems to be two possible reasons why the training captain should have closed both throttles almost immediately after he said 'I'VE GOT IT'. He may have seen that impact with the ground was inevitable and imminent, but if he did it is difficult to understand why he should have increased power again only 2 seconds before the impact. It seems more likely that he instinctively felt that the violent rolling manoeuvres were being driven by unsymmetrical power and closed the throttles during the steep right bank to cure this condition before reapplying power.

It must be asked if the training captain left it too late before taking control of the aircraft but it is difficult to identify an earlier point when he should have taken control. The handling pilot had more than 570 hours on the F27 and had demonstrated his ability to handle the aircraft in the hour preceding the accident by coping successfully with a practice engine failure after take-off and a single-engined go-around. It seems reasonable that the training captain should have thought him capable of handling the aircraft in the conditions that existed just before the accident. Whether or not he anticipated the handling pilot's decision to go-around, the situation was still not one where it would clearly have been right for the training captain to take control. With the aircraft still some 300 feet above the ground and power available on both engines, it seems reasonable that the training captain should have considered that he could at any time restore the aircraft to normal flight and remain clear of the ground. It is considered therefore that the handover/takeover of control took place soon after power was applied to the right engine for the go-around and that the handover itself was not the cause of the accident.

2.8 The effects of the ice formation.

No defects were found in the aircraft, and its airspeed remained well above both the minimum control speed and the stalling speed. As the possibility of gross mishandling on the part of two experienced pilots is very remote, it must be concluded that the behaviour of the aircraft was caused by the accumulated ice. Whilst the behaviour of the F27 in icing conditions cannot be related directly to the results obtained by NASA on the Twin Otter, there is ample evidence that glaze ice formations cause reductions in lift coefficients and considerable increases in drag on all aerofoils, the drag increase being most severe at high angles of attack. Other demonstrated effects of glaze ice are significant increases in stalling speeds and decreases in stalling angle of attack. In the circumstances of this accident, it is likely that the incremental drag due to the ice became much more significant as the angle of attack was increased for the go-around and may well have caused a sharp reduction of airspeed and an inability to accelerate. The reduction of lift would aggravate the situation by requiring a higher than normal angle of attack with yet more drag, a process that could continue until the wing stalled.

It is known that ice accumulations on aircraft tailplanes reduce longitudinal stability, as was seen in the case of the fatal accident to the Viscount at Bromma, Sweden, in 1977. In the case of G-BMAU, however, no eye witness observed any unusual pitching motion, and tailplane ice may not be specially significant in this accident.

No reports have been found that deal in any detail with the effect of leading edge ice on aileron effectiveness at low airspeeds but it is reasonable to suppose that, if the ice on the leading edge of the wing disturbs the airflow over the ailerons, then their effectiveness is likely to be reduced. Any reduction of aileron effectiveness could have made it very difficult for the handling pilot, and later the training captain, to control the aircraft laterally. Certainly the recovery from the steep roll to the right would have been made more difficult and would probably have required a large amount of left rudder to level the wings. It cannot, however, be assumed that the behaviour and effect of the rudder were normal in the circumstances for, again, there is very little data available on the behaviour of fin and rudder assemblies in icing conditions. Such trials as have been reported have tended to show that ice on the fin has little effect but these trials, for the most part, have been conducted without violent manoeuvres and at speeds well above the stall. It may be that effects similar to those found on tailplanes and elevators at high angles of incidence might also affect fins and rudders at high angles of sideslip. If this is indeed the case, as seems likely, then the effectiveness of the fin and rudder could have been reduced by the ice accumulation, and rudder pedal forces could have increased considerably during the manoeuvres seen to have been performed by the aircraft. Moreover, as the F27 requires full rudder and half aileron deflection with a failed engine at second segment climb-out speed (89 kt), any reduction in the effectiveness of the fin and rudder could result in loss of directional control at speeds well above the minimum control speed.

A further factor that might have affected directional control was the loss of slipstream and the turbulent propeller wash that could have occurred if the left propeller had been producing negative thrust. However, at a fuel flow just below 400 lb/hr, as the speed declined towards 90 kt, the propeller would begin to produce positive thrust. In any case, the main influences on the airstream over the rudder would have been airflow due to forward airspeed and the slipstream from the right engine at high power. The low power setting on the left engine would thus have caused only a minor change from the conditions under which minimum control speed is measured.

