

AIRCRAFT ACCIDENT REPORT 3/95

Air Accidents Investigation Branch

Department of Transport

**Report on the accident to
Vickers Viscount 813, G-OHOT
near Uttoxeter, Staffordshire
on 25 February 1994**

**This investigation was carried out in accordance with
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**Department of Transport
Air Accidents Investigation Branch
Defence Research Agency
Farnborough
Hampshire GU14 6TD**

23 February 1995

*The Right Honourable Dr Brian Mawhinney
Secretary of State for Transport*

Sir,

I have the honour to submit the report by Mr R StJ Whidborne, an Inspector of Air Accidents, on the circumstances of the accident to Vickers Viscount 813, G-OHOT, near Uttoxeter, Staffordshire on 25 February 1994.

I have the honour to be
Sir
Your obedient servant

**K P R Smart
Chief Inspector of Air Accidents**

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch	IAS	Indicated Airspeed
AAR	Aircraft Accident Report	ICAO	International Civil Aviation Organisation
AC	Alternating Current	IDA	In-depth Audit
AIC	Aeronautical Information Circular	IOAT	Indicated Outside Air Temperature
AIP	Aeronautical Information Publication	IRE	Instrument Rating Examiner
AIS	Aeronautical Information Service	JAA	Joint Aviation Authorities
ANO	Air Navigation Order	JARs	Joint Airworthiness Requirements
AOC	Air Operator's Certificate	KIAS	Knots Indicated Airspeed
ASI	Airspeed Indicator	LATCC	London Air Traffic Control Centre
ATC (O)	Air Traffic Control (Officer)	LOFT	Line Oriented Flying Training
ATPL	Airline Transport Pilot's Licence	MATS	Manual of Air Traffic Services
ATSU	Air Traffic Service Unit	mb	millibars
ATIS	Automatic terminal Information Service	MCT	Manchester VOR
BAF	British Air Ferries	MHz	Mega Hertz
BCARs	British Civil Airworthiness Requirements	MOR	Mandatory Occurrence Report
BWL	British World Airlines	NDB	Non-Directional Beacon
°C, M	°Celsius, magnetic	NOTAM	Notice to Airmen
CAA	Civil Aviation Authority	OSAP	Operating Standards Appraisal Programme
CAP	Civil Aviation Publication	PES	Power Emergency Switch
CCF	Co-ordinated Control Function	PMS	Power Master Switch
CRM	Crew Resource Management	PUD	Power Unit De-icing
CVR	Cockpit Voice Recorder	OM	Operations Manual
D&D	Distress and Diversion	QNH	Corrected mean sea level pressure
DC	Direct Current	QRF	Quick Release Fastening
DRA	Defence Research Agency	RCC	Rescue Co-ordination Centre
EPAC	Emergency Power Auto Control	RPM	Revolutions per minute
ERPM	Engine revolutions per minute	RT	Radio Telephony
FDR	Flight Data Recorder	SMP	Standard Maintenance Practices
FOI	Flight Operations Inspector	TGT	Turbine gas temperature
GEB	Generator Emergency Busbar	TRE	Type Rating Examiner
GEPS	Generator Emergency Power Switch	UTC	Co-ordinated Universal Time
HF	Human Factors	VHF	Very High Frequency
HT	High tension	VMC	Visual Meteorological Conditions
		VSU	Voltage Sensing Unit

Air Accidents Investigation Branch

Aircraft Accident Report No: 3/95

(EW/C94/2/5)

Registered Owner and Operator: British World Airlines Limited
(Formerly British Air Ferries Limited)

Aircraft Type and Model: Vickers Viscount 813

Registration: G-OHOT

Nationality: United Kingdom

Place of accident: 4 nm south west of Uttoxeter, Staffordshire
Latitude: 52° 51' 12" North
Longitude: 001° 57' 11" West

Date and Time: 25 February 1994 at about 1946 hrs

All times in this report are UTC

Synopsis

The accident was notified to the AAIB shortly after it had occurred and an investigation team travelled immediately to the site. The AAIB team comprised: Mr R StJ Whidborne (Investigator in charge), Mr R G Matthew (Operations), Mr C I Coghill (Engineering), Mr T G Wild (Flight Recorders). Technical assistance was provided by the companies listed in Appendix A. The aircraft, which was engaged on a freight (packages) flight to Coventry, took off from Edinburgh at 1843 hrs in weather conditions of rain and snow. After takeoff, the aircraft climbed in cloud to FL 190, descending again so as to be at FL 180 when crossing the Manchester VOR. During the further descent, at 1932 hrs, still in cloud and approaching FL 150, the No 2 engine failed and the propeller autofeathered. Less than a minute later the No 3 engine started to run down and the crew requested an immediate descent and navigational assistance from ATC radar. At that time the aircraft was 16 nm from Manchester Airport and was descending through FL 140. At 1937 hrs, when unsuccessful attempts had been made to re-start Nos 2 and 3 engines, the crew declared an emergency with Birmingham Airport requested as the diversion. At this time the aircraft was descending through 9,400 feet, some 28 nm from Birmingham and 17 nm from East Midlands. No 2 engine was re-started successfully but, during this process, No 4 engine failed. Despite further attempts to re-start Nos 3 and 4 engines, the remainder of the flight was conducted on the two left-hand engines

alone. Throughout this report the term 'engine failure' means an engine that has flamed out as a consequence of ice ingestion.

The aircraft was subsequently unable to maintain height and latterly the commander was unable to control the aircraft in yaw. The aircraft struck the ground and an intense fire consumed the cabin section between the rear of the flight deck and the front of the empennage. The commander did not survive the impact, but the seriously injured first officer was assisted from the flight deck wreckage by two bystanders and taken to hospital. There were no other crew members or passengers.

The following causal factors were identified:

- (i) Multiple engine failures occurred as a result of flight in extreme icing conditions.
- (ii) Incomplete performance of the emergency drills by the crew, as a result of not referring to the Emergency Checklist, prejudiced the chances of successful engine re-starts.
- (iii) Crew actions for securing and re-starting the failed engines, which were not in accordance with the operator's procedures, limited the power available. The drag from two unfeathered propellers of the failed engines and the weight of the heavily iced airframe resulted in a loss of height and control before the chosen diversion airfield could be reached.
- (iv) Poor Crew Resource Management reduced the potential for emergency planning, decision making and workload sharing. Consequently, the crew had no contingency plan for the avoidance of the forecast severe icing conditions, and also was unaware of the relative position of a closer diversion airfield which could have been chosen by making more effective use of air traffic services.

Two safety recommendations have been made.

1 Factual Information

1.1 History of the flight

1.1.1 General

The 'Parcel Force' flight, callsign 'British World (BWL) 4272', was normally scheduled for a 1930 hrs departure from Edinburgh to Coventry but, on the day of the accident, it was despatched 50 minutes early in anticipation of worsening weather en route. It was sleeting at the time and both pilots inspected the aircraft surfaces for residual ice or slush but found none and there was no need to de-ice the aircraft.

The general en route weather was forecast as rain and drizzle with 4 to 7 oktas of cloud between 600 and 1,500 feet and 6 to 8 oktas in layers between 1,500 feet and 16,000 feet. In hilly areas and in the area of the two warm fronts, lying along a northwest southeast line bisecting the UK, there were 8 oktas of layered cloud between 200 feet and 18,000 feet. The forecast also warned of moderate icing in cloud and severe icing in nimbostratus cloud.

The aircraft had been refuelled to a total ramp fuel of 1,080 Imp Gal which gave a take-off weight of 26,544 kg which, with a traffic load of 4,250 kg, was 6,341 kg below the Maximum Take-off Weight. The aircraft's No 1 engine generator was unserviceable and this was the only 'Acceptable Deferred Defect' recorded as being carried.

The Flight Data Recorder (FDR) did not record any of the relevant flight and the reason for this will be explained in Paragraph 1.11. Consequently, all the evidence for the detail of events throughout the flight has been provided by a combination of the Cockpit Voice Recorder (CVR), the Air Traffic Control (ATC) recordings, the radar track plot, which is at Appendix B, and recollections by the first officer.

1.1.2 Departure and en route

The flight took off at 1843 hrs with the commander as handling pilot. Because of the inclement weather conditions, the ice protection systems for all of the engines and the airframe were selected to ON throughout the flight. The aircraft climbed in cloud to FL 190. Six or seven minutes into the climb an OVERHEAT warning indicated that the right wing de-icing duct temperature was excessive and it

required manual controlling before establishing at the normal temperature of 165°C. A little later, the commander commented to the first officer that the Power Unit De-icing (PUD) system on No 2 engine was only drawing about 16 amperes (A) as opposed to the normal 20A. At 1913 hrs, the crew commented that the de-icing system was working well and, at 1920 hrs, the first officer observed that there was a little surface ice on No 4 engine, but that it was shedding. He also remarked that there was some ice on the spinner but none on the wings.

At 1926 hrs, London Air Traffic Control Centre (LATCC), Pole Hill sector, re-cleared the aircraft on a direct track to the Manchester VOR (MCT) to be at FL 180 when crossing MCT. At 1928 hrs BWL 4272 passed MCT and was given further descent, by Manchester radar, to FL 150 with a routing via Lichfield NDB to the destination airfield, Coventry.

1.1.3 Engine failures

At 1932 hrs, as the aircraft approached FL 150, the No 2 engine failed and the propeller blades automatically feathered. Less than a minute later, when the crew had just completed the shutdown drills on No 2 engine and the first officer had stated that he was selecting Nos 1 and 3 engine igniters ON, the No 3 engine started to run down. At 1933 hrs the first officer stated that he was going to switch Nos 1, 2 and 4 igniters ON. At that time the commander instructed the first officer to "GET AN IMMEDIATE DESCENT" and to "DECLARE AN EMERGENCY". The first officer transmitted "MANCHESTER MANCHESTER THIS IS BRITISH WORLD FOUR TWO SEVEN TWO WE'VE JUST HAD A DOUBLE ENGINE FAILURE DUE ICE REQUEST IMMEDIATE DESCENT PLEASE AND RADAR VECTORS". He did not declare an emergency or use the pro-words 'MAYDAY' or 'PAN PAN'. At the time the aircraft was 16 nm south of Manchester Airport, descending through FL 140. Manchester immediately cleared the aircraft to descend to FL 70 then to FL 50 on a continued heading of 150° and, at 1934 hrs, passed control of the aircraft to Birmingham radar. At this point the failure of Nos 2 and 3 engines had deprived the aircraft of its only source of wing and tail de-icing. The respective airframe de-icing switches are required to be selected to OFF. This checklist item was apparently not performed.

At 1938 hrs, as the aircraft descended through FL 84, No 4 engine failed. Almost simultaneously, a successful attempt was made to re-start No 2, but it is believed that in the short period between No 4 engine failing and No 2 engine

starting there was a momentary loss of all generated electrical power. The automatic electrical switching which would result from these losses are described later in the report. During the subsequent descent, attempts were made to re-start No 3 and No 4 engines, but these were unsuccessful. A diagram of the sequence of engine failures is at Appendix C.

1.1.4 Diversions

At 1936 hrs, the flight was further cleared to 2,500 feet and at 1937 hrs the first officer transmitted "BIRMINGHAM THIS IS BRITISH WORLD FOUR TWO SEVEN TWO I AM DECLARING AN EMERGENCY REQUEST A DIVERSION TO BIRMINGHAM PLEASE". Both pilots were familiar with Birmingham and its approaches.

Seconds later, the first officer informed Birmingham that both No 2 and No 3 engines had failed. The pro-words 'MAYDAY' or 'PAN PAN' were again omitted. At this time the aircraft was descending through FL 94, at a range of 28 nm from Birmingham and 17 nm from East Midlands. The aircraft was then instructed to turn right onto a heading of 190° for Birmingham.

Birmingham ATC then asked "IS EAST MIDLANDS ANY GOOD TO YOU", but although this was acknowledged and the East Midlands weather was passed as : "THE WIND IS 140° AT ONE TWO KNOTS THREE THOUSAND FIVE HUNDRED METRES RAIN CLOUD IS BROKEN AT 600 FEET THE TEMPERATURE PLUS TWO 1009". The crew acknowledged this but did not state an intention to change the diversion to East Midlands.

Following the engine re-start, RT communications were increasingly distorted by a warbling sound which also affected the intercom and forced the pilots to shout in order to communicate with each other. After No 2 engine had re-started, the pulse rate of the igniters, audible on the CVR, reduced and then became intermittent.

1.1.5 Final emergency phase

While No 4 engine was running down and No 2 was starting up, the pilot had flown an inadvertent 170° turn to the right until the aircraft was heading north. The Birmingham controller queried this and suggested a heading of 095° for East Midlands, which was correctly read back by the crew. A short time later the aircraft made a series of turns and again the Birmingham controller suggested a heading for East Midlands (see Appendix B). This information was not

acknowledged by the crew who shortly after selected the transponder Emergency Code '7700', stating "WE'RE ON EMERGENCY NOW". Between 1940 hrs and 1943 hrs, the aircraft turned left towards 295°, but carried on through that heading towards south, during which time the first officer tried unsuccessfully to start No 3 engine and the commander stated that he was losing control in yaw and needed his torch to read the instruments. At 1942:20 hrs, the aircraft descended through its cleared altitude of 2,500 feet and appears to have been unable to maintain altitude, despite the nose being raised a second or two later. This adjustment in pitch, whilst momentarily arresting the descent, resulted in approximately 45 kt loss of airspeed before descent had to be resumed in order to maintain flying speed. At 1944 hrs, the first officer again tried to re-start No 3 engine and the commander said "WE'RE GOING TO STALL...". No 3 engine did not re-start but the propeller remained unfeathered and it was apparent that an attempt to re-start it was still being made at impact.

Between 1945:17 hrs and 1945:28 hrs, the first officer transmitted two 'MAYDAY' messages on 121.5 MHz but, probably as a result of the aircraft's failing electrical supplies, neither was heard or recorded by ATC. At about 1946 hrs the aircraft struck a down-sloping forest of mature trees which caused considerable disintegration of the aircraft structure. It came to rest in a field on the edge of the forest. An intense fire consumed the cabin section between the rear of the flight deck and the front of the empennage.

The aircraft commander received fatal injuries in the impact but the seriously injured first officer was freed from the aircraft by two witnesses who had hurried to the scene. There they moved him to a safe area away from the fire to await the arrival of the emergency services.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	1	-	-
Serious	1	-	-
Minor/None	-	-	-

1.3 Damage to aircraft

The aircraft was destroyed by impact with trees and the ground, and by post-crash fire.

1.4 Other damage

The aircraft crashed into Drointon Wood at the northern edge of Chartley Moss which is designated as an Area of Special Scientific Interest. Twenty eight trees were damaged including nine destroyed and nine which suffered major damage. The whole of the crash site was contaminated with fuel and small amounts of other aircraft fluids. Because of the ground slope direction this drained away from the Moss, and the National Rivers Authority took measures to collect it and to stop it draining beyond the local ditches and streams.

1.5 Personnel information

1.5.1	Commander:	Male, aged 32 years
	Licence:	Airline Transport Pilot's Licence Valid to 6 February 1999
	Aircraft Ratings:	Viscount Series 700 and 800 Conversion to Viscount 810, 15 May 1993 Line Check Captain, P1 and P2
	Instrument Rating:	Valid to 13 June 1994
	Base Check:	Valid to 13 June 1994
	Line Check:	Valid to 15 June 1994
	Medical Certificate:	Class One (Spectacles to correct for distant vision) Valid to 1 May 1994
	Flying experience:	Total flying: 5,121 hours On type: 1,121 hours Last 90 days: 66 hours Last 28 days: 28 hours Last 24 hours: 5 hours Previous rest period: 27.5 hours

Having received his initial flying training as a cadet pilot in the Royal Australian Air Force, the commander was awarded an Australian Senior Commercial Pilot's Licence in July 1981. In February 1989, he immigrated to the UK and joined Baltic Airlines, which merged with British Air Ferries (BAF), as a 'direct command entry' on Viscount aircraft.

1.5.2	First officer:	Male, aged 39 years
	Licence:	Airline Transport Pilot's Licence Valid to 15 October 2000

Aircraft Ratings:	Viscount 800 Series, Shorts SD3-30, PA-44	
Instrument Rating:	Valid to 10 June 1994	
Base Check:	Valid to 10 June 1994	
Line Check:	Valid to 12 June 1994	
Medical Certificate:	Class One (No waivers or restrictions) Valid to 1 June 1994	
Flying experience:	Total flying:	3,334 hours
	On type:	2,181 hours
	Last 90 days:	61 hours
	Last 28 days:	24 hours
	Last 24 hours:	5 hours
	Previous rest period:	27.5 hours

The first officer gained his Commercial Pilot's Licence in 1986 and in 1987 joined BAF as a first officer on Shorts SD3-30. He transferred to the Viscount 800 series later that year. He left the company to attend a US based Boeing 737 course in February 1989, returning to BAF as a first officer in August 1989 and gaining an ATPL in October 1990.

1.5.3 Crew Resource Management (CRM)

In line with many UK AOC holders, the operator was in the process of introducing CRM training to all of its pilots. The company Type Rating Examiners (TREs) and Instrument Rating Examiners (IREs) had completed their initial courses and the remaining professional licence holders in the company were planned to have completed theirs by 1 January 1995, although some had already done so. The operating crew in this accident were due to attend their courses the following month.

A description of CRM, including its Applicability and Time Schedules was published by the CAA in UK Aeronautical Information Circular (AIC) 143/1993 (Pink 90) on 23 September 1993. The AIC describes the requirement for CRM training as 'a natural development from the Human Factors (HF) Flight Crew Licence examinations introduced by the Authority's Flight Crew Licensing Department and will bring the UK into line with the European and North American approach to the training of flight crew.'

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer:	Vickers-Armstrongs (Aircraft) Limited
Aircraft type:	Vickers Viscount 813
Constructor's serial number:	349H
Date of manufacture:	1958
Engines:	4 Rolls-Royce Dart Mk 530 turboprop engines
Certificate of Airworthiness:	UK Transport Category (Passenger) Last renewed 22 December 1993 Valid until 21 December 1996
Certificate of Maintenance Review:	22 December 1993 at 50,907 hours
Certificate of Release to Service:	Issued 22 December 1993 at 50,907 hours Valid until 51,307 hours
Total airframe hours at accident:	50,995 hours

1.6.2 Aircraft history and maintenance records

Between 1989 and 1993 the aircraft had been subjected to a large number of inspections and modifications, most of which were part of a manufacturer's life extension programme. In October 1990 the engines were removed and the aircraft was laid up. In January 1992, as part of the life extension programme, detailed checks were carried out on electrical wiring, terminations, connectors and lockings, earthing bolts and aluminium busbars. Also in January 1992 the Power Unit De-icer (PUD) wiring in nacelles No 2 and No 3 was checked for overheating or chafing. In February 1992 the aircraft was returned to service; a 400 hour check was carried out, it was converted to cargo/passenger configuration and its C of A (Certificate of Airworthiness) was renewed. The aircraft was again laid up in May 1992 and when it was finally re-activated in December 1993, a 400 hour check was carried out and the C of A was renewed. The batteries which were then installed had been tested for condition in November 1993 when the capacities were individually recorded as 97%, 95%, 95% and 81%. The weather radar was changed to make the installation compatible with the rest of the operator's fleet.

The Technical Log showed that, during the period of operation in the two months before the accident, problems had been experienced with a number of systems which were relevant to the circumstances of the accident. The No 2 PUD was

declared unserviceable on three occasions and, in turn, the alternator (twice), cyclic switch (twice), intake cowl, voltage regulator and transformer-rectifier unit were each changed. The system was signed off as serviceable for the last time on 12 February 1994 and no further defects were recorded.

On two occasions the No 3 airframe de-icing jet pipe scoop would not close when selected 'OFF'. On the first occasion a plug at the 'inching' control was found to be loose. When the plug had been cleaned and secured, prolonged functional testing showed the system to be serviceable. On the second occurrence the scoop actuator was replaced and a functional test was carried out satisfactorily.

On 29 January 1994 a flight had been abandoned because of smoke on the flight deck. It was found that a wire had burned out behind a circuit breaker panel. The wire appeared to be an undocumented and unapproved modification which joined two separate busbars. The wire was removed. This was the subject of Mandatory Occurrence Reporting (MOR) action.

On the day before the accident flight the No 1 generator was reported as not taking load and producing only 4V output. This unserviceability was entered as an acceptable deferred defect¹ and was the only such defect outstanding on the aircraft at the time of the accident. It was planned that the generator would be replaced after the aircraft's arrival at Coventry.

1.6.3 Weight and balance

Maximum permitted Take-off Weight:	32,885 kg	(72,500 lb)
Regulated Take-off Weight: (Zero Fuel Weight considerations)	30,081 kg	(66,316 lb)
Actual Take-off Weight:	26,544 kg	(58,519 lb)
Accident weight (Approx):	25,000 kg	(55,115 lb)

Loading: The Centre of Gravity was within the specified limits of 413.9 to 436.0 inches aft of datum.

¹ Operations Manual Vol 2A Sect 8 Minimum Equipment List: Item 20, Generators 'one acceptable inoperative'.

1.6.4 Engines

1.6.4.1 Propeller synchronisation

No 3 is the master engine to which the others can be synchronised. The slave engines each have a corrector motor in their throttle linkage which makes fine adjustments to the throttle control to match their speeds to that of No 3 engine. The adjustment range of the synchronisation system is ± 400 engine RPM. If No 3 engine fails then the emergency procedure requires that the synchronisation system be switched to OFF so that all corrector motors return to their null, or datum position. If No 3 engine fails and the system is not switched to OFF then, as the reference RPM from No 3 reduces, the other operating engines will have their RPM reduced by an amount between zero and 800 RPM. Typically, if engine RPM had been well matched before synchronisation was switched ON, the reduction will be 400 RPM.

1.6.4.2 Engine fuel datum trimmers

Volume 3B, Section 2 of the BAF Operation Manual (OM) contains the following description in Section 2.3 - Engine Description and Power Control:

'While the throttle lever ensures a correct air/fuel ratio under normal operating conditions, variations from standard conditions of ambient air temperature and pressure can result in high or low turbine gas temperature.

A fuel datum trimmer control is therefore fitted and can be used to adjust the fuel flow irrespective of throttle lever position. This is achieved by an electric actuator which adjusts the throttle control rod linkage. By this means the throttle valve opening for a specific lever position can be increased or decreased, while the propeller control setting (and hence the RPM and mass air flow) remain constant.

Fuel datum trim is controlled by four single pole switches (one for each engine), sprung to the centre OFF position. Movement of the switch to INCREASE, increases the fuel flow at a specific RPM. Movement to DECREASE, decreases the fuel flow.

A desynn indicator is fitted in the cockpit, and shows the state of fuel trim in %; 0% indicates FULL DECREASE (minimum fuel flow) while 100% indicates FULL INCREASE (maximum fuel flow). Use of the indicator in conjunction with the switch enables the fuel datum to be inched to the required position. It must be remembered that any reduction in fuel flow results in a corresponding loss of power at constant RPM.'

At take-off power FULL DECREASE represents a reduction of 25% in engine fuel flow with a concomitant reduction in power but with no change in the RPM.

The aircraft Flight Manual Section II 'Operating Procedures', Part B, under the heading 'Descent Technique' gives the following instruction:

'When reducing power for the descent there is a possibility of exceeding the TGT limitations. To reduce this risk, set the fuel trimmer to full decrease and then reduce power slowly.'

It is believed that the crew complied with this instruction when the descent was initiated.

1.6.4.3 The Operator's Emergency Checklist

The operator's Emergency Checklist for its Viscount aircraft was printed on sheets of pink A4 paper in a loose leaf binder. They were not an accurate reflection of the lists detailed in the Flight Manual, which was prepared by the manufacturer.

Items detailed in the Emergency and Abnormal Checklist are:

AIR RELIGHT

- | | | |
|----|------------------|----------------------|
| 1. | AIRSPEED | OPTIMUM 140 - 160 KT |
| 2. | FLAPS | UP |
| 3. | THROTTLE | CLOSED |
| 4. | FUEL TRIM | MIN. 50% AVERAGE |
| 5. | LP COCK | OPEN |
| 6. | AIR RELIGHT SW. | ON |
| 7. | HP COCK | LOCKS WITHDRAWN |
| 8. | FEATHER BUTTON * | PULL FOR RPM RISE |
| 9. | TGT | CHECKED RISING |

IF NO TGT RISE: THROTTLE TO 11000 RPM

IF RELIGHT CONFIRMED

- | | | |
|-----|---------------------|----------------|
| 10. | AIR RELIGHT SW | OFF |
| 11. | OIL PRESS/TEMP | CHECK |
| 12. | HP COCK | OPEN |
| 13. | GENERATOR | CHECK |
| 14. | FEATHER MOTOR LIGHT | OUT |
| 15. | DE-ICING | AS REQD |
| 16. | FUEL MANAGEMENT | AS REQD |

the minimum amount of ice ingestion required to cause a Dart engine to 'flame-out' showed that flame extinction occurred with the rapid ingestion of between 3 and 3.5 lb of wet ice. This is approximately equivalent to a layer of ice 0.5 inch thick over the inlet lip of the intake cowl.

Electrical supply to the heating mats is cyclically supplied to either the cowl or the propeller and spinner and the rate of cycling is automatically changed between a FAST or a SLOW setting depending on ambient air temperature ('FAST' cycle from +10°C to -6°C, 'SLOW' cycle below -6°C). The single ammeter in the flight deck overhead panel which can be switched to indicate current supply to each engine system would normally show either 3.5 or 20 amps with the de-icing switched 'ON' depending on the position in the cycle (3.5 amps being the continuous load, 20 amps being the total load when any cycled section of the heating elements is 'ON'). The Operator's Operations Manual notes:

Note: If the higher of these two indications falls below 16 amperes there may be inadequate ice protection.

1.6.5 Fuel

Refuelling of the aircraft for the flight to Coventry, to a total of 1,080 Imp gall, was completed at 1820 hrs from a mobile bowser and under the supervision of one of the airline's ground engineers.

Before the aircraft was refuelled he checked the contents of the inner tanks using the drip-stick indicators and calculated the quantities in those tanks which, with the outer tanks filled to the automatic cut-off, would give the required total. The pre-departure Checklist requires that, following any fuel adjustment, the fuel contents gauge readings be cross-checked by drip-stick readings of the tank contents but because the departure time had been brought forward the ground engineer did not drip-check the tank contents after the refuelling.

1.6.6 Airframe de-icing system

Heated air for the de-icing of the wing, tailplane and fin leading edges and the fuel vents is supplied through an air intake and a heat exchanger in each of the inboard nacelles only (Nos 2 and 3 engines). The hot side of the heat exchanger is provided with engine exhaust gas by a scoop, operated by an electrical actuator, which opens into the jet pipe exhaust stream. Either system can supply heated air to the whole airframe, in which case fresh air entrainment through the unused system can be blocked by a pair of electrically actuated butterfly valves at the exit

from the heat exchanger. Ducting around the twin butterfly valves allows the active system to supply heated air to the wing leading edges outboard of the unused system. When a system is activated, by flight deck selection, the jet pipe scoop and the butterfly valves are opened.

The engine failure Checklist requires the airframe de-icing system for that engine, if it is an inboard engine, to be closed. If this is omitted then unheated air will enter the system, diluting the tail unit de-icing and causing the wing de-icing to be asymmetric.

1.6.7 Electrical generation and supply

1.6.7.1 The DC supply

On the Viscount 813 each engine drives a 28V DC generator through a nacelle mounted auxiliary gearbox. The regulators and control equipment for the generators and the aircraft's four batteries are mounted in the fuselage aft under floor equipment bay. A system diagram (simplified) is at Appendix D.

The DC distribution system (Appendix D, Figure 1) comprises a Battery Busbar, a Main Busbar, which feeds Nos 1, 2 and 3 Busbars, and three Emergency Busbars, 1A, 2A and 3A. The batteries receive charge from the Main Busbar, via the Battery Busbar. There is also a Generator Emergency Busbar (GEB), which is automatically energised, initially by the batteries (see below), if the Main Busbars fail. Under emergency electrical operating conditions, the selection of the Generator Emergency Power Switch (GEPS) to either No 1 or No 4 will allow the selected generator to power the GEB.

In the event of a voltage drop on the main busbar the electrical supply to essential services is protected initially by the normally de-energised Emergency Power Auto Control (EPAC) relay (see Appendix 2, Figure 2). The EPAC relay is energised via relay contacts in the voltage sensing unit (VSU), the same contacts also control the supply to two 'Low Bus Volts' red warning lamp indicators. The VSU relay is normally energised whilst the voltage on the main busbar is greater than a nominal 24.7V. Should the voltage fall below this value for more than two seconds the VSU is de-energised, the warning lamps will flash, the EPAC relay will energise and will be electrically interlocked via its own contacts. The warning lamps will continue to flash until a manual selection is made to cancel the warning or the Main Busbar voltage is restored.

Operation of the EPAC relay:

- a) Isolates the Main Busbars (1, 2 and 3) from the emergency busbars,
- b) Disconnects the Battery Busbar from the Main Busbar,
- c) Connects the Battery Busbar to 2A Emergency Busbar and the GEB,
- d) Connects the GEB to the Emergency Busbars 1A and 3A.

To complete the protection of the necessary electrical services a gang bar is required to be pulled which selects:

- a) All four generators to OFF,
- b) The Power Master Switch to OFF,
- c) The Battery Emergency Power Switch to ON,
- d) The GEPS to Generator No 1 (This can be reset to No 4 if No 1 is unavailable).

The EPAC is de-energised when the GEPS is operated but its effects are replicated by the ganged switch selections and additionally:

- a) The Main Busbar is de-energised (unless subsequently supplied by a serviceable generator which has been re-selected to ON),
- b) The batteries are isolated from the GEB whilst continuing to power Emergency Busbar 2A,
- c) The GEB, and thus Emergency Busbars 1A, 3A and the Emergency inverter, are powered by No 1 or No 4 generator.

If this procedure is followed and it becomes possible to re-instate the Main Busbar then this can be done by selecting the appropriate generators 'ON', the GEPS and the BEPS to 'OFF' and the Power Master Switch (PMS) to 'ON'. But if the EPAC relay is still energised then operation of the PMS will not reconnect the Main Busbar to the Battery Busbar and to the essential services supplied by it which, in the circumstances of this accident, included the services fed from the GEB. The EPAC relay would have to be de-energised by the opening and closing of circuit breaker No 1 (CB1) for the system to be re-instated.

The sequence of engine failures reduced the generated power, firstly to two generators, then to one at which point the EPAC relay appears to have been energised (see paragraph 1.11.2.1). For a brief period, following the failure of No 4 engine, there was no generated supply until No 2 engine was restored. The first officer recalls that, during this sequence, he did not operate the gang bar or the GEPS.

1.6.7.2 The AC supply

The aircraft's AC electrical requirements are provided by three inverters: Main, Auxiliary and Emergency. In normal operation, the Main inverter supplies all AC current requirements except for the weather radar, which is always supplied by the Auxiliary inverter. In the event of the Auxiliary inverter being used as the primary (active) power source, the weather radar will not be available. Both the Main and the Auxiliary inverters are supplied by the Main Busbar and the Emergency inverter is supplied by the GEB, provided that it is live, regardless of the continued operation of either of the other two inverters.

1.6.8 Certification for penetration of icing conditions

The British Civil Airworthiness Requirements (BCARs), extant at the time of the aircraft's manufacture, defined conditions of temperature, liquid water droplet size and duration of exposure for which it was necessary to prove the aircraft's satisfactory performance. The Viscount 800 series aircraft had met these requirements, extracts of which are given in Appendix E.

1.7 Meteorological information

1.7.1 The general low level area forecast was issued by the Meteorological Office, Bracknell on METFORM 215 at 1545 hrs on 25 February 1994 valid between 1800 hrs and 2400 hrs. The diagrammatic presentation of the synoptic situation as at 2100 hrs, showed two warm fronts lying diagonally across the British Isles, one from the Isle of Man to the Thames Estuary and one from Stranraer to Norwich, moving towards the northeast.

This frontal system gave rise to the following forecast:

<u>Frequency</u>	<u>Visibility</u>	<u>Weather</u>	<u>Cloud (type & extent in feet)</u>
General	6 km	Ra/Dz	4-7/8 St 600/1,500, 6-8/8 layered 1,500/1,6000
occasionally	3000 metres	Mist/Dz	8/8 StSc 100/6000, 5-8/8 layered 1,2000/1,6000
occasionally near front and over hills in N	1000 metres	RaSn/Sn	8/8 layered 200/18,000
isolated	12 km	Nil	4-7/8 St Sc 100/3,500, 6-8/8 layered 10,000-15,000
local to fronts in W	2000 metres	Heavy Rn	8/8 Ns 200/24,000

Moderate ice and moderate turbulence in cloud. Cloud on hills. Moderate, occasionally severe, turbulence below 6,000 feet over land. Severe icing in nimbostratus.

Outlook until February 26 at 0600 hrs: Conditions will continue to spread NE, with increasing amounts of snow. Otherwise little change.

1.7.2 The weather briefing given to the crew before departure included the following Terminal Area Forecasts (TAFs):

<u>STATION</u> (period: hrs)	<u>WIND</u>	<u>VIS & WEATHER</u>	<u>CLOUD</u>
<u>Edinburgh</u> 19-04	100°/15-30 kt	9 km, Rn Sn	SCT 1,200 feet
becmg 19-21			OVC 3,500 feet 3,000 m Sn
tempo 19-04			BKN 400 feet 800 m Sn
<u>Coventry</u> 19-04	130°/12 kt	3,000 m Rn	OVC 500 feet
tempo 19-20			BKN 300 feet

Birmingham: The forecast was not available.

1.7.3 Sigmet²

In the London Flight Information Region (FIR) SIGMET No 2 was valid between 25 February 1994 1700 hrs and 2100 hrs and advised: 'Isolated severe turbulence forecast below FL60 over land west of 03° W moving east at 10 kts.'

In the Scottish FIR SIGMET No 2 was valid between 25 February 1994 1710 hrs and 2110 hrs and advised: 'Severe turbulence forecast over land below FL 60 over land southwest of 58° N 07°W to 55°N 02°W extending slowly northeast'.

² Weather advisory service to warn of potentially hazardous (significant) extreme conditions dangerous to most aircraft, eg extreme turbulence, severe icing, squall lines, dense fog.

1.7.4 Aftercasts

1.7.4.1 An aftercast provided by the Meteorological Office, Bracknell described the specific weather in the area of the accident site:

'The synoptic situation at 2000 hrs showed a warm front lying from Chester to Ipswich moving slowly northwards. Weather: Occasional rain and snow; Visibility 2,000 to 3,000 metres, overcast with stratus, base 200 to 400 feet, with broken/overcast thick layer, base 1,000 to 1,500 feet, tops 24,000 feet.

<u>Height</u>	<u>Winds</u>	<u>Temperatures</u>
Surface	140°/10 kt	+2°C
2,000 feet	180°/30 kt	Zero
5,000 feet	220°/35 kt	+2°C
10,000 feet	240°/25 kt	-6°C
18,000 feet	250°/35 kt	-22°C

Remarks:

The upper air soundings appropriate to the warm front were very moist and the winds were warm, advecting strongly from the southwest, driving the warm air over the cold southeasterly air near the surface. Consequently, precipitation was continuous and moderate or heavy north of the crash site. From the radar rainfall pictures it would appear that the whole flight from Edinburgh to crash was within the precipitation area associated with the warm front.'

1.7.4.2 A more detailed analysis of the recorded data relevant to the accident was compiled by a member of the Royal Meteorological Society and his report is at Appendix F.

1.8 Aids to navigation

The only aid to navigation used by the crew following the emergency was that provided by ATC radars. Since the crew did not ask for diversion to the 'nearest suitable airfield', ATC directed the aircraft towards the requested diversion, which was Birmingham.

1.9 Communications

The Manchester radar controller had been in position for some 45 seconds when BWL 4272 reported: "MANCHESTER MANCHESTER THIS IS THE BRITISH WORLD FOUR TWO SEVEN TWO WE'VE JUST HAD A DOUBLE ENGINE FAILURE DUE ICE

REQUESTING IMMEDIATE DESCENT PLEASE AND RADAR VECTORS". The controller cleared the aircraft to FL 70 and, later, to FL 50 to continue of a heading of 150°. At 1934 hrs the flight was handed over to Birmingham.

It was only after another three minutes, during which time the flight had been given, and correctly acknowledged, a descent clearance to 2,500 feet, that the crew declared an emergency and requested a diversion to Birmingham, but without using the appropriate pro-words (MAYDAY or PAN PAN). In response, the Birmingham radar controller asked for details of the aircraft's problems. The first officer's answer of "DOUBLE ENGINE FAILURE SIR NUMBER TWO AND NUMBER THREE" convinced the Birmingham radar controller of the gravity of the situation and, realising that the aircraft was closer to East Midlands than to Birmingham, he enquired "IS EAST MIDLANDS ANY GOOD TO YOU?", although he did not give the relative distances to the airfields.

Following the declaration of emergency, seeing that the aircraft was in a position to make a straight in approach to Runway 09 at East Midlands, Birmingham radar transmitted "THE RUNWAY IN USE AT EAST MIDLANDS IS ZERO NINE". Although it was obvious to the radar controller that East Midlands was the closest suitable airport to the flight, he has since stated that, being aware that the crew had declared the intention to proceed to Birmingham, he did not wish to cause them any undue distraction by informing them of this.

At 1941:35 hrs, the first officer selected the emergency Transponder Code '7700' and this was received by Birmingham radar and the Distress and Diversion (D&D) cell at LATCC. The D&D controller immediately spoke with Manchester and Birmingham Air Traffic Service Units (ATSUs) and, at 1946 hrs, when they lost radar contact with the aircraft, they alerted the Rescue Co-ordination Centre (RCC) at Pitreavie, Edinburgh.

The Manual of Air Traffic Services (MATS) Part I Section 5 states that a controller may suspect that an aircraft is in an emergency situation when '.... a pilot makes a report about the malfunctioning of his aircraft ...' (MATS 1 5-1) and continues 'If the controller is in radio contact with the aircraft he should ask the pilot if he wishes to declare an emergency'

However, any declaration of emergency by a pilot should be notified using appropriate pro-words either MAYDAY MAYDAY MAYDAY or PAN-PAN PAN-PAN PAN-PAN which, apart from removing any ambiguity regarding the state of emergency, should also ensure that all stations on the frequency are aware that an

emergency situation exists. The handling of emergencies by ATC is detailed in paragraph 1.18.1.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

1.11.1 Flight Data Recorder

An Epsilon Flight Data Acquisition System was fitted in the tail of the aircraft and normally recorded nine parameters. When the undamaged recorder was replayed at the AAIB no useful data was recovered. Examination of the data which was on the wire recorder indicated that either the analogue to digital converter or the multiplexer may have been faulty; both conditions would allow some data to be recorded thus inhibiting the flight deck fault light, indicative of recorder malfunction, from illuminating.

The system had been calibrated in early December 1993 prior to the aircraft returning to service. The Standard Maintenance Practices Manual (SMP) calls for an annual or 2,000 hours calibration period whichever is sooner but this may not necessarily have shown up faults in components. The SMP also specifies replays every 400 hours when the wire recorder is removed from the aircraft and the recorded data is analysed for correctness. The last routine replay was in November 1989, since when the aircraft had flown 700 hours.

1.11.2 Cockpit Voice Recorder (CVR)

The CVR was a Fairchild A 100, which had a 30 minute duration using an endless loop of tape. The audio information was recorded on four tracks as follows:

- TRACK 1 - Commander's headset signals
- TRACK 2 - Cockpit area microphone
- TRACK 3 - Commander's and first officer's 'live' microphones
- TRACK 4 - First officer's headset signals

The replay quality was good from the start of the recording, at 1913 hrs, until the end, at 1945 hrs, with the exception of the last five minutes when tracks 1 and 4 became unusable due to interference. Little intelligible speech was recorded from

the Cockpit Area Microphone (CAM), located in the centre of the main instrument panel, due to the high levels of noise on the flight deck.

In addition to voice the CVR also recorded other sounds which provided information on the functioning of the aircraft's systems. These sounds were analysed using a spectrum analyser and also by making comparisons with audio recordings from other Viscount aircraft.

1.11.2.1 CVR audio data

At 1932 hrs, the first officer announced the failure of the No 2 engine. Half a minute later, following the shutdown drills and a comment by the commander regarding the icing, the first officer said "OKAY I'M PUTTING ON NUMBER THREE AND NUMBER ONE"³. Coincident with the first officer's statement a 'fizzing' sound, pulsing once per second, started on track three indicating that at least one engine igniter unit had been switched ON. Fifteen seconds later the commander said "WE'RE LOSING THREE", there then followed a brief break in the recording of no more than two seconds. When the recording resumed, two frequencies of 400 Hz, as opposed to the previous single frequency, were visible on the spectrum analyser indicating that there were now two inverters running. As the flight continued these two frequencies gradually diverged, one remaining at 400 Hz and the other decreasing. At 1933 hrs, the first officer said he was going to switch on Nos 1, 4 and 2, and simultaneously the CVR recorded an increase in the level of the 'fizzing' sound.

The No 4 engine failed at 1938 hrs, at about the time of a re-start on the No 2 engine. The CVR recording was not interrupted by the engine failure, however, brief tones were heard which indicated that there had been a momentary loss of power to the recorder. Following the re-start of No 2 engine, RT communications were increasingly affected by a warbling sound and a reduction in volume which also affected the intercom and led, at 1940 hrs, to the pilots having to shout at one another to communicate. Also, following the re-start of No 2, the pulse rate of the igniters' 'fizzing' sound started to reduce and, at 1940 hrs, became intermittent. By 1942 hrs the sound had stopped and was not heard again, however, there were periods when the sound would have been masked by the pilots' speech and attempted radio transmissions.

³ This is believed to refer to the IGNITER switches, as is the later reference to "numbers 1, 4 and 2".

During the five minutes prior to impact it was apparent from the changes in pitch of the pilots' voices that the CVR's tape was slowing down due to electrical effects which are discussed in paragraph 2.7.2.

The weather radar switch was found in the STANDBY position but, from the start of the CVR recording until the failure of the No 3 engine at 1932 hrs, only one inverter frequency was recorded on the CVR indicating that only one inverter was running. For the weather radar to be ON or at STANDBY it was necessary for the Auxiliary and Main inverters to be running as described in paragraph 1.6.7.2. After the failure of the No 3 engine two inverter frequencies were recorded on the CVR and comparison with recordings from other Viscount aircraft show that neither of these was from the inverter powering the radar. It is therefore evident that the weather radar was not powered during the course of the CVR recording or presumably during any stage of the flight. This also shows that it was the emergency inverter that started to run after the failure of No 3 engine, that the GEB was live and that the EPAC relay had been energised at that time.

1.12 Wreckage and impact information

1.12.1 The accident site

The aircraft, while descending on a flight path 10° below the horizontal and banked 10° to the right, had crashed at an altitude of about 400 feet into a wood of mature trees, generally about 80 feet tall, on the side of a low ridge at the northern edge of Chartley Moss. Its heading at impact was 055°M and it passed down the side of the ridge for 150 metres until the major sections of wreckage emerged from the trees to come to rest on an open but boggy field some 170 metres from the first tree impacts. The aircraft had been destroyed by impact with the trees rather than the ground. Early debris from the aircraft's underside showed that it had been upright at impact and the presence of wing trailing edge material and tailplane pieces suggest that the aircraft may have been pitched significantly nose-up when it entered the trees. Very little was seen of characteristic propeller slashes in the tree debris to indicate that any propeller was rotating at high speed or was under power.

The main cabin from immediately aft of the flight deck was burned out. Although the flight deck was not damaged by the fire and had remained to some extent intact it had suffered heavy impact damage. The under floor structure, together

with the nose undercarriage, had been removed and a large ragged hole had been torn in the left side.

1.12.2 Engines

The four engines were stripped and examined for evidence of any pre-existing mechanical failure or fault and for evidence of their power condition at impact. The engine-mounted fuel control and ancillary units from Nos 2, 3 and 4 engines were rig tested or, in the few cases where this was not possible because of fire damage, stripped and examined. The fuel burners, except for two which were not found, were checked for flow rate and spray pattern and the igniter plugs tested. Although there were minor discrepancies, typical of engines returned from service, no significant pre-existing defect was identified in any engine or its equipment.

No 1 engine, which other evidence indicated had not suffered a power failure, was found to have a hole (2 x 0.75 inches) in its first stage impeller casing. This overload rupture appeared to have been caused by an impact from inside the casing which may have been caused by debris released when the propeller became detached during the impact. Impact damage inside the engine cowl, made presumably by the ejected fragment, showed no sign of there having been a high pressure air leak present for any length of time. The failure in the propeller shaft which had released the propeller showed evidence of torsion as well as bending in the failure, an indication of rotational energy in the engine if not necessarily of power. Some mechanical damage which normally results from high power at impact was missing but evidence of compacted vegetation, which was charred in the combustion area and turbine, confirmed that the engine was rotating energetically with a high airflow and that there was combustion. The precise level of power being produced could not be assessed.

No 2 engine showed similar evidence to No 1 of high airflow and combustion and substantially more mechanical damage from its high rotational energy at impact.

No 3 engine contained evidence of high rotational energy and ingestion of vegetation. Only a limited amount of combustion was evident and this suggested that the engine was windmilling and in the process of being re-started.

No 4 engine showed some evidence of rotation and airflow but this was weaker than that seen in Nos 2 and 3 engines and there was no evidence of combustion.

The mashed vegetation that was recovered from the turbine still smelled fresh and it contained no trace of fuel although fuel had been recovered from the engine pipework.

1.12.2.1 Engine fuel trimmers

The electrical actuators were of a type not readily back-driven by impact loads and so the position in which they were found was a reliable indication of their condition when electrical power was removed. The four actuators found were at, or close to, the 'fully weak' fuel trimmed condition.

1.12.2.2 Engine de-icing

The cowl heater mats had all suffered severe impact damage. No 3 engine's cowl mat had also been burned and the electrical conducting strips had been exposed and were damaged or had been completely removed. All the failures found in the electrical conductors in the mats were associated with impact damage and no pre-existing defects such as overheated or fused elements, were identified. Similar examination of the propeller and spinner heating circuits, all badly damaged, did not identify any pre-existing failures or defects and all four propeller de-icing systems were considered to have been in good mechanical and electrical condition prior to the accident.

The alternators had each survived with only minor damage. The alternators from positions 2, 3 and 4 were tested and they performed satisfactorily. The control units from positions 3 and 4 were fire damaged and could not be tested. The control units from No 2 engine's de-icing system were all tested individually and performed with only minor deviations from specification. When the alternator, regulator and transformer-rectifier unit were tested together they were found to produce an output which was 5% low; this would have resulted in a current supply to the heater mats of 19 amps compared to the nominal 20 amps on No 2 engine.

The control relays for the engine de-icing system were contained in a single box located in the fuselage. Despite impact and fire damage all the individual relays were found to operate correctly and no anomalies other than crash damage were found in the other components, wiring and connectors within the box. All the control relays exhibited 'drop out' voltages of less than 10V.

Using surviving equipment from G-OHOT some tests were carried out to assess the effects of low aircraft voltage supply on the alternator system over a range of engine RPM. It was found that, with a 28V DC supply, the full 208V AC supply could be provided to the heating mats down to flight idle, 11,000 RPM. At battery voltage, 24V DC, the 208V AC supply could be maintained at the mats at 15,000 RPM but it would have decreased at lower engine speeds with a loss of about 12% (183V AC) at 11,000 RPM. At an engine speed of 7,000 RPM, representing a windmilling condition, the system would still be able to supply between 67 and 72% of its normal output to the cowls depending on whether the field supply to the alternator was battery voltage (24V DC) or generator voltage (28V DC).

The cyclic timing of the engine de-icing and its distribution to either the cowl or the propeller is controlled by a cyclic switch in each system. The switches in nacelle Nos 1 and 4 were a solid state electronic type and those in Nos 2 and 3 were an older electromechanical type. No 2's switch was capable of being tested and performed within specification. When it was tested at reducing supply voltages (to 22V) its operation was found to slow appreciably. However, an example of the solid state type, as fitted to nacelle No 4, was found to be stable in its timing cycle down to 20V. It stayed 'ON' down to 12V but would not re-start below 19V.

1.12.2.3 Igniter units

All the igniter units (two per engine) were of the original type, which used a vibrator and contact points to generate an HT output. They were not of the later transistorised type. The units from Nos 2, 3 and 4 engines were tested, where possible, and all were stripped and examined. Some anomalies were found in their assembly and component standards but, since it was assessed that this was unlikely to have rendered them unserviceable, what is reported here is their functional behaviour.

The No 2 outboard box operated satisfactorily over a 15 minute test period.

No 3 engine's inboard box was too heavily fire damaged to test. On strip its contact points were found to be welded. Its discharge tube was tested separately and found to be serviceable. No wiring faults were seen inside the box but other components were too heat affected to test. The outboard box showed some variability of performance but completed a 15 minute test.

No 4 engine both boxes were functional although the front one produced a low spark rate.

The boxes which could be operated were tested at low supply voltages. It was found that they would all operate down to 12V or less albeit at reduced spark rates. On Nos 2 and 3 engines at least one igniter was found to be capable of working and on No 4 engine both were functional even though, as with others there were some anomalies in their build.

1.12.3 Propellers

The propellers were examined for evidence of their pitch setting at impact and for indications of the level of power being transmitted. The indications of power transmission were not clear and were sometimes contradictory and the evidence of blade angle at impact was very light and difficult to identify. Given that No 1 and No 2 engines were under power and, allowing for inaccuracies in the evidence, the blade angles obtained for those propellers (37° and 36° respectively) at the flight conditions immediately before impact represent a condition in the powered range between maximum fuel flow at 11,000 ERPM and maximum power at 15,000 ERPM. The blade angle evidence for Nos 3 and 4 propellers shows that neither was feathered at impact. Some of the evidence for No 3 is consistent with the pitch change mechanism being on the Flight Idle Stop (25°) which is the position it adopts during the air re-start sequence. Given that No 4 engine was not under power, the evidence from its propeller was consistent with the pitch change mechanism resting on the Cruise Stop (36° to 38°). It is possible for the propeller to have achieved this position following an autofeather depending on crew actions, which may have included an earlier attempt at feathering. This would have resulted in a low speed and low drag windmilling condition.

1.12.4 Propeller synchronisation

The synchronisation control, a rotatable knob, was found undamaged and in the ON position after the accident. The corrector motor from No 1 engine, which was the only one retrieved, was examined. Its internal worm gear drive, which is not susceptible to being back-driven by impact loads on the output shaft, was found to be at the extreme end of its range of travel in the direction consistent with an engine speed reduction demand. This confirmed that the synchronisation system had not been switched OFF after the failure of No 3 engine and that the remaining engines, Nos 1 and 4, would have suffered a reduction in RPM and a restriction

in the available maximum RPM. When engine No 2 was re-started it would also have been restricted in maximum RPM and power.

1.12.5 Fuel

Shortly after the accident there was a smell of fuel along the whole wreckage trail. The fuel tanks in the outer wings had been disrupted with the wing structure. The tanks in the inner wings appeared to have remained mainly intact but they had burned out in the ground fire and no fuel was recovered from the airframe. Some fuel was recovered on site, however, from the low pressure filters and pipes on No 1, 2 and 4 engines. The filters from all four engines were found to be clean.

Fuel samples recovered from the Nos 1, 2 and 4 engines were examined by gas chromatography and found to be JET A1. They were contaminated by soil, vegetation, some fine debris and, in two cases, a small amount of water but this appeared to have been a result of the exposed conditions in which the fuel had lain in the disrupted engine pipework.

Bowser and airfield tank records together with previous aircraft fuel usage showed that there was no significant discrepancy in fuel load at takeoff. The aircraft's gauges confirmed the correct amount on board at impact. Samples for test were later taken from the bowser and the relevant airfield supply tank and samples from each were laboratory tested. The samples conformed to specification for JET A1 and were fit for use.

1.12.6 Airframe de-icing system

On both inboard engines the actuators operating the scoops and butterfly valves for the supply of hot air used for airframe de-icing were found to be extended, which corresponded to them being open. All the actuators from the aircraft are not readily back-driven.

1.12.7 Aircraft electrical system

The array of four generator control assemblies had suffered severe fire damage with only copper and steel components remaining and no useful information was obtained from it.

The drive trains to and through the auxiliary gearboxes were found to be intact. The generators from positions No 2 and No 4 were examined as the units critical

to the generation of power following the failure of No 2 and No 3 engines (Generator No 4 remaining operating) and, later, the re-start of No 2 engine and its generator and the failure of No 4 engine. Both No 2 and No 4 generators had suffered impact damage but it was found possible to run No 4 and subject it to test. Controlled by a regulator similar to that on the aircraft it performed satisfactorily with only minor deviations from pass-off test requirements. It was then subjected to an overload test with load being increased rapidly in steps to a maximum of 620 amps for a short period of time (5 seconds). It produced 620 amps with no reduction in output voltage. When it was stripped and examined no defects other than normal, in service, deterioration were found and there were no signs of heat distress from overloading either on the rig or during the accident flight. No 2 generator could not be tested because of impact damage but a visual examination following strip found no evidence of any pre-existing fault.

Almost all of the main power supply leads had been stripped of insulation by fire and some aluminium leads had melted. Two short lengths of wound copper cable were found which terminated in a rupture. In each case the ruptured end was in the form of a flat diagonal face with no distortion of the cable windings on either side of the rupture. The wire ends had fused, indicating that both ends of the cable had been subjected to electrical arcing. The cable ends were only an approximate match but taken together the two cable parts appeared to comprise a battery lead from one of the starboard batteries to the connector to which the four batteries were connected and from which a single lead was taken to the Battery Busbar. No aluminium contamination of the fused areas was found to confirm that the cable had shorted to the airframe and the circumstances of this failure and the time at which it took place could not be determined.

The Battery Busbar was badly fire damaged but all connections to it appeared to have been made. The four batteries were fire damaged and their electrolyte had escaped by leakage or boiling. Sample positive plates from each battery were examined chemically and the percentages of PbO_2 present, ie 63, 63, 64 and 59, represented discharged conditions. For a high discharge rate these figures would represent fully discharged batteries. At a low discharge rate the batteries would be able to discharge to about 50%.

1.13 Medical and pathological information

The commander was fully fit and able to perform his duties on the flight. He did not survive the impact forces having sustained injuries which were consistent with those which would have occurred as a result of this accident.

The first officer was also medically fit and able to conduct the flight. Although surviving the accident, he suffered a number of serious injuries and, having been assisted from the wreckage, was taken to hospital.

1.14 Fire

There was no evidence of fire having occurred prior to impact. Wing fuel tanks were ruptured early in the break-up sequence as the outer wings were destroyed. A ground fire had burned locally around No 4 engine and nacelle which had completely detached from the wing and lay in the wood 110 metres beyond the first tree impacts. There was sooting on the jet pipe heat shield aft of the position at which the main fuel pipe had ruptured which showed that the released fuel had ignited and, therefore, that fire had initiated while the aircraft was breaking up. The subsequent ground fire had gutted the fuel tanks in the two major portions of remaining wing structure and the main cabin section of the fuselage which lay next to the right inboard wing.

1.15 Survival aspects

Two people in the vicinity of the accident went immediately to the scene and, despite the fire, assisted the first officer out of the aircraft through a hole in the side of the inverted and crushed flight deck. They realised that the commander had not survived the impact. They took the first officer to a safe area where they looked after him until the emergency services arrived, at 2144 hrs, and took him by ambulance to the North Staffordshire Infirmary from where he was discharged two weeks later.

The flight deck came to rest almost inverted. The commander was found out of his seat lying against the right side window and roof panel. Much of the flight deck left wall and floor had been removed by impact damage which had also released the commander's seat. The Quick Release Fastener (QRF) of his four-point harness was found undone. The first officer is certain that both he and the commander were wearing the full harness and that his own was fastened. He also recalls seeing the commander rising in his seat, and post-mortem examination of the commander did not display evidence typical of that normally left by an

upper torso restraint harness. The harness webbing was undamaged and there was no indication of distortion on the harness lugs or the QRF body. The QRF was of a type which has a single rotary release action; release of the harness lugs being achieved by rotation of the QRF face in either direction. For this particular QRF the amount of rotation required to release the lugs was normal being approximately 55° clockwise and 60° anti-clockwise. It is possible for single release action QRFs to release during crash conditions because of some inadvertent contact on the QRF face. Single action QRFs comply with current airworthiness requirements (CAA Specification No 4) where the strength of the QRF in the closed condition and its ease of release for evacuation purposes are the prime considerations.

1.16 Tests and research

On the 6 July 1994, British World Airlines Limited provided a Viscount 810 Series, G-BFZL, with a crew, to enable the investigation team to gain some idea of the value of minimum control speed (V_{MCA}) with both right-hand engines failed but with neither propeller feathered. This data was not available from the manufacturer and would not routinely be required.

All significant features of the aircraft were identical to those of G-OHOT, except for the operating weight, which was about 2,400 kg lighter. It should be noted that, apart from affecting stall speeds, weight will not generally affect V_{MCA} . The test was conducted at heights around 5,000 feet, where the OAT was +9°C. Having initially shut down the two right-hand engines, feathered the propellers and deselected propeller synchronisation, the speed was stabilised at a cruise RPM of 14,200 on the live engines. The propellers were then unfeathered allowing them to windmill at 7,000 engine RPM, the fuel trimmers set to 0% and the RPM on the live engines increased to 14,800 RPM (maximum power). Banking slightly towards the live engines, the speed was allowed to reduce until the onset of loss of directional control occurred at 120 KIAS.

1.17 Organisational and management information

1.17.1 History of the operator

Like many of the smaller UK airlines, the operator had undergone several changes of ownership and management throughout its 48 year history. Combined with this had been periods of uncertainty arising from varied financial

fortunes. At the time of the accident the company was concentrating on its 'ad hoc' charter work together with some longer term contracts for which its various types of aircraft, including the Viscount, were particularly suited.

The company was renamed British World Airlines on 1 April 1992 under the ownership of British World Aviation. Shortly before the accident the General Manager had resigned and the Operations Director left the company on the day of the accident. The Chief Pilot left his post shortly after the accident. The existing Chairman assumed the role of Managing Director and other company personnel were appointed as Operations Director and Chief Pilot. In August 1994 a new Chief Training Captain was being recruited.

1.17.2 Regulatory supervision

Air Operator's Certificates (AOC) are issued by the CAA and, within that organisation, it is the role of the Flight Operations Inspectorate of the Safety Regulation Group to monitor and advise AOC holders in the routine conduct of their operations.

Some shortfalls in the regulatory system were identified by the CAA Flight Operations Department as a result of their Operating Standards Appraisal Program (OSAP). In response to this, a Flight Operations Study Group was established in 1991 to review the methods used by Inspectors when discharging their duties. The Group recommended changes to the methods of inspecting, including a move towards audit based inspection techniques. These changes were implemented and further refined, in October 1993, because of representations from Industry and because of the need to align with proposed Joint Aviation Authorities (JAA) legislation.

Whereas the previous system involved periodic checks by the assigned FOI (Flight Operations Inspector) of individual items such as retained documentation, flight time limitation records, training records, ramp checks and flight inspections, much of this task is now performed by an In Depth Audit (IDA). This leaves the FOI with more time to conduct flight inspections and liaison visits, the results of which are reported to his line managers and recorded on file, as are the results of the IDA and the ramp checks. Any significant shortfalls by the operating company are thereby noted and the Head of Section allocates a time for a revisit to the company to ensure that the shortfalls have been corrected. The monitoring of training standards was the responsibility of the Flight Operations Inspectors and the Training Inspectors. However, a large portion of

the responsibility for the maintenance of standards is now delegated by the CAA to the company's authorised Type Rating Examiners (TRE) and Instrument Rating Examiners (IREs) who, themselves, are periodically examined by the CAA Flight Operations (Training) Inspectors.

The investigation noted that the system of regulatory supervision had undergone some changes and was likely to change further with the advent of JAA regulations. In June 1994 the Chief Flight Operations Inspector (CFOI) wrote to all AOC Holders to explain interim measures for the implementation of the Quality Systems which are called for in the draft Joint Airworthiness Requirements (JAR-OPS 1 and 3 1.035⁴).

The CFOI's letter included a draft paper in which current thinking on the proposed Flight Operations Internal Quality Assurance procedures was set out. The aim, background and conclusions of this draft paper are shown in Appendix G.

AOC holders themselves are thus likely to be more accountable for safety standards, through their own safety management systems, which in turn will be monitored by the CAA.

1.17.3 FOI surveillance of British World Airlines Limited

Throughout its recent history the operator had worked with a number of assigned FOIs, two since late 1991. Routine inspections were made and little of significance was reported to the Head of Section and CFOI.

At the request of the FOI Section Head and because of recent management changes, an IDA of the operator was conducted by an FOI team during the period 9 and 26 May 1994. The IDA report listed five items requiring attention under the heading of Training, four of which are relevant to this accident:

- a) a review of all manuals,
- b) a review of 'ab initio' training of pilots,
- c) formalisation of command training,
- d) lack of Line-Oriented Flying Training (LOFT) or practical CRM.

These items had not been identified as 'significant' during previous checks made by the assigned FOIs.

⁴ Joint Airworthiness Requirements (JAR) are the equivalent of British Civil Airworthiness Requirements (BCAR) but issued under the authority of the Joint Aviation Authorities (JAA). JAR-OPS 1 and 3 deal with aeroplanes and helicopters respectively.

1.18 Additional information

1.18.1 ATC: Handling of emergencies

Following the aircraft accident to BAC One Eleven, G-BJRT, over Didcot, Oxfordshire on 10 June 1990 (AAR 1/92) the AAIB made a number of Safety Recommendations including one regarding initial and continuation training for Air Traffic Controllers in both the theoretical and practical handling of emergency situations. The Recommendation was accepted by the Authority and a programme to institute such training was commenced. It will become a requirement from January 1996, notified in CAP 160 (Air Traffic Control Licensing), for controllers to undergo such training. However, units have