AIRCRAFT ACCIDENT REPORT 6/87

Accidents Investigation Branch

Department of Transport

Report on the accident to Shorts SD3-60 EI-BEM 3.5 km from East Midlands Airport on 31 January 1986

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List of Aircraft Accidents Reports issued by AIB in 1986/87

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2/86	Vickers Varsity T1 G–BDFT at Marchington, Nr Uttoxeter, Staffordshire August 1984	October 1986
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6/87	Shorts SD3-60 EI–BEM 3.5 km from East Midlands Airport January 1986	December 1987

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

7 October 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 a Shorts SD3-60 EI–BEM, which occurred 3.5 km from East Midlands Airport on 31 January 1986.

I have the honour to be
Sir
Your obedient Servant

D A COOPER
Chief Inspector of Accidents

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Accidents Investigation Branch

Aircraft Accident Report No. 6/87
(EW/C947)

Operator:	Aer Lingus Commuter
Aircraft: Type:	Shorts SD3-60
Nationality:	Irish
Registration:	EI–BEM
Place of accident:	3.5 km from East Midlands Airport Latitude 52° 49.3′ N Longitude 001° 23.5′ W
Date and Time:	31 January 1986 at 1851 hrs All times in this report are UTC

Synopsis

The accident was reported to the Accidents Investigation Branch on 31 January 1986 and the investigation began the same day.

The aircraft, on a flight from Dublin to East Midlands, was making an instrument approach to runway 09 at East Midlands. As it passed 1000 feet, fully established on the Instrument Landing System, it began a series of divergent rolling oscillations which were accompanied by a very high rate of descent. The commander was able to regain control of the aircraft only as it struck some power cables, before making fairly gentle contact with the ground. It came to rest on the edge of a small wood, some 460 metres from its initial impact with the power cables. There was no fire and there was little damage to the cabin. The passengers and crew evacuated the aircraft without further incident.

The accident most probably occurred as a result of the effects of a significant accumulation of airframe ice degrading the aircraft's stability and control characteristics, such that the crew were unable to maintain control. Turbulence and or downdraught may have contributed to the accident. Other contributory factors were the difficulty in detecting clear ice at night on the SD3-60 which resulted in the airframe de-icing system not being used. The delay in application of go-around power may also have contributed to the accident.

1. Factual Information

1.1 History of the flight

The aircraft, using the callsign "Shamrock 328", was scheduled to fly from Dublin to East Midlands Airport. The crew, comprising two qualified captains, one of whom was designated as the aircraft commander, and one air hostess, reported for duty at the normal time.

During the pre-flight briefing the crew learned that at East Midlands the precision (3 cm) radar was unserviceable and that, although the visual approach slope indicators (VASI) had been withdrawn, the precision approach path indicators (PAPI) were operational. The en-route weather was reported as being overcast for the whole journey, with cloud tops at flight level (FL) 70 and a probability of icing when flying in the cloud. There had also been a pilot's report of severe icing between FL 30 and FL 70 in the Birmingham area, some 30 nm south-west of East Midlands Airport. The terminal area forecast for East Midlands suggested a brisk north-easterly wind and a cloud base of 1200 feet.

The aircraft was fully serviceable and 33 passengers were boarded for the flight which took off, on schedule, at 1725 hrs. The crew report that they exercised the wing and tail de-icing system during the climb to FL 90, the level which had been assigned for the flight, and that at that level they were above the layers of stratiform cloud. Following an uneventful flight, via Wallasey, to the non-directional radio beacon (NDB) at Whitegate, some 50 nm to the north-west of East Midlands Airport, they were taken under radar control directly towards the airport and given descent clearance, eventually to 3000 feet, to intercept the instrument landing system (ILS) approach path for runway 09. (Appendix I).

During the descent and before entering the cloud tops at about FL 60, the crew switched on the aircraft's anti-ice system, which heats the windscreen, engine air intakes, propellers, static air vents and pitot probes but, in accordance with normal operating procedure, they did not use the wing and tail de-icing system. At this time, the freezing level (0°C isotherm) was at 1000 feet, the temperature at FL 60 was minus 6°C and the air was saturated. Whilst in the cloud, which according to the non-handling pilot was particularly dense, ice thrown from the propellers was heard striking the side of the aircraft fuselage, and it was suggested that the propeller rpm be increased to expedite the removal of the ice. Both pilots state that, at some time during the descent, they visually checked the aircraft for ice but saw none. Nevertheless, several other flights during that evening have since reported the occurrence of severe icing.

Having levelled at 3000 feet, still in and out of cloud, the aircraft was directed by radar to intercept the ILS and was fully established on the glideslope and centreline by 10 nm, at which point the final descent was initiated. A normal approach was established and continued, past the outer marker beacon situated at 3.9 nm from touchdown, down to around 1000 feet above the runway threshold height. The crew state that up to this point they had neither experienced any significant turbulence nor observed any ice forming on the aircraft. The last meteorological information passed to the crew gave the wind as 060°/15 kt, however, over the previous hour the wind speed in the area, although not automatically recorded at the airport, is reported as gusting up to 30 kt.

As the aircraft descended through about 1000 feet, it suddenly rolled very sharply to the left without apparent cause. With the application of corrective aileron and rudder the aircraft rolled rapidly right, well beyond the wings level position. This alternate left and right rolling motion continued with the angles of bank increasing for some 30 seconds, causing the commander to believe that the aircraft might roll right over onto its back. The angles of bank then gradually decreased. During this period and the subsequent few seconds the aircraft established a very high descent rate approaching 3000 feet/min. Subsequently, with the aid of full engine power, the airspeed increased and the rate of descent was arrested just as the aircraft struck an 11 KV power cable. It continued through another similar cable, two of the supporting wooden poles and the tops of two trees, before coming to rest nose into a small wood edging a field of barley, some 460 metres from the impact with the first power cable. (See map at Appendix II).

The accident occurred at 1851 hrs. The cockpit and passenger cabin were relatively undamaged and there was no fire. The aircraft came to rest lying virtually upright and the passengers, and subsequently the crew, successfully evacuated from the front and rear emergency exits. The crew assembled the passengers a short distance away from the aircraft and ensured that everyone was present. One passenger had suffered a broken wrist and another an injured back but the crew and the remaining passengers were unhurt.

When the emergency vehicles arrived the survivors were escorted down through the field and were subsequently taken to the airport terminal. The two injured passengers were taken to the Derbyshire Royal Infirmary.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	2	–
Minor/None	3	31	

One of the crew of the Airport Fire Service 'Javelin 2000' sustained severe injury and another suffered minor injury when their vehicle overturned on the soft sloping ground.

1.3 Damage to aircraft

The left wing was torn off at the root during the groundslide, as was the left landing gear and associated stub wing. The right wing was pushed rearwards relative to the fuselage, crippling the wing spar and damaging the fuselage centre section in the area of the wing attachment. The nose and forward baggage hold were damaged as a result of ground contact, and the cabin window adjacent to seat row 7 on the left hand side was broken. Damage was also caused to both propellers due to contact with the ground, trees and, on the left side only, power cables.

1.4 Other damage

Two 11KV power cables and three of their supporting poles were broken. Minor damage was inflicted upon a tree and hedge. Several square metres of a cultivated barley field were damaged by the passage of the aircraft, and subsequently by the rescue and recovery vehicles and other personnel.

1.5 Personnel information

1.5.1	Commander:		Male, aged 33 years
	Licence:		Irish Airline Transport Pilot's Licence, first issued 19 January 1982
	Certificate of Test:		20 November 1985
	Ratings:	Part I:	SD3-60; Morane Rallye series
		Part II:	Boeing 737 and 707; SD3-60 Qualified instructor, Rallye series
	Instrument rating:		Valid to 19 December 1986
	Medical Certificate:		Valid to 30 June 1986
	Total pilot hours:		7528
	Total hours on type:		123
1.5.2	Co-pilot:		Male, aged 28 years
	Licence:		Irish Airline Transport Pilot's Licence, first issued 21 January 1983
	Certificate of Test:		7 January 1986
	Ratings:	Part I:	SD3-60; Cessna 100 series
		Part II:	Boeing 737 Qualified instructor, Cessna 100 series
	Instrument rating:		Valid to 6 February 1987
	Medical Certificate:		Valid to 30 June 1986
	Total pilot hours:		4299
	Total hours on type:		1240

1.5.3	Air hostess:	Female, aged 25 years
	Completion of general safety training:	29 May 1985
	Last emergency safety training:	12 December 1985

1.6 Aircraft information

1.6.1 Leading particulars

Type:	Shorts SD3-60
Registration:	EI–BEM
Manufacturer:	Short Brothers PLC, Belfast, Ireland
Date of manufacture:	1984
Serial No:	SH 3642
Certificate of Airworthiness:	
Category:	Transport of Passengers I
Issued:	20 June 1984
Valid to:	18 June 1986
Certificate of Registration:	
Registered owner:	Aer Lingus
Issued:	15 June 1984
Legal owner:	Sandal Leasing Ltd
Operator:	Aer Lingus Commuter Ltd
Engines:	Two Pratt and Whitney PT6A-65R
Propellers:	Two Hartzell HC-B5MP-3C
Airframe hours:	3226.85

1.6.2 Aircraft weight and balance

Maximum authorised take-off weight:	26453 lb (11999 kg)
Actual take-off weight:	25994 lb (11790 kg)
Zero fuel weight:	23544 lb (10679 kg)
Maximum authorised landing weight:	26100 lb (11839 kg)

Estimated accident weight: 24843 lb (11268 kg)

Centre of gravity limits at accident weight: 22.4% – 33.5% of Standard Mean Chord (SMC)

Centre of gravity at 24843 lb: 26% SMC

1.6.3 Ice protection

A diagram of the protected areas is shown at Appendix III.

1.6.3.1 Anti-icing

The dynamic (pitot) and static air instruments supply sources are provided with electrical heating elements. The stall warning detector is also electrically heated, as are the engine air-intakes. Both windscreens are heated by a sandwich element.

It is standard practice to switch on all the anti-icing services when flight in icing conditions is anticipated. On the accident aircraft, the crew switched on these services prior to descending through cloud and the switches were subsequently found in the ON position.

1.6.3.2 De-icing

The leading edges of both wings outboard of the engines, both horizontal stabilisers and the fin are provided with pneumatically inflating de-icing ‘boots’. These function by selection in 1 minute or 3 minute cycles and are normally, apart from test purposes, selected to ON only when a moderate build-up of ice is visually detected. These were not selected ON in the accident aircraft, and were subsequently found in the OFF position.

Throughout the flight, the de-icing boots were managed according to the standard operating procedure. In the situation which the crew found themselves during the approach there was apparently no requirement to operate the boots.

From experience gained over many years, de-icing boots are not used until there is a visible build-up of ice on the leading edges of the wings and tail. The reason for not doing so is that a thin layer of rime ice may not be brittle enough to fracture and may not be shed effectively.

1.6.3.3 Ice detection

The presence of ice on the SD3-60 can be detected by three methods:

(a) A warning light activated by a rotating ice detector under the nose section of the fuselage.

(b) A visible build-up of ice on the windscreen wiper hinges.

(c) Visible ice on the leading edges of the wings or the aileron balance weights or the wing struts. A spotlight focussed on port wing leading edge facilitates the detection of ice at night.

It is noteworthy that clear ice is difficult to see at all times particularly at night in drizzle or rain and, of course, cannot be seen on top of the wing.

1.6.3.4 *The ice detector*

The ice detector is located on the underside of the nose and consists of an electrically driven serrated wheel operating in close proximity to a knife edged cutter. The shaving action that occurs during ice accretion results in a rise in the motor torque, which is detected and results in an ICE caption illuminating on the central warning panel.

The crew stated that the ice detector had been selected to ON during the descent but did not indicate the presence of ice, and it was found in the ON position subsequent to the accident.

There are, of course, certain conditions under which the detector will not indicate the presence of ice:

(a) When there is no ice.

(b) A combination of ambient temperature and airspeed providing a 'total temperature' which does not allow ice to form on the detector in sufficient quantity to promote a warning. This may also depend upon the position of the detector with reference to the flightpath and aircraft attitude (flap setting).

Examination of the graph at Appendix IV shows that, in the prevailing conditions of temperature and airspeed, the detector was operating in a range of parameters defined by the manufacturers as close to the ice detection threshold.

1.6.4 *Flight characteristics*

1.6.4.1 *Roll characteristics*

In common with similar aircraft, during the flight certification trials the SD3-60 was required, by British Civil Airworthiness Requirements (BCAR) D2-8 paragraph 6.5.2, to demonstrate that a roll of 60°, 30° bank one way to 30° bank the other, can be achieved in less than seven seconds in the approach configuration. This and the single engine landing configuration roll recovery requirements were fully met, as were those of BCAR D2-11 paragraph 2.1.2 showing that roll can be corrected and reversed by use of aileron alone at speeds down to the stall with engine power both on and off. However, the use of rudder to prevent yaw is permitted during the approach to the stall.

When, subsequent to the accident, a test flight was conducted, the aircraft complied with all relevant handling requirements but, it was found that the rate of roll could be increased considerably when rudder was used to augment the effect of aileron deflection. Details of this test are given in paragraph 1.16.

1.6.4.2 *Flight in icing conditions*

The SD3-60 de-icing and anti-icing have been approved for operation in icing conditions and fulfil the requirements of BCAR D1-2 and FAR/JAR Part 25.

The icing trials were carried out in natural icing conditions and the effect of rime ice up to 3 inches thick on unprotected surfaces noted. The relevant details of the findings were as follows:

(a) Stalling speed (Vs) (at all flap settings) increased by 8 kt indicated airspeed (IAS). (The stall on the SD3-60 is defined as the point at which full up elevator is needed to maintain the flightpath.)

(b) There were occasions when rime ice accretion, to depths greater than 0.75 inches, caused the leading edge stall warning devices to fail to operate. However, in these conditions, there was a marked increase in pre-stall airframe buffet thus providing an adequate 5 kt natural stall warning. Since the discovery of this failure, a replacement element with greater heating capability, has been fitted to all production aircraft of serial number 3685 and onwards.

The effect of 2¾ inches of rime ice on the protected surfaces was also investigated. For this purpose the de-icing boots were not switched on, and the aircraft was manoeuvred down to the stall in the en-route configuration. The following effects were noted:

(a) On reducing airspeed at less than 1 kt/sec, handling was satisfactory down to the stall, which then occurred approximately 20 kt (indicated) higher than the computed stall speed for a clean aircraft. A pronounced buffet started 8-10 kt before the actual stalling speed. If, however, airspeed is reduced at 1 kt/sec, lower stalling speeds can be achieved.

(b) Sideslips were carried out at 1.2 x Vs (scheduled) and the rudder overbalanced at approximately half deflection, however, no difficulty was experienced in reducing the rudder angle.

The specific effects of clear icing were not investigated, nor are they required to be.

1.6.4.3 *Stall characteristics*

Artificial stall warning, comprising stick-shake and horn, is initiated at approximately 7 kt IAS above Vs. With power off this may be followed by a light airframe buffet and any rolling tendency can be controlled by use of the ailerons. Yaw is controlled by rudder. At the stall, a small nose-down pitch is evident and the rate of descent increases markedly. Recovery is immediate upon release of rearward pressure on the control column. In the configuration of 15° flap, at the estimated accident weight of 24843 lb (11268 kg), the stall warning occurs at 91 kt IAS and the stall at 84 kt.

1.7 Meteorological information

1.7.1 Pre-flight briefing

Prior to the flight, the commander received the following meteorological data:

(a) East Midlands Airport (EGNX): forecast period 0600 hrs – 0100 hrs. 060°/18-35 kt, 4 km, rain, 3 oktas stratus 900 feet, 8 oktas stratocumulus 1600 feet. Temporarily: 7 km, rain and snow, 7 oktas stratus 700 feet.

(b) En-route: (verbally presented general situation) cloud overcast throughout the route, with cloud tops reported to be at 7000 feet. Icing in cloud for the whole area and one report of severe icing between FL 30 and FL 70 in the Birmingham area. Probably no snow but rain or sleet. Possible low level turbulence.

1.7.2 En-route briefing

Whilst en-route to East Midlands, the crew recorded on their log the following meteorological reports:

(a)	East Midlands:	1750 hrs
	Wind:	060°/18 kt
	Visibility:	3500 metres, recent drizzle
	Cloud:	6 oktas at 600 feet 8 oktas at 1400 feet
	Temperature:	Plus 2°C
(b)	Birmingham:	1750 hrs
	Wind:	060°/13 kt
	Visibility:	7 km in sleet or rain
	Cloud:	3 oktas at 800 feet 4 oktas at 1000 feet 8 oktas at 1400 feet
	Temperature:	Plus 2°C; Dewpoint 1°C
	Pressure setting:	1008 mb
(c)	Liverpool:	1750 hrs
	Wind:	070°/15-20 kt
	Visibility:	7 km in drizzle
	Cloud:	2 oktas at 1200 feet 4 oktas at 2000 feet 7 oktas at 2500 feet
	Temperature:	Plus 3°C
	Pressure setting:	1011 mb

(d) East Midlands:	(Time not recorded)
Wind:	050°/23 kt
Visibility:	5 km in drizzle
Cloud:	6 oktas at 600 feet 8 oktas at 1400 feet
Temperature:	Plus 2°C
Pressure setting:	QNH[1] 1008, QFE[2] 997

If the source of the weather recorded at (d) was a message passed by Air Traffic Control (ATC) at 1841 hrs to Shamrock 328, it was mistakenly acknowledged by another aircraft and the crew did not pick up the wind information accurately. This message was recorded by ATC and stated:

> "The wind zero six zero, twenty three knots, OCCASIONALLY TWENTY EIGHT KNOTS".

It could not be established whether this message was in fact the 1841 hrs ATC transmission.

At 1847.50 hrs, Aerodrome Control informed Shamrock 328 that they were clear to land and that the present weather was:

> "Surface wind zero six zero, one five knots, runway surface wet".

1.7.3 *Local area meteorological conditions*

1.7.3.1 *Aftercast*

The Meteorological Office at Bracknell supplied an aftercast for East Midlands Airport relevant to 1851 hrs on 31 January 1986:

Special features:	Depression centred S Germany at 1800 hrs moving slowly NW. Strong ENE flow over England.
Winds:	Surface: 050°/20 kt occasional gusts to 35 kt 2000 feet: 070°/45 kt temperature minus 2°C
Cloud:	4-6 oktas stratus base 900-1200 feet. 8 oktas stratocumulus base 1800-3000 feet, tops 5000-7000 feet.
Surface visibility:	4000 metres – 6 km
0° isotherm:	1000 feet

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[1] Footnote 1. QNH: Pressure datum setting, in millibars (mb), such that the altimeter reads height above mean sea level.

[2] Footnote 2. QFE: Pressure datum setting, in millibars (mb), such that the altimeter reads height above the runway threshold.

Airframe icing:	Moderate to severe
Warnings/Turbulence:	Marked inversion near 5000 feet (temperature rise of 5°C in 500 feet). Moderate to severe low level turbulence. Possible rotor streaming.
Pressure setting:	QNH 1008; QFE 997

1.7.3.2 *Synoptic situation*

Two mini-sonde ascents (balloon suspended atmospheric sensing devices) were made at 0609 hrs and 1121 hrs at RAF Waddington, and others from Hemsby at midnight and 1200 hrs. In the opinion of the Meteorological Office, there is no evidence to suggest that the situation at these times and locations would be any different from that occurring at East Midlands at 1851 hrs.

The stratocumulus cloud, continuous between 1000 feet and 5500 feet, was extremely wet and completely supercooled, hence it would be very unlikely that an aircraft descending through it would not experience clear icing. Furthermore, with the occurrence of precipitation, the largest water droplets would be found near the base of the cloud and freezing rain or drizzle would be experienced at this level.

1.7.3.3 *Reports from other aircraft*

Very similar meteorological conditions to those present during the accident period had prevailed for the previous and subsequent two days. Because of this, aircrew who had flown into East Midlands during that period were asked to report on any unusual meteorological phenomena experienced. They variously reported:

30 January:

Merchantman: The ice which had, despite the normally very effective windscreen heating, formed on the windscreen during the descent, "melted at about 2500 feet. At 1000 feet agl, a sudden increase of descent rate experienced"

31 January:

SD3-60:	"2½ inches of ice broke off the airframe at cloud-break"
F27:	"Severe ice accretion at FL 40. Windshear and high sink rate experienced on final approach"
Viscount:	"Severe ice in cloud, very turbulent"
Twin Commanche:	"At 1500 feet above ground level, very severe turbulence, moderate icing, a sudden 200 feet downdraught on finals"
SD3-60:	"After landing, large pieces of ice were seen dropping off the aircraft".

The crew of the accident aircraft reported:

"Very little turbulence and no sign of ice".

At 1920 hrs on 31 January, the crew of an SD3-60 flying into Edinburgh, in very similar conditions to those at East Midlands, reported that:

> "Although no ice was seen by the crew on visual inspection, when the de-icing boots were exercised, large pieces of clear ice were seen to fly off the wings".

1.7.4 Local area features

Reference to the map at Appendix V shows that there are several factors which could have influenced meteorological phenomena affecting an aircraft making its final approach to runway 09 at East Midlands Airport on the night of 31 January 1986.

Ratcliffe power station lies 10 km to the north east of the approach path and has 8 cooling towers. Castle Donington power station has 4 towers and lies 4 km north east of the approach path. Each of these were directly upwind of the aircraft. However, turbulence produced by these structures is likely, only in conditions of non-turbulent airflow, to cover a distance downwind of 10-12 diameters of the obstruction. The approach path, in each case, is well beyond this distance, being respectively 8 and 20 times that distance from the towers and, in the gusty wind conditions, it is not likely that the airflow would have remained laminar between the towers and the approach path. Furthermore, analysis by the Meteorological Office indicates that the heat escaping from Ratcliffe would have influenced the temperature in the area of the aircraft's path by only 0.01°C and that from Castle Donington by 0.1°C. The airmass was already fully saturated at the heights under consideration and neither this increase of temperature nor that of liquid water content (0.01 gm/kg and 0.1 gm/kg respectively) can be considered likely to have influenced the conditions in the area of the final approach path.

The Trent Valley lies immediately to the north of the approach path. There is an 'S' bend in this valley, 200 metres to the north of the flightpath on the other side of a wooded ridge 200 feet high. This orographic situation is capable of inducing phenomena of wind behaviour such as accelerated windspeed, downdraughts and turbulence in the area where the initial disturbance of the aircraft's flightpath occurred. However, the likelihood of this feature producing lee or rotor waves is considerably lessened by the comparatively great height of the temperature inversion at 6000 feet. The precise symmetry of the roll oscillations are unlikely to have been produced by random turbulence. Although several other flights reported downdraught and turbulence, the crew of EI–BEM reported none and the Digital Flight Data Recorder (DFDR) 'g' and IAS traces confirm the absence of any such phenomena.

1.8 Aids to navigation

With the exception of the precision approach (3 cm) radar, all the navigational aids at East Midlands were fully operational as the aircraft began its approach to runway 09.

Both of the aircraft's VHF navigation receivers were tuned to the ILS frequency (109.9 MHz) and both NDB receivers to the locator outer marker beacon (393 KHz). The cockpit voice recorder shows that both these facilities had been properly tuned and identified and there is no evidence to suggest any malfunction.

At 1851 hrs, the lights in the control tower momentarily dimmed. This clearly coincided with the aircraft's passage through the 11 KV cables. However, although the PAPIs and the airfield lighting suffered the same momentary dimming, the radio aids, supplied by constantly recharging batteries, did not falter. Nevertheless, following the accident, an immediate flight check and a ground technical check of the aids was carried out and they were found to be fully operational.

The navigational aids are considered not to have been contributory to the accident.

1.9 Communications

At 1838 hrs 'Shamrock 328' established radio communications with East Midlands 'approach control', on 119.65 MHz. Communications were normal until the aircraft was passed to 'aerodrome control', on 124.0 MHz at 1848 hrs. At this time 'Shamrock 328' was cleared to land on runway 09 and informed that the surface wind was 060°/15 kt and that the runway surface was wet. This transmission was acknowledged.

At 1851 hrs Air Traffic Control again, and thence repeatedly, called the aircraft but, receiving no response, alerted the Airport Fire Service (AFS). The AFS reported that there was no sign of the aircraft within the airfield boundaries, and at 1856 hrs, the ATC controller initiated the full "Aircraft Disaster" procedure.

1.10 Aerodrome information

East Midlands Airport at Castle Donington, has a single runway 09/27, at an elevation of 310 feet above mean sea level. The ground to the west of the runway slopes down towards the accident site, which averages some 60 feet below airfield elevation.

Runway 09, in use at the time of the accident, had an ILS transmitting on a frequency of 109.9 MHz and PAPIs, each providing a glideslope angle of 3°. The airport is served by a full ATC service consisting of approach control with radar and aerodrome control.

The airport is served by an Airport Fire Service which, although licensed to require the lesser Category 7 equipment scale, has equipment to Category 8 comprising:

1 Javelin vehicle
1 Carmichael Jet Ranger 2000
1 Rapid Intervention Vehicle (6 wheel Landrover)
1 Carmichael Jet Ranger

1.11 Flight recorders

The aircraft was equipped with a Plessey PV 1584 DFDR and a Fairchild A100 cockpit voice recorder (CVR). Both were mounted in the rear fuselage immediately aft of the rear baggage hold. They were recovered intact, and successful replays were obtained. That of the DFDR is shown at Appendix VI.

1.11.1 Digital flight data recorder

A total of 16 parameters were recorded plus 7 discretes (switch positions). The recorder had functioned correctly and no difficulty was experienced with the replay. However, there were problems with some of the input parameters. PITCH TRIM indications were not functioning, and the other control position signals (AILERON, ELEVATOR and RUDDER) were 'noisy' throughout the entire 25 hours of recording, particularly so in the case of the elevator. The potentiometers sensing these positions were removed and taken to the manufacturers for examination. PITCH TRIM had not functioned because its flexible drive from the trim mechanism had failed some time before the accident. All of the other potentiometers exhibited varying degrees of wear on the tracks, around the neutral positions, in particular the elevator potentiometer showed severe wear.

1.12 Wreckage and impact information

1.12.1 On site examination

1.12.1.1 The impact sequence

A map showing the accident site is shown at Appendix VIII.

The aircraft had come to rest some 460 metres from its first point of impact on a heading of 010°M at the edge of a coppice in Donington Deer Park. The first impact had been with a rough hedge above which, and parallel to it, ran some 11 KV power cables. The cables were suspended 25-28 feet above the ground and it was apparent that these were responsible for the wire strike marks on the radome of the aircraft. The orientation of the marks, together with the shape of a swathe cut through the hedge, indicated that the aircraft had rolled approximately 20-25° to the left at this stage. Some 90 metres further on, the left wing had cut through a wooden pole carrying another set of power cables orientated approximately 90° to the first set. The shape of the indentation in the left wing leading edge indicated that the aircraft was then approximately level in the rolling plane. These two points of impact, together with subsequent ones, gave an impact track of 075°M.

The power cables had been severed by the left propeller and a number of fragments had become embedded in the left hand side of the fuselage. Some 180 metres from the hedge, another power cable support pole had been knocked over as a result of being struck on the conductor carrier on top of the pole. The next pole was also lying on the ground but it was clear that this had been dragged down as the aircraft passed through the cables.

Approximately 300 metres from the first point of impact, the left wing of the aircraft had struck holly and elm trees which imparted a yaw to the left as the aircraft struck the ground 70 metres further on. The left wing tip and left main undercarriage were the first parts of the aircraft to contact the ground, with the undercarriage and associated stub wing assembly failing as the aircraft subsequently passed through the remains of a cut down hedge. The ground marks indicated that the right wing tip had contacted the ground as the aircraft slewed to the left before coming to rest leaning approximately 10° to the left, and that the right wing leading edge had ridden up the trunks of the trees.

1.12.1.2 Flightdeck readings and selections

Left hand altimeter:	Subscale setting: 993 mb Reading: Minus 180 feet
Right hand altimeter:	Subscale setting: 997 mb Reading: Minus 100 feet
Engine intake anti-ice:	ON
Propeller anti-ice:	ON
Windshield anti-ice:	ON
Pilot/static/stall warning heaters:	ON
Airframe de-ice:	OFF
Ice detection:	ON
Trim positions:	
Rudder:	½ division left of neutral
Aileron:	Full left wing down (cable broken due to left wing detachment)
Elevator:	Take-off position
Power levers:	
Left:	1 inch short of fully forward (lever moved easily)
Right:	Slightly forward of "flight idle"
Propellers:	
Left:	Feather position
Right:	Feather position

Fuel:

Left:	OFF
Right:	1 inch forward of OFF
Flaps:	15° selected

The remainder of the instruments and gauges were showing the normal "electrical power off" indications.

1.12.2 *Subsequent detailed examination*

Following the on-site examination, the wreckage was recovered to AIB's hangar at RAE Farnborough.

1.12.2.1 *The airframe*

Both wings had failed, although they remained attached at the pin joint immediately outboard of the engines. In the case of the left wing, failure had clearly occurred when the left undercarriage, the sponson of which supports the wing strut, became detached. This had induced a compressive load into the wing strut which consequently deflected the outer mainplane upwards. Examination of the wing upper surface revealed that the edge of the skin, running chordwise above the pin joints, had a permanent upwards set of 90° and that the outer wing must have deflected upwards at an angle of 90° for this to occur.

The right outer mainplane failure had clearly occurred during the final slew to the left when the right wing tip contacted the ground. The wing spar, inboard of the engine, had been distorted when the right wing was pushed rearwards as the aircraft came to rest in the trees.

The detachment of the left sponson had resulted in the landing gear retraction/extension jack breaking free. It was apparent that this had been responsible for punching the hole in the cabin window, adjacent to seat row 7 on the left side, which allowed mud to be thrown into the cabin during the groundslide.

1.12.2.2 *Flying controls*

The primary flying controls are all manual, comprising push-pull rods and bellcranks.

The elevator circuit was still intact but one of the rudder system push-pull rods beneath the flight deck floor had been broken, clearly the result of impact forces as the underside of the forward fuselage was disrupted. The remainder of the rudder circuit was intact. The aileron circuit was intact as far as the bellcrank in the fuselage roof, where push-pull rods split left and right into the wing trailing edges. Downstream of this point, several fractures had resulted from the disruption of the wing structure. All failures were attributable to forces generated by the final impact.

Detailed examination of the flap system was also carried out. The flap surfaces could be moved only with difficulty (ie, they were still restrained by the actuators) and some fluid spillage was found around the broken hydraulic pipes in the left wing root.

The flaps had been selected to 15°, however, when the engines stopped, as there is no hydraulic or mechanical lock other than at the retracted position, the surfaces had drooped to their full 30° deflection. When the mid and outer flaps were subsequently pushed (by hand) to the retracted position, the mechanical locks within the wing mounted actuators operated correctly, thus preventing their return to the previously set position. The inboard actuators were no longer connected to the flap surfaces but had remained at their pre-impact positions. Both rams were extended to identical amounts equating to a 15° flap position.

The flap selection lever movement is initially absorbed by a spring box upstream of the flap actuators and the actuators then move until the input signal is nulled. The inboard flap actuators, which are located in the centre section along with their signalling mechanism, had remained intact. The flap selection circuit was also intact up to this point. The signalling mechanism for the mid and outer flap actuators consists of pulleys and cables, with push-pull rods forming the final link between each pulley and actuator package. Three out of the four signalling rods had broken: The exception was the left outboard unit. It was apparent that, during the impact, excess tension had been generated in the signalling cables, due to the relative movement between the wings and fuselage, this, in turn, caused over-rotation of the pulleys and consequent breakage of the rods.

The links preventing relative movement between the mid and outer flap surfaces had remained intact. The flap actuators, with the exception of the right one which had sustained impact damage were tested on a hydraulic rig and performed satisfactorily with no excessive internal leakage rates.

1.12.2.3 Hydraulic system

The hydraulic system supplying the flaps, landing gear, brakes and nosewheel steering was examined. Particular regard was paid to the flap system operation, as any independent movement or asymmetric condition could in theory have influenced the violent lateral oscillations that the aircraft experienced prior to the accident.

The system, which operates at 3000 psi, is supplied by the two engine driven hydraulic pumps which draw fluid from a 300 cubic inch (5 litre) reservoir. The contents gauge was found indicating 50 cubic inches. In the event of a main system failure, the flap system accumulator will maintain a flap selection for a limited period. The accumulator, along with three other accumulators (for landing gear, main system and emergency braking) is gas charged from a panel in the left landing gear sponson. A lack of gas pressure was found in the accumulators but was almost certainly consequent upon the rupturing of pipework when the left landing gear and sponson became detached. The flap system accumulator was found almost exhausted suggesting that the fluid had been lost overboard following the disruption to the hydraulic lines in the wing roots.

A compressed air supply was subsequently connected to the severed pipes in the wings to test for leaks, none were found.

1.12.2.4 *The stall warning system*

Although the aircraft wings carrying the stall warning vanes had been removed it was possible to restore electrical power to the system, whereupon the stall warning and associated stick-shaker test facilities operated satisfactorily.

The detector vanes were removed from the wings and tested for switch functions. Their operation was satisfactory.

1.12.2.5 *Ice detection and protection systems*

Despite the disruption that had occurred in the nose area, the ice detector could be operated when electrical power was restored, and the ICE caption illuminated when the serrated wheel was slowed down. The applied torque necessary to activate the light was calibrated and found to be within limits.

The de-icing boots on the wing and tail empennage leading edges are inflated by air which is bled from the engine compressors, via engine bleed valves, to five de-icing flow control valves. The normal position for the bleed valves is OPEN and they are closed only in the event of an overheat. Examination confirmed that the bleed valves were OPEN, in agreement with the cockpit selection, but the system was not switched on at the time of the accident. The boots were examined and then inflated with compressed air to check for leaks; the only damage found was that resulting from the left wing leading edge striking the power cable support pole.

The electrically heated mats for ice protection of the engine intakes and propellers were found to be selected to ON but could not be checked for operation. The engine intakes also have an inertial anti-ice system, comprising electrically deployed vanes which prevent the compressor inlet screen from clogging with ice. The system was found to be selected ON and agreed with the positions of the vanes.

The electrical heaters for the pitot heads and static vents operated satisfactorily when electrical power was restored to the aircraft systems.

The heater mats for the stall warning detector vanes were tested with a meter and found to be serviceable.

The ice detection spotlight was also found to be serviceable and correctly aligned.

1.12.2.6 *Pitot and static system*

The commander's and co-pilot's airspeed indicators (ASI's) are driven from separate systems. A pressure tester was applied to each system and no leaks were found.

The calibration of both ASI's was checked and found to be satisfactory, zero error was recorded for the captain's instrument over the 80-120 kt range and a maximum error of +2½ kt for the co-pilot's instrument.

1.12.2.7 Engine instruments

The propeller rpm and engine torque indicating systems were calibrated in order to validate the engine data from the DFDR.

The rpm indicators are driven from tacho-generators which were spun up and the output voltages and frequencies, together with indicator readings, were recorded. The results were satisfactory despite a slightly "noisy" right engine tacho-generator signal.

Propeller torque, for the purpose of indication, is converted to proportional pressure by means of a floating gear-and-piston assembly in the engine and this pressure is applied to a pressure transmitter. It was found that the left engine pressure transmitter had a datum off-set, possibly as a result of damage to a diaphragm within the transmitter. It was, however, concluded that this defect could not have been present before the accident, otherwise the indicator would have registered incorrectly when the engine was at rest. The remainder of the system was satisfactory.

1.13 Medical and pathological information

All three crew members were fully fit to carry out their respective duties. One passenger had suffered a broken wrist and another exacerbated an already injured back.

1.14 Fire

There was no fire, however, the accident site was attended by the Derbyshire Fire Service with 4 fire vehicles, the Leicester Fire Service with 6 fire vehicles and the Airport Fire Service with 2 vehicles.

1.15 Survival aspects

1.15.1 The evacuation

When the aircraft had come to rest, the fuselage was in an almost upright position, with its nose section just into the edge of a wooded area. The aircraft lay to the north of the western loop of the Donington Park racing circuit adjacent to the main road, at the edge of a wood. The area between the racing circuit and the aircraft comprised 250 metres of steeply sloped and muddy barley field. This is shown at Appendix VIII.

The interior of the fuselage had remained largely undamaged, although the forward two seats on the right side had become detached from their wall mounting and the window adjacent to seat 7A had broken, allowing mud to spray into the cabin. The air hostess was unable to open the main passenger door at the rear of the aircraft on the left side, due to a combination of slight structural deformation and the fact that the base of the door was a few inches below ground level. However, all the emergency exits, two forward and one aft, were opened without difficulty.

Twenty passengers, and subsequently the aircraft commander, left via the forward emergency exit and the remaining eleven, followed by the air hostess and subsequently the co-pilot, from the rear right emergency exit. The crew then assembled the passengers a short distance from the aircraft and, having ensured that everyone was present, went back into the aircraft to collect coats and blankets.

When the first of the emergency services arrived the survivors walked, with the exception of one with an injured back who was carried, down to the race track and thence to the road to meet them.

1.15.2 *The emergency services*

The accident occurred at 1851 hrs but, because of other ATC radio communications, and the necessity to establish that the aircraft was in fact missing, it was not until 1853 hrs that ATC alerted the AFS that the aircraft might have crashed at the western end of the airfield. At 1856 hrs the AFS reported that there was no sign of the aircraft in that area and the ATC controller instituted the full "Aircraft Disaster" procedure with the exact location unknown. At 1905 hrs, the AFS were told of the location and despatched the first of two vehicles to attend the accident.

In the meantime, however, the emergency services at Derby, having received two '999' calls describing the accident and giving an approximate location, diverted two cars to the scene. The details of the accident were immediately circulated to the appropriate emergency services and, between 1856 hrs and 1903 hrs, the Derbyshire services were mobilised together with those of Leicestershire, although the exact location of the accident was still unknown.

At 1905 hrs, a Derbyshire Police traffic car reported the exact position of the accident, which was immediately passed to all units, including the Airport and Leicestershire Fire services.

At 1913 hrs, the Derbyshire Ambulance and Fire services arrived at the point on the road nearest to the accident and the first AFS vehicle turned into the adjacent field containing the western loop of the race track. At 1920 hrs, the remaining Derbyshire, Leicestershire and AFS vehicles arrived. Shortly after this, one of the AFS vehicles overturned in the soft mud, seriously injuring one of its crew and slightly injuring another.

When the survivors arrived at the roadside, they were surprised that the emergency vehicles did not immediately take them aboard to afford them shelter and, also, that they were then shuttled a number of times between the vehicles at the end of the cart track and those at the south-west entry point from the road into Donington Park, some 75 metres away.

Following the survivor's arrival at East Midlands Airport, 1 hour and 20 minutes was occupied by identification, welfare and injury assessment. Because of the accident location and the aircraft location this involved the authorities from Leicestershire, Derbyshire and the airline.

1.16 Tests and research

1.16.1 Flight test

In conjunction with the manufacturer and the operator a flight test was conducted on an SD3-60 from Dublin and demonstrated that the SD3-60 complied with all the relevant handling requirements. It was loaded with ballast to represent the condition of EI–BEM when the accident occurred and a series of demonstrations were carried out in order to put on record (DFDR) the various handling characteristics of the aircraft, with particular reference to stability and control response. These are shown at Appendix VII.

Power on and power off stalls showed that, as designed, the aircraft was very stable in the rolling plane and even at speeds below the normal Vs (84 kt for the weight and configuration) there was no tendency to drop a wing. On the occasions when a wing drop was, with difficulty, induced by very coarse use of rudder, the aircraft displayed a natural tendency to right itself and both the rudder and the ailerons maintained an adequate response throughout the manoeuvre. Recovery from high angles of bank was demonstrated using, on separate occasions, only aileron and only rudder. In each case immediate recovery was effected, albeit less rapidly than when using co-ordinated rudder and aileron and furthermore, when using the rudder only, considerable degrees of heading change were noted. Finally, an attempt was made to reproduce the events of 31 January. The timings of the rolls and the power settings were copied from the DFDR trace of the accident and the control movements were made, where possible, in the same manner as those of EI–BEM. However, whilst it was possible to induce comparable rates of roll and roll reversal, this was achieved by maintaining full pro-roll aileron and rudder to the point of reversal. If the controls were centralised as the wings passed the horizontal, the roll stopped immediately. It was not found possible to induce the aircraft to continue rolling against control input, thus demonstrating the low rolling inertia produced by light "dry" wings in the high wing configuration. Throughout the entire sequence, the aircraft displayed normal roll stability and control response and it did not build up a descent rate comparable to that of the accident aircraft.

1.16.2 Performance comparison

A check was carried out on the achieved performance of the aircraft during its descent from 7000 feet. This was done by selecting a number of periods where airspeed and altitude were reasonably constant or varying at a reasonably steady rate. For these periods, the rate of change of energy height was calculated using straight lines through the measured points.

Data on the theoretical climb and descent performance of the aircraft was supplied by the manufacturers and the achieved rate of change of energy height could be compared with this theoretical rate of change. A total of 16 separate periods were used in this check, 12 with zero flap, 1 with 5° of flap, and 3 with 15° of flap, all at 1200 propeller rpm.

The difference between achieved and theoretical rate of change was deduced and converted into an equivalent drag coefficient difference (Δ C_D). This is shown plotted, together with height, against elapsed time in Appendix X. It should be noted that it is not possible to determine whether this is in fact a drag difference, an engine thrust difference, or a combination of the two.

It can be seen from the graph that the aircraft suffered a steady reduction in performance which started at approximately 5000 feet (based on 1013.25 mb), which was shortly after it is believed to have entered the cloud layer.

As torque indications were higher than scheduled for the descent rates achieved, there was obviously no problem with engine power. Part of the reduction in performance may have been due to a loss of propeller efficiency due to ice contamination but it is thought that this would be a small influence and is unlikely because ice was heard shedding from the propellers.

The readouts of the DFDR from this flight also enabled comparison of the lateral/directional motion occurring during the accident flight, arbitrary time datum 55-81 seconds (Appendix VI) was made with that of the test flight, datum 8-43 seconds (Appendix VII) and provided significant data which was analysed by aerodynamicists of the Royal Aircraft Establishment.

Although in the latter case the pilot inputs of aileron and rudder were slightly more square and of a slightly shorter period, this should have no marked effect on related aircraft motion. In both cases, the rudder was in phase with the aileron, however, when a plot was made of bank angle versus aileron movement, very clear differences were apparent, and these are shown at Appendix IX.

In figure 1, the clockwise loop shows that the aircraft motion is being driven by the controls and that the roll reverses virtually as soon as the aileron is reversed. Figure 2 on the other hand clearly shows that the phasing of aircraft movement to control displacement is very different. There is no sign of the clockwise loop required to indicate that the aircraft movement was being driven by the controls, and it can be seen that the angle of roll continues to increase for a significant time after the aileron is reversed. It is also apparent that, as the aileron is, in general, not reversed until near the wings level position and there is little evidence of anti-clockwise loops, the controls are not being used to their best effect to damp out the motion.

The breadth of the plotted lines shown encompass the very large number of individual points originally plotted but, nevertheless, accurately portrays the characteristics of the original graphs. The lack of similarity between the lateral/directional characteristics of the two flights is self evident and is consistent with that which might be produced by modification of the aerodynamic surfaces of EI–BEM.

As a check, the same performance comparison method was used for a number of periods on the test flight, and these compared well with the predicted performance.

For the final rolling manoeuvre, the wing incidence at mid-aileron span was estimated. This was done for the wings level points by summing the incidence calculated from the descent rate with recorded pitch attitude and that due to the rolling motion of the aircraft. No account was taken of heading changes as these were considered to be small and of secondary effect. The absence of large heading fluctuation could have been disguised by a considerable degree of yaw correction. It was determined that the downgoing wing experienced some very high values of incidence, the maximum being about 30°.

1.16.3 Research into icing phenomena

Detailed research carried out in the United States by The Boeing Company, Ohio State University and NASA demonstrate, that ice accretion has distinctive and characteristic effects on the performance of an aerofoil. An abstract of the findings common to all four sources is as follows:

The drag and other aerodynamic effects of rime ice are much less severe than those of glaze ice. The latter forms in conditions of high liquid water content (in the air) and surface temperatures near freezing. In these conditions, not all of the water droplets freeze on impact but some run a short distance before freezing and form a blunt or double-horned ice shape on the upper and lower surface of the aerofoil leading edge. It is the upper surface horn which has the greatest effect and acts as a spoiler, affecting the aerodynamic characteristics in terms of increased drag and a decreased maximum lift coefficient. The drag increase due to ice increases sharply with landing flap settings and the decreased maximum lift coefficient can give rise to safety problems due to the increased stalling speed and the necessity to increase the angle of attack in order to maintain the same lift.

On a typical twin-engined commuter type aircraft used for the NASA tests, it was noted that, in conditions of mixed rime and glaze ice, the increase of drag was in the order of 75% above that of the un-iced aircraft and the lift coefficient was 16% lower.

The effects of glaze ice on the horizontal stabiliser were also measured. With no flap selected, a 10% degradation of elevator power and effectiveness occurred, with no noticeable change in pitch damping. However, with 10° of flap selected, the former increased to 16% and there was a 23% degradation of pitch damping. It was also observed that increased engine power literally overwhelmed any changes in static pitching moment caused by icing.

1.17 Additional information

1.17.1 Karman vortices

Research undertaken by the CEGB since the introduction of cooling towers has indicated that their fluid dynamic drag, in certain conditions of wind, can produce vortices which continue downwind. The particular effects noted by Karman take the form of a series of regularly spaced scroll type vortices on alternate sides of a straight line trailing downwind from the tower. The intensity and duration of these vortices can be defined as a function of the tower diameter and the wind speed. However, only if the ambient airflow is laminar, and remains undisturbed by other turbulence factors, can the Karman vortices be expected to continue, and then only for a distance of 10 times to 12 times the tower's diameter downwind.

The diameter of the cooling towers is 64 metres, which suggests that the vortices from even the closer of the two power stations could continue for some 640-770 metres downwind. These towers, however, lie some 4000 metres upwind of the aircraft's position.

1.18 New investigation techniques

None.

2. Analysis

2.1 Introduction

The flight from Dublin to East Midlands was, from the evidence provided by the recorders, well managed and accurately flown. The crew conducted the approach in a professional and competent manner and they had no reason to believe that the approach should be other than totally uneventful right down to the runway. The onset of the divergent rolling motion and the rapid increase in the rate of descent must have been very alarming to the crew particularly when so close to the ground. When the meteorological conditions are also taken into account there are four possible reasons for the loss of control that caused EI–BEM to crash on the final approach to East Midlands Airport on the night of 31 January 1986:

(a) Technical defect
(b) Turbulence/Downdraught
(c) Control inputs
(d) Ice

These possibilities which may have occurred in combination are discussed below together with an analysis of the abnormal descent rate.

2.2 Technical Defect

The engineering investigation of the wreckage yielded no clues as to the cause of the accident. As far as could be determined the aircraft was perfectly serviceable just before the crash and all systems were functioning correctly. Unless some undiscovered obscure defect caused the loss of control, and it is hard to imagine one that would cause such a condition, then a mechanical defect can be eliminated as the cause of the accident.

2.3 Turbulence

Considerable effort was put into the investigation of the meteorological situation at the time of the accident, both with regard to the possibility of icing and to turbulence. From the reports of other aircraft making approaches to the same runway at East Midlands in the period before and after the accident, and from the meteorological data that was collected and subsequently analysed, there seems little doubt that most aircraft experienced turbulence of some sort during the approach. The degree of turbulence reported varied considerably, as did the reported surface wind, but no other aircraft encountered rates of descent of the same magnitude as EI–BEM nor did they experience a consistent rolling oscillation comparable to that demonstrated by EI–BEM. The weather system that affected the East Midlands area at the time of the accident lasted for 4 days and it is therefore likely that had turbulence been the causal factor then at least one other of the many aircraft that made approaches would have reported an event similar to but perhaps not of the same magnitude as that encountered by EI–BEM.

The crew reported smooth flight conditions on the approach and the FDR analysis supports this up to the point where the aircraft's violent manoeuvres precluded accurate assessment.

The study of the topography of the local area yielded no ready explanation for the regular nature of the divergent/convergent rolling oscillations experienced. However, other aircraft did report turbulence on the approach and the terrain may have been responsible for some turbulent effect at about the point where the initial disturbance occurred.

In considering turbulence as the prime causal factor of the accident there is little doubt that the aircraft experienced some turbulence at or about the time of the initial disturbance but the available evidence suggests that the magnitude of any such phenomenon would normally have been insufficient to have caused an SD3-60 to demonstrate such lack of controllability. Furthermore, the study of the topography and meteorological situation suggests that conditions of the magnitude required to produce such an event would not have been produced at East Midlands on the day in question.

2.4 Control inputs

The two characteristics of the rolls experienced were the very high rotational accelerations and rotational velocities achieved. The former occurs close to the point of roll reversal and the latter at the wings-level position, although the velocities may not have varied for a considerable number of degrees either side of these positions.

At the points on the DFDR graph displaying maximum rotational velocities the angles of attack at the mid aileron span of the down-going wing reached high values and the aileron on that wing may have stalled. In these circumstances the roll momentum will have a much increased effect when corrected by only a single aileron and might well explain why the anti-roll controls, applied at the wings-level position, during the developed oscillations initially had little or no effect. This, in turn, provides a good reason why the commander felt it necessary to apply full control deflections. The necessity for this is demonstrated by the lateral/directional plots shown at Appendix IX, which show that the response to control inputs was not typical of the aircraft's normal behaviour.

Finally, when viewing the divergent nature of the roll oscillations and the increasing descent rate shown in the DFDR graphs, it is evident that a considerably earlier selection of go-around power might have remedied the situation. However, as the commander was no doubt anticipating turbulence from the strength of the reported wind, the initial disturbance was almost expected and was quickly rectified. Consequently, it is not unreasonable to suppose that the onset of the symmetrical oscillations was thought to be merely a repeat of the first disturbance, and would be as easily corrected without the application of full power.

Following realisation that he could not control the increasing angles of bank, the belief that the aircraft would roll onto its back could again, understandably, make the commander reluctant to apply full power.

Whilst it would therefore be unreasonable to criticize the delay in the application of full power, it must nevertheless be considered as a contributory factor.

2.5 Ice

2.5.1 The evidence

The meteorological evidence indicated that the weather system which covered the area was highly conducive to the formation of clear ice and the en-route forecast warned of icing, a prognosis supported by a pilot's report of severe icing between FL30 and FL70 in the Birmingham area. The aircraft that made an approach before EI–BEM and the first aircraft making an approach after the accident both reported icing. Investigations revealed that during the period that the weather system covered the area, there were no other aircraft that did not experience ice during the approach to East Midlands Airport and there are well documented reports of severe and abnormal ice build up.

The crew had switched on the anti-icing systems in anticipation of icing conditions, however, in accordance with standard operating procedures, the pneumatic boot de-icing system for protection of the flying surfaces was not selected ON because, even though they were specifically checking for the presence of ice, the crew did not see any ice build up. Consequently, there was no opportunity for the boots to break off any ice that had formed. The apparent lack of both visual ice and an ice detector warning gives rise to two possibilities:

(a) EI–BEM was the only aircraft to experience freak conditions in not encountering ice on the approach, in meteorological conditions that were ideal for ice formation.

(b) The crew, despite their best efforts, were unable to detect the clear ice building up and the detector may have been operating outside its limits of operation.

There is, however, other evidence that ice built up on the aircraft. From the CVR it was established that ice would be heard breaking off from the propellers as their de-icing heater mats operated. Furthermore, from performance calculations, it was possible to determine that the aircraft suffered a gradual but progressive degradation in performance during the period that it was in cloud (see Appendix IX) and the only significant factors which then changed were the air temperature and water content. These must therefore be the origin of the degradation and ice accumulation is the only reasonable explanation. This is supported by the in-flight reports of clear icing and also the meteorological evidence.

It might be considered that the performance degradation was due to ice on only the propellers, which were selected to a slightly lower rpm than the optimum for ice clearance. Nevertheless, they are fitted with anti-icing (electrical heating) which must have been effective, as ice shedding from them could be heard (on the CVR) hitting the fuselage. If ice had formed on the propellers then it must have also formed on the airframe and so there is again little doubt that the performance degradation was caused mainly by ice on the airframe.

The crew were expecting icing conditions to exist during the approach, as shown by their selection of the anti-icing systems. They were also actively looking for ice build up of sufficient thickness to suggest use of the pneumatic boots. However, the SD3-60 is equipped with an ice inspection light only on the left side and if, as in this case, the captain is flying the approach, then he is unable, other than by handing over control to the co-pilot, to spare the time for an extensive examination of the wing leading edge. The co-pilot has much more opportunity to check for ice but at night his only source of illumination to carry out the check is his torch shone through the flight deck window. Moreover, on this occasion, the aircraft was in thick cloud and then in rain, which would further inhibit visual detection of clear ice. Although the illumination was far from ideal it should have revealed the presence of some ice, although perhaps not of sufficient thickness to warrant the use of the de-icing boots. The crew are certain that they checked for ice and there was none visible. However, if clear ice as opposed to rime ice was present, these poor illumination conditions would make it difficult if not impossible to detect visually. Furthermore, from a human factors standpoint, if the crew were expecting to see ice forming then they may have been anticipating the more usual rime ice rather than clear ice that is rarely encountered in England, but shown to be very likely by the low level meteorological balloon ascents.

The lack of warning by the ice detector is more difficult to explain as the system appeared to be working correctly. However, a study of the effectiveness of ice warnings, in different conditions of temperature and water content, showed that in the conditions encountered on the night of the accident it is possible that the detector would not provide a warning. (See Appendix IV).

From the previous paragraphs it can be deduced that ice built up on EI–BEM, just as it did on all the other aircraft on the approach to East Midlands, but that the continuing effect of the build up on EI–BEM differed in that the de-icing boots were not used for the reasons previously explained. However, assuming that the boots would have discarded any existing ice, then exercising them would have improved the situation compared with leaving that ice to be compounded by further accretion.

2.5.2 Loss of control

The approach was completely normal down to 1000 feet, which was also the height of the 0° isotherm and the cloud base. The initial disturbance that began the divergent rolling oscillations may well have been turbulence but, as previously discussed, turbulence could not have sustained the regular nature of the rolling motion. The tests undertaken after the accident indicated that a normal SD3-60 has good roll stability, with low rolling inertia and pilot inputs alone could not reproduce the manoeuvres seen in the accident. Furthermore, certification flight trials had shown that the SD3-60 retained good low speed handling characteristics despite the build up of 2¾ inches of rime ice. Therefore some factor changed a normally docile aircraft into one where control was almost lost.

Analysis of the divergent rolling motion showed that the pilot, in view of the response the aircraft was making, was operating the controls in a reasonable manner to counteract the oscillations. There were parts of the oscillatory roll cycles where the control inputs were actually driving the condition but, overall, the pilot's actions would have normally damped the rolling oscillations.

However, in spite of this, the aircraft continued in an uncontrolled manoeuvre. The only difference between EI–BEM just before the departure from controlled flight, and any other SD3–60 including that used in the test flight, was the presence of ice on the airframe. The severity of the build-up and its precise nature will never be known but, from the meteorological evidence and from other aircraft reports, it is probable that there was a significant build-up of clear ice and, because the de-icing boots were never operated, it remained attached. Moreover, the start of the rolling motion coincided with the 0° isotherm, so the possibility exists that ice was being shed, perhaps in an asymmetric fashion. The nature of clear ice is such that part of the liquid content flows back to freeze further back on the aerodynamic surface than is the case with rime ice so the shape of the various aerodynamic surfaces on EI–BEM may have been modified, perhaps in the manner suggested by the NASA research outlined in para 1.16.3. Nevertheless, whatever form it took it resulted in entirely different handling characteristics to those demonstrated during the icing certification trials and the subsequent test flight.

Furthermore, during those trials the rime ice was accrued in the cruise configuration, following which low speed handling was assessed clear of cloud. The clear ice on EI–BEM was accrued during the descent and in the approach configuration which would, doubtless, have contributed to the build-up of a different profile giving different handling characteristics.

2.6 The rate of descent

During the trial flight, whilst simulating the roll oscillations, it was not possible to achieve a descent rate as great as that of the accident flight. The precise mechanism by which the aircraft achieved the very high rate of descent seen on the DFDR is therefore not precisely understood. However, ice contamination and its consequent weight increase were factors that could not be simulated and, thus, were conditions which differed from those experienced by EI–BEM. There are therefore three factors which might have influenced the rate of descent: Downdraught, weight of ice and the loss of lift/increase in drag caused by ice contamination of the aerodynamic surfaces.

Although it is not possible to quantify the relative influence of each of these factors, it is quite likely that a combination of them was responsible for the descent rate being increased significantly above that intended.

The rate of descent during the accident sequence was finally arrested just before ground contact as the aircraft pitched nose-up, but there is insufficient evidence to state whether the sudden recovery of elevator authority was due to the slipstream produced by the increased engine power, the increased speed when that power was applied, or perhaps upon the ice shedding because of increasing air temperature or turbulence and manoeuvre induced wing flexing.

2.7 Summary

Although largely circumstantial, the weight of evidence provided by the meteorological situation, the other flights, the degradation of aircraft performance and the fact that this occurred when the aircraft entered clouds highly conducive to clear ice accretion, can leave no doubt that ice was accruing on the aerofoil surfaces of the aircraft as it descended through the cloud. This is substantiated by the factual evidence that ice was heard impacting the side of the fuselage, as it was thrown from the propellers. Nevertheless, the quantity and the profile of its formation cannot be exactly determined except to say that it was sufficient to degrade progressively the aircraft's performance.

It is concluded that the departure from controlled flight was linked with the build up of ice and it is likely that the accretion of ice upon the airframe had modified the aerodynamics of the aircraft such that its normally good roll stability had been severely degraded so that the aircraft was not responding to the application of roll controls in the normal manner. Nevertheless, the precise shape or position of the ice which modified the aerodynamics is not known, as, by the very nature of icing, the evidence had disappeared before examination was possible.

There can be no doubt that ice was the major factor responsible for the initial departure from controlled flight. However, the oscillations, once established, were doubtless sustained to some degree by the magnitude and timing of the control inputs during the period of very high roll rates.

The logical conclusion, therefore, is that the essential factor, without which the accident sequence would not have occurred, was the presence of clear ice on the aerofoil surfaces.

2.8 Emergency services

The apparent lack of response by the emergency services was the product of two factors:

(a) The first emergency vehicle crew is specifically charged with staying apart from the rescue scene in order to co-ordinate the efforts of the other units.

(b) The coincidence of the County boundary, between Leicestershire and Derbyshire, with the accident site. The airport is within the area of responsibility of the Leicestershire County Authorities. However, the accident occurred some 190 metres into the Derbyshire territory and thus was the concern of the Derbyshire Authorities. Although both emergency services responded with their customary promptness, it was administratively necessary to designate a controlling Authority, a matter which took a little time to co-ordinate.

3. Conclusions

(a) *Findings*

(i) The commander and co-pilot were properly licensed, medically fit and qualified to carry out the flight.

(ii) The commander operated the ice protection systems in accordance with the approved operating instructions.

(iii) The aircraft was correctly loaded and was maintained in accordance with the approved maintenance schedule.

(iv) The aircraft was fully serviceable prior to the accident.

(v) The aircraft's performance degraded steadily during the descent through cloud and was most probably caused by the indicated accretion of clear ice on the airframe. Ice on the propeller may have contributed to a small extent.

(vi) At around 1000 feet agl almost all control was lost.

(vii) The major factor responsible for the initial departure from controlled flight was the continued presence of ice on the aerodynamic surfaces but turbulence may have precipitated it.

(viii) The precise profile of the ice formation on the airframe could not be determined, nor therefore could the manner in which the airflow was modified.

(ix) Full scale and at times out of phase aileron and rudder deflections may have been factors in prolonging the roll oscillations, but the continued presence of ice may have been an influence.

(x) The commander's use of control inputs was understandable at the time of the occurrence.

(xi) It is likely that an earlier application of full engine power would have caused an earlier recovery but the commander's delay in its application was also understandable in the circumstances.

(xii) Downdraught may have contributed to the rate of descent.

(b) *Cause*

The accident most probably occurred as a result of the effects of a significant accumulation of airframe ice degrading the aircraft's stability and control characteristics, such that the crew were unable to maintain control. Turbulence and or downdraught may have contributed to the accident. Other contributory factors were the difficulty in detecting clear ice at night on the SD3-60 which resulted in the airframe de-icing system not being used. The delay in application of go-around power may have also contributed to the accident.

4. Safety Recommendations

It is recommended that:

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.

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 recently flown in conditions conducive to the accretion of ice.

4.3 Consideration be given to the effectiveness of the ice detection spotlight on the SD3-60 and to whether they should be fitted to both sides of the aircraft.

R C McKinlay
Inspector of Accidents

Accidents Investigation Branch
Department of Transport

September 1987

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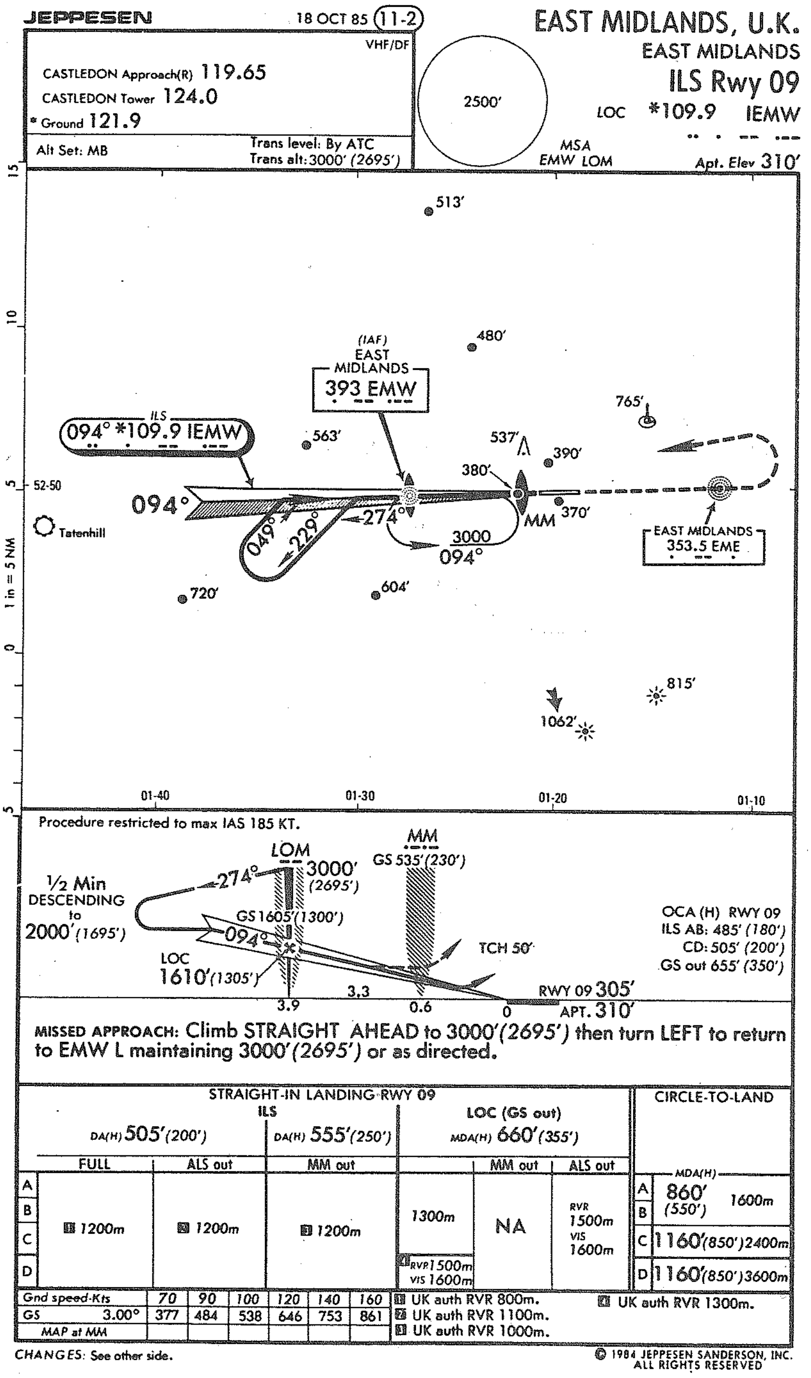


JEPPESEN 18 OCT 85 (11-2)

EAST MIDLANDS, U.K.
EAST MIDLANDS
ILS Rwy 09
LOC *109.9 IEMW

VHF/DF
CASTLEDON Approach(R) 119.65
CASTLEDON Tower 124.0
* Ground 121.9

Alt Set: MB
Trans level: By ATC
Trans alt: 3000' (2695')

MSA EMW LOM
Apt. Elev 310'

Procedure restricted to max IAS 185 KT.

OCA (H) RWY 09
ILS AB: 485' (180')
CD: 505' (200')
GS out 655' (350')

MISSED APPROACH: Climb STRAIGHT AHEAD to 3000' (2695') then turn LEFT to return to EMW L maintaining 3000' (2695') or as directed.

STRAIGHT-IN LANDING RWY 09

	ILS DA(H) 505' (200')		ILS DA(H) 555' (250')	LOC (GS out) MDA(H) 660' (355')		
	FULL	ALS out	MM out		MM out	ALS out
A	[1] 1200m	[2] 1200m	[3] 1200m	1300m	NA	RVR 1500m VIS 1600m
B						
C						
D				[4] RVR 1500m VIS 1600m		

CIRCLE-TO-LAND

	MDA(H)	
A	860' (550')	1600m
B		
C	1160' (850')	2400m
D	1160' (850')	3600m

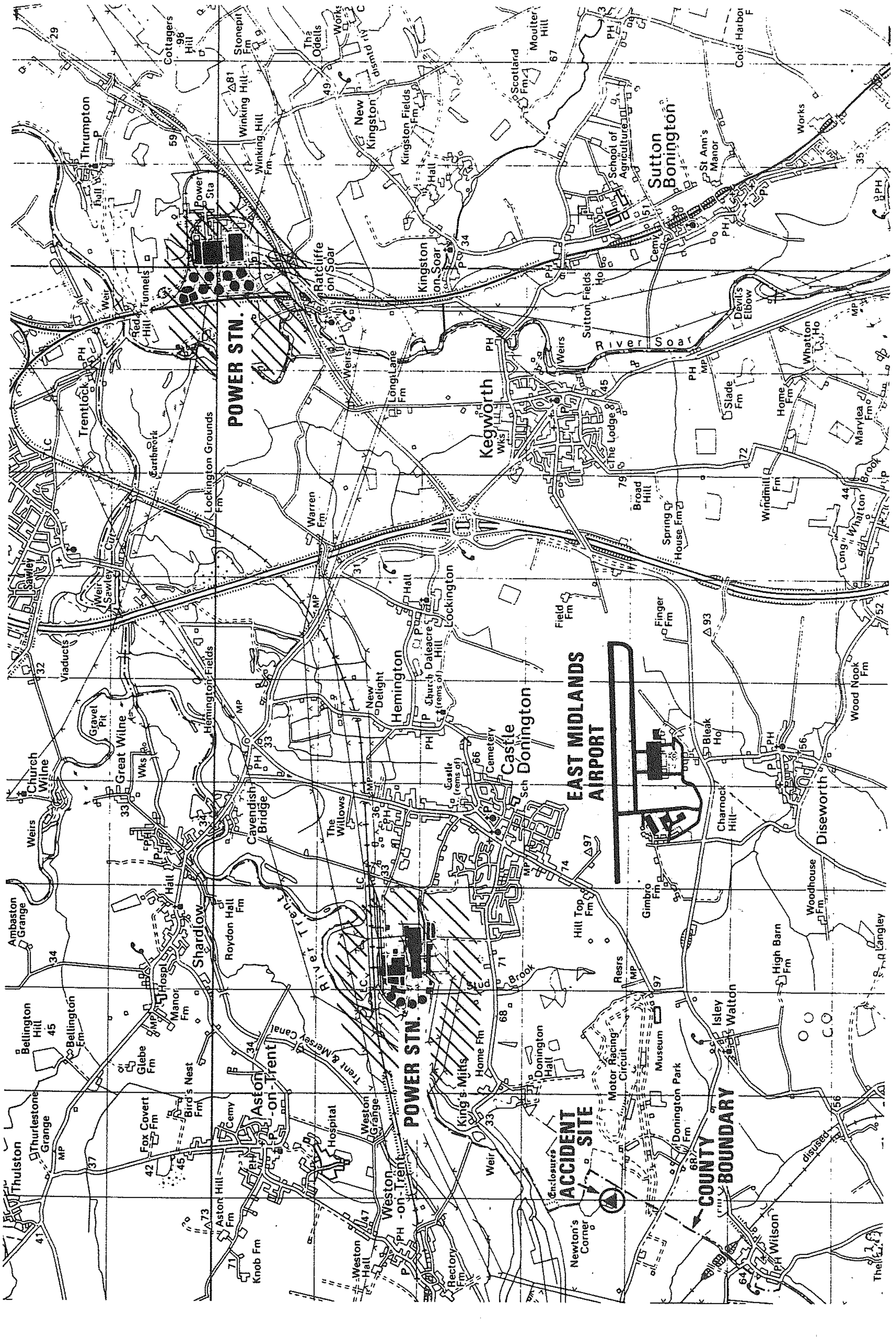
Gnd speed-Kts	70	90	100	120	140	160
GS 3.00°	377	484	538	646	753	861
MAP at MM						

[1] UK auth RVR 800m.
[2] UK auth RVR 1100m.
[3] UK auth RVR 1000m.
[4] UK auth RVR 1300m.

CHANGES: See other side.

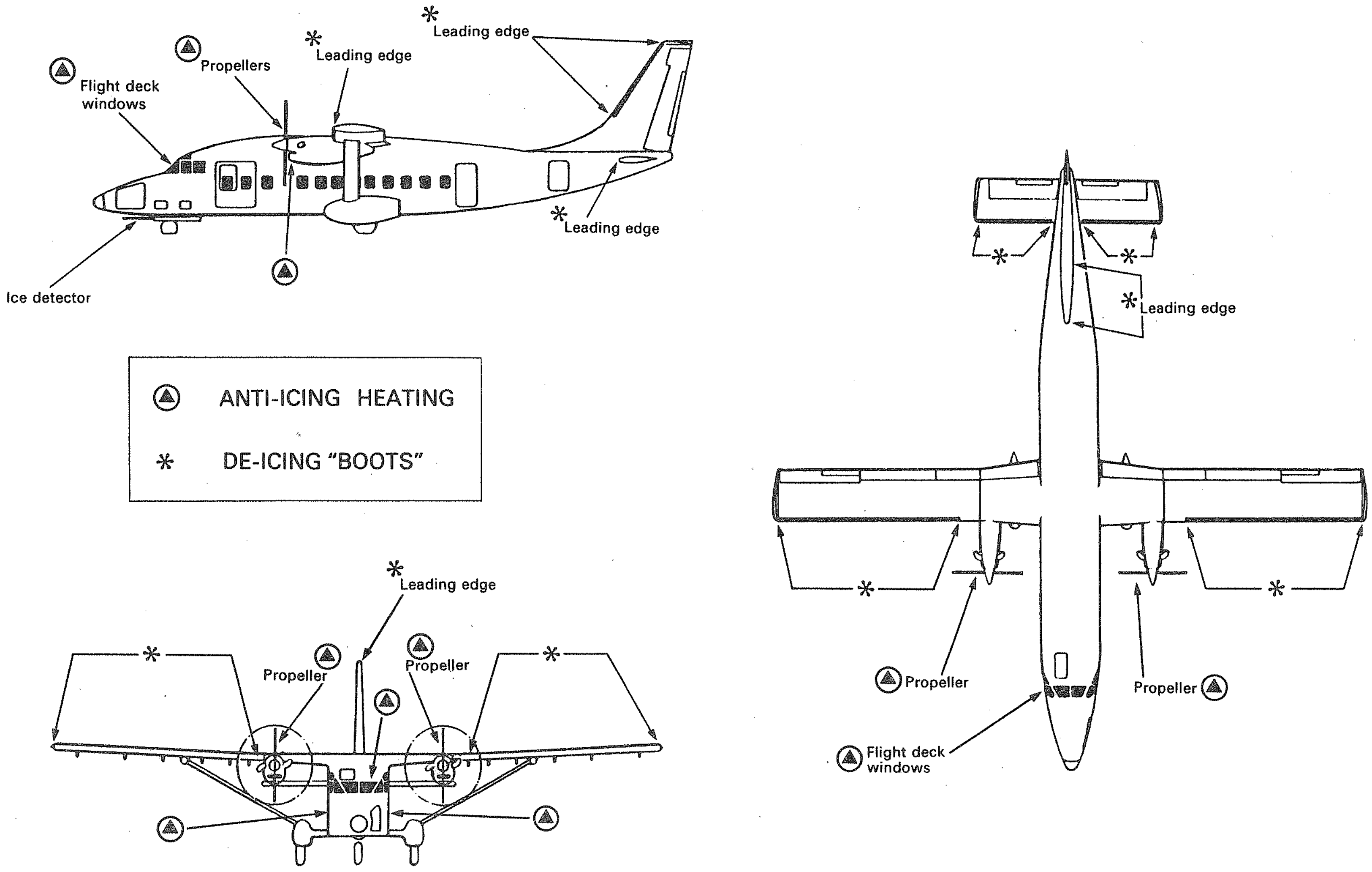
APPROACH CHART TO RUNWAY 09, USED BY THE CREW OF EI-BEM

Appendix II



THE ACCIDENT SITE AREA

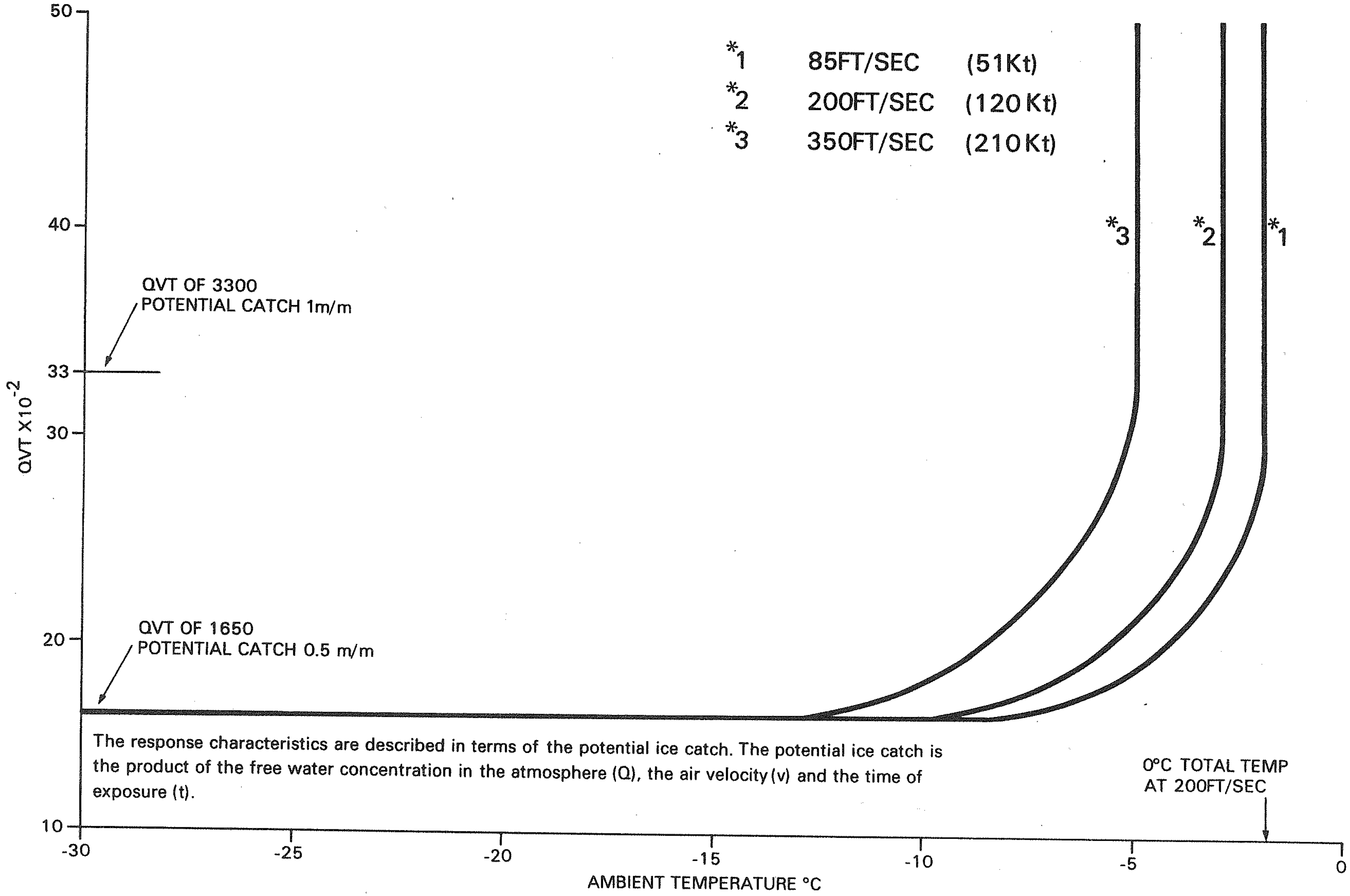
Appendix III



▲ ANTI-ICING HEATING

* DE-ICING "BOOTS"

ICE PROTECTION EQUIPMENT (Protected Surfaces)

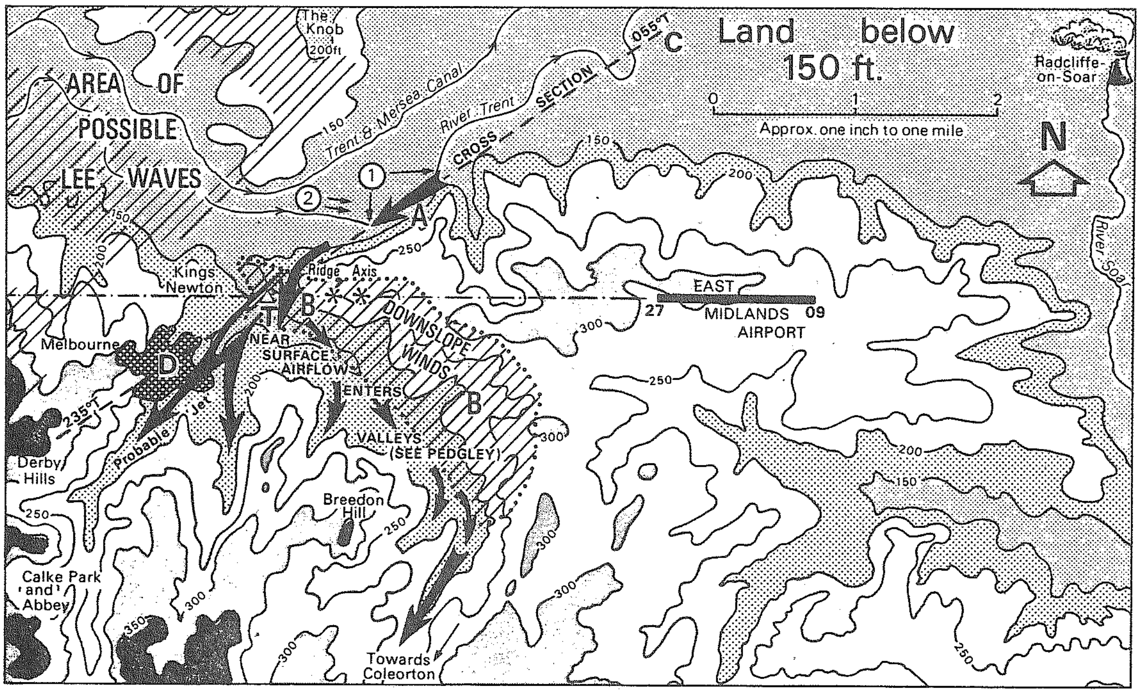


The response characteristics are described in terms of the potential ice catch. The potential ice catch is the product of the free water concentration in the atmosphere (Q), the air velocity (v) and the time of exposure (t).

ROTATING CYLINDER ICE DETECTOR – GENERAL PERFORMANCE CHARACTERISTICS

Appendix V

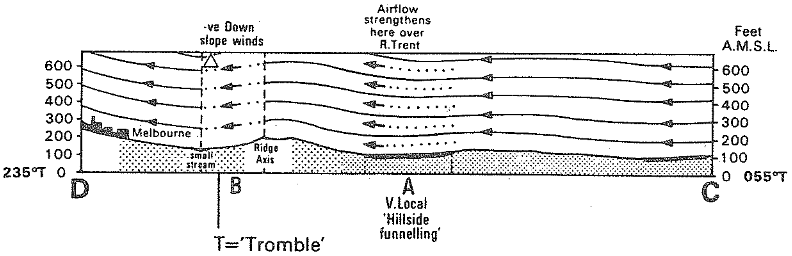
LOCAL TOPOGRAPHY: EFFECT OF STRONG WINDS ENTERING A VALLEY



① R.Trent 'Enlarging' it's valley here

② Strengthening wind 'Funnels' along steeper valley side

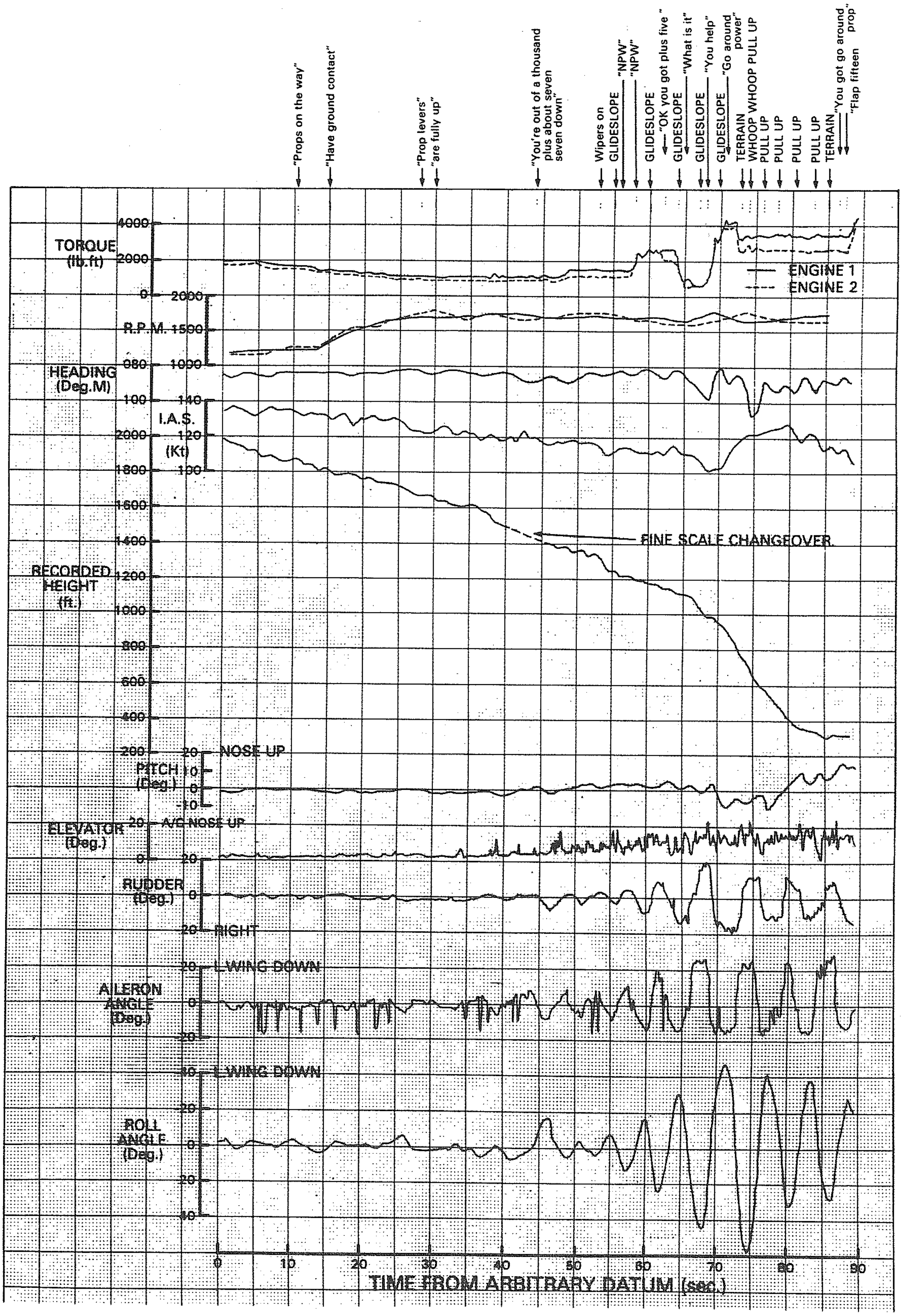
Pioneering work on winds entering a side valley has been done using a group of observers with hand-held anemometers around Llyn Idwal in Snowdonia. Although the 'model' is for August in much more mountainous terrain, certain similarities apply to the nameless valley between Melbourne and Donington Park lying at right angles to prevailing winds. Airflow near the surface tends to follow height contours and enter valleys.



CROSS SECTION

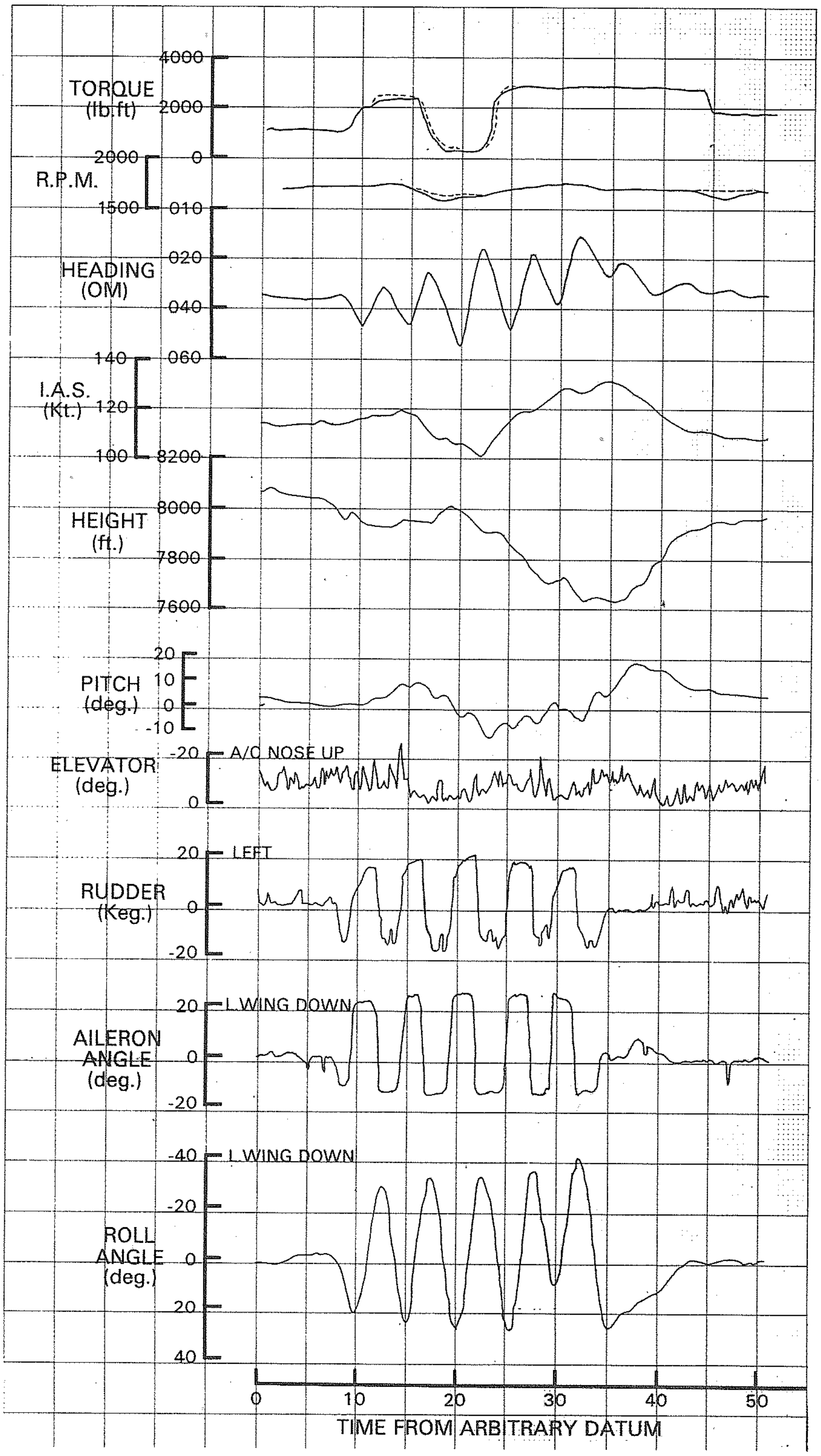
Appendix VI

EI-BEM ACCIDENT ON APPROACH TO EAST MIDLANDS ON 31st JAN 1986

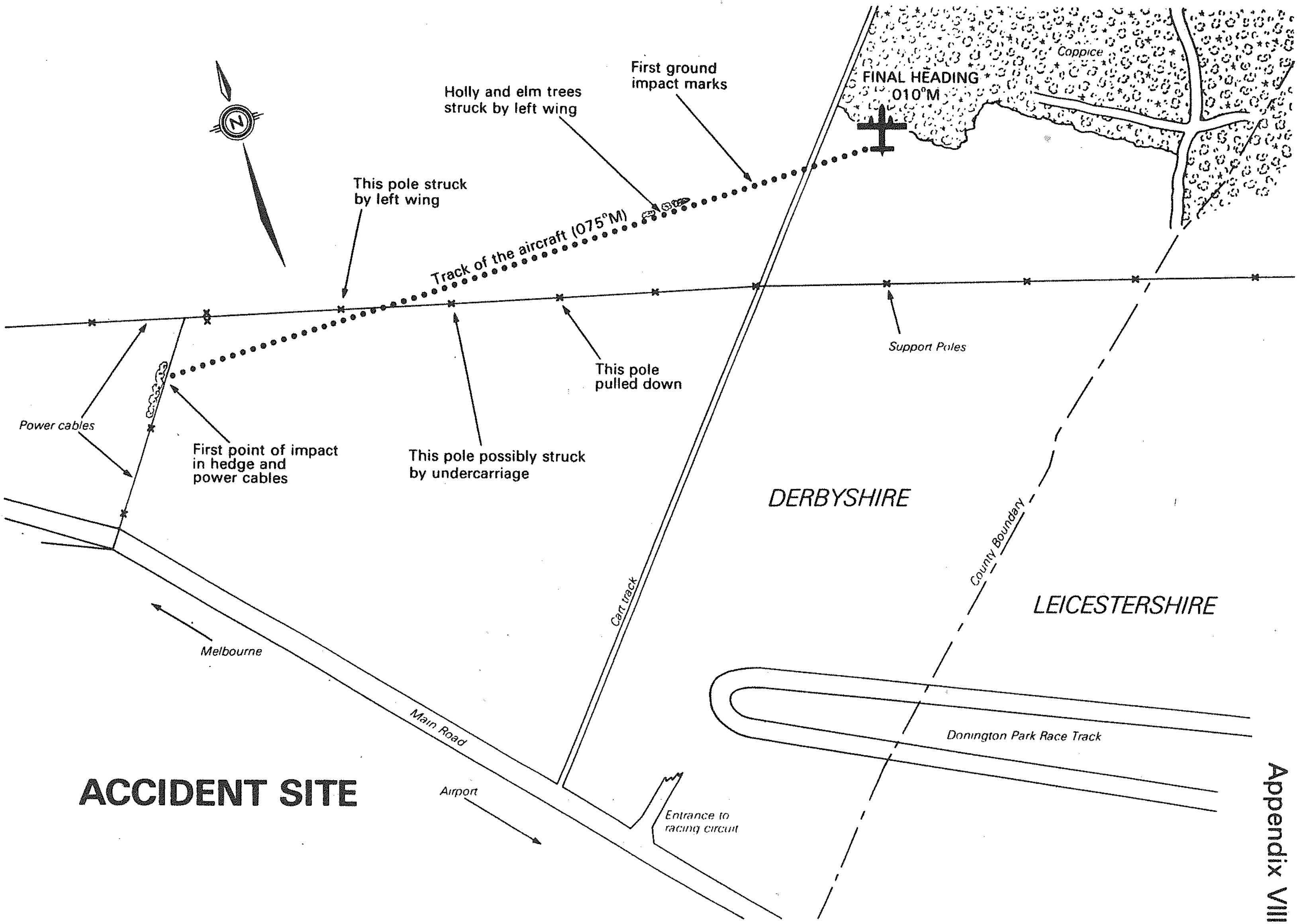


Appendix VII

EI-BPD-TEST FLIGHT DATA



Appendix VIII



ACCIDENT SITE

FIGURE 1.
THE TEST FLIGHT.

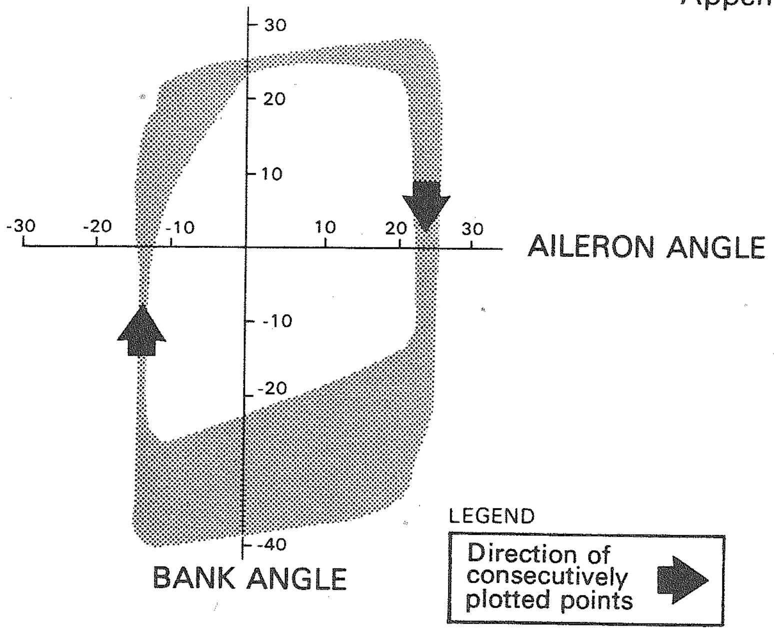
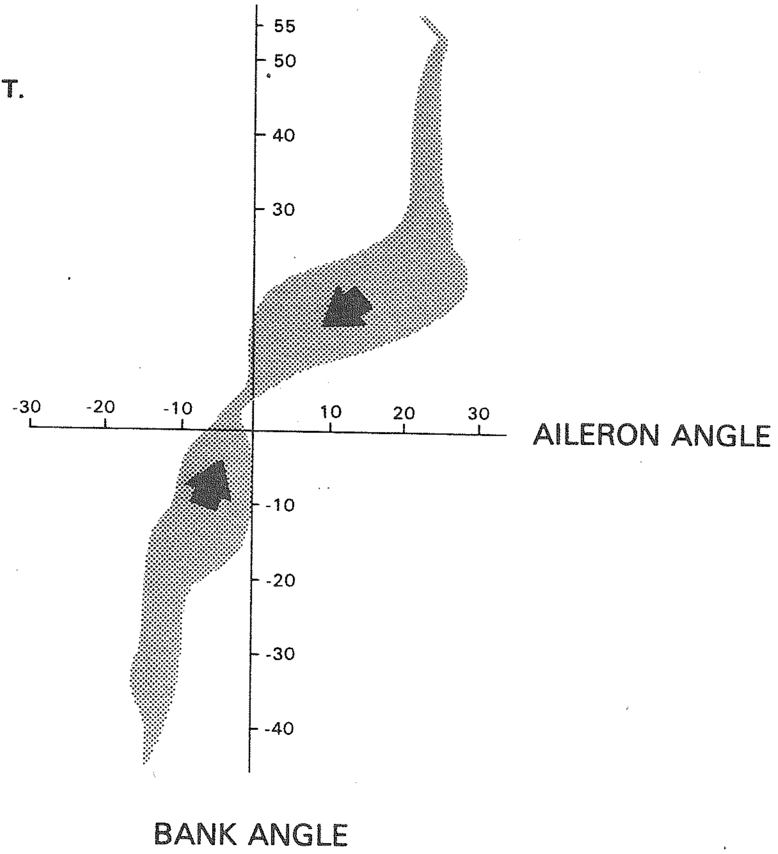


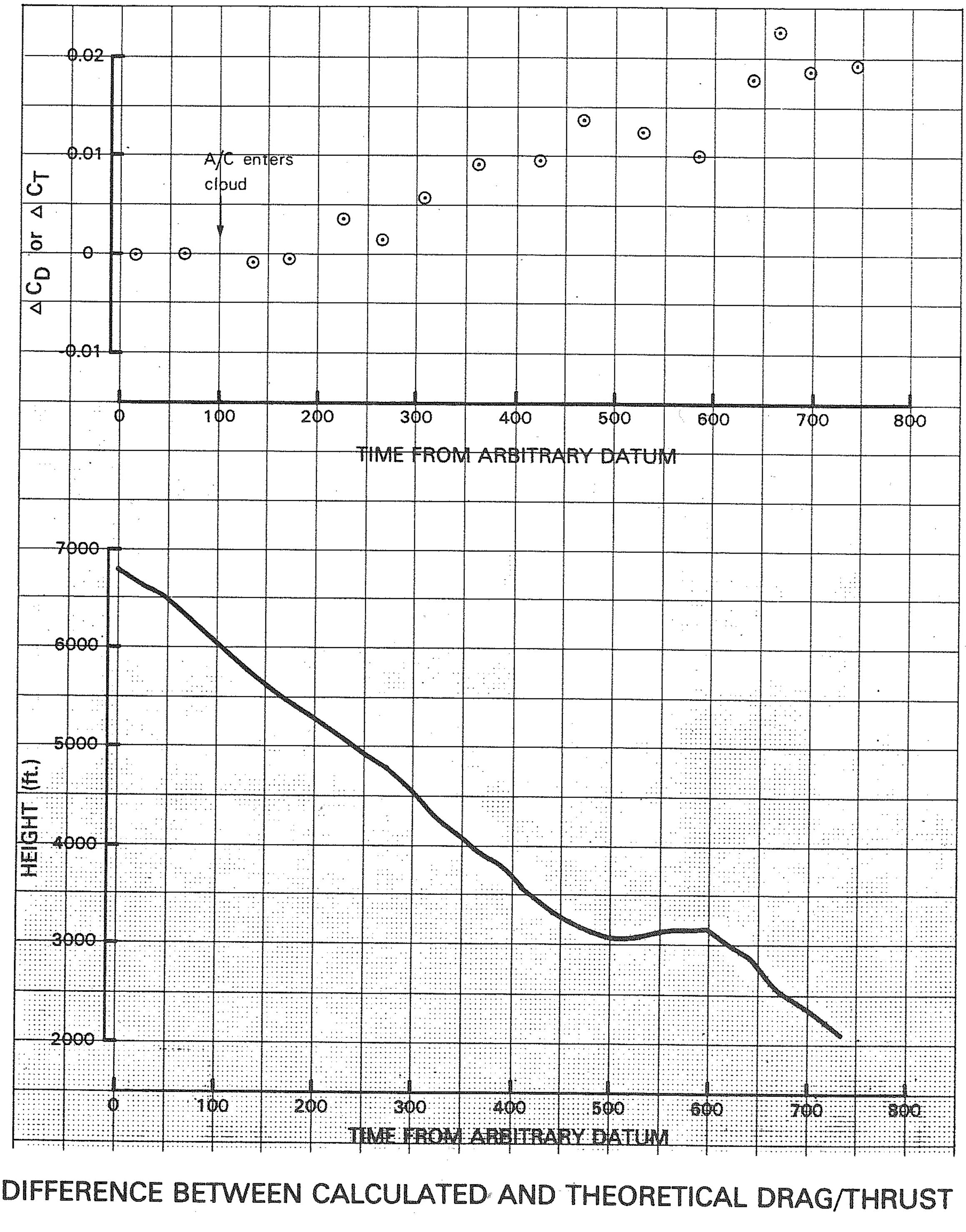
FIGURE 2.
THE ACCIDENT FLIGHT.



The right side of the two graphs represents aileron displacement which should provide left wing down aircraft motion, and the lower half of each displays the left wing down bank achieved.

CONTROL DISPLACEMENT/RESPONSE GRAPHS

AER-LINGUS SD3-60 EI-BEM



DIFFERENCE BETWEEN CALCULATED AND THEORETICAL DRAG/THRUST