2.9 The certification of aircraft for flight in icing conditions

Very little work appears to have been done on how aircraft behave at the lower end of their speed range under asymmetric power with significant accumulations of ice. When the F27 was certificated for the British register in the late 1950s, there was no requirement for engine-out performance to be demonstrated in icing conditions for certification purposes. The Flight Manual for the F27, for example, states that more than one inch of ice should not be allowed to accumulate on the airframe but carries no warning of possible related deficiencies in engine-out performance. This statement implies that the flying and handling characteristics of the aircraft do not change significantly until the ice accumulation exceeds one inch. Although more comprehensive testing of the safety of aircraft in icing conditions is undertaken nowadays, there is still no formal requirement for safety to be demonstrated with an engine inoperative. The current certification requirement is stated in Joint Airworthiness Requirement (JAR) 25.1419, which requires that an aircraft 'must be able to safely operate' in certain specified conditions and that analysis of its performance is to be 'on the basis of the aircraft's operational needs'. It is considered that, in interpreting this requirement, airworthiness authorities should require aircraft manufacturers to demonstrate satisfactory low-speed handling characteristics with one engine inoperative. The effect of ice on stalling speeds should also be assessed and, when they are shown to be increased, suitable increments to approach and threshold speeds should be specified in flight manuals to preserve safety margins. A minimum safe airspeed for engine-out approaches in icing conditions should also be specified in flight manuals.

2.10 The probable cause of the accident

The accident sequence began with an apparent loss of directional control and the aircraft subsequently behaved as if stalled. Evidence of airspeed at the start of the accident sequence shows that it could not have been less than 92 kt ie 13 kt above the minimum control speed and 19 kt above the stalling speed for the configuration and weight. Although the airspeed had been allowed to fall below the recommended approach speed, it is unrealistic to suppose that an experienced training captain could not have maintained control of the aircraft in normal circumstances.

Analysis of past accidents showed many cases where lateral instability was a feature in accidents attributable to icing and it is reasonable to suppose that the ice caused such lateral instability in this case. The further effects of the ice would be to increase the stalling speed of the aircraft and reduce the effectiveness of its fin and rudder but there is insufficient data available to quantify these effects. It is clear, however, that if there had been no ice on the aircraft its speed could never have approached the stalling speed during the go-around manoeuvre. It is concluded that the probable cause of the accident was that the aircraft became uncontrollable at an airspeed well above both its stalling speed and minimum control speed because its flying and handling characteristics were degraded by an accumulation of ice. The decision by the training captain not to operate the airframe de-icing system was an underlying cause but he could not have been expected to foresee this at the time. A contributory factor was that the operating crew allowed the airspeed to fall below the normal approach speed during the latter stages of the approach.

3. CONCLUSION

(a) Findings:

(i) The aircraft was engaged on a training flight and the crew were properly licenced and adequately experienced to conduct the flight.

(ii) The aircraft had a valid Certificate of Airworthiness and a valid Certificate of Maintenance and there was no evidence of any defect or malfunction in the aircraft that could have caused or contributed to the accident.

(iii) The weight and centre of gravity of the aircraft were within the permitted limits.

(iv) The aircraft had flown in conditions of light icing for 1 hour and 10 minutes prior to the accident and had accumulated 1 inch of ice on the leading edges of the flying surfaces.

(v) The airframe de-icing system had not been operated in the period immediately preceding the accident.

(vi) The commander used an abnormally low power setting on the left engine to simulate an asymmetric condition during an NDB approach..

(vii) During the final stages of the approach, airspeed fell below the normal approach speed.

(viii) Control of the aircraft was lost during the subsequent attempt to fly a missed approach procedure.

(ix) Because of an equipment fault no recording could be retrieved from the FDR.

(x) The aircraft flight manual contained no warning of a likely increase in stalling speed with ice on the wings and no recommendation that approach speed should be increased for landing in icing conditions.

(b) Cause

The probable cause of the accident was that the aircraft became uncontrollable at an airspeed well above both its stalling speed and minimum control speed because its flying and handling characteristics were degraded by an accumulation of ice. The decision by the training captain not to operate the airframe de-icing system was an underlying cause but he could not have been expected to foresee this at the time. A contributory factor was that the operating crew allowed the airspeed to fall below the normal approach speed during the latter stages of the approach.

4. SAFETY RECOMMENDATIONS

It is recommended that:

4.1 Airworthiness authorities should require aircraft manufacturers to demonstrate satisfactory low speed handling characteristics in icing conditions with one engine inoperative before certifying the airworthiness of aircraft.

4.2 A minimum safe airspeed for approaches in icing conditions should be specified in flight manuals where appropriate.

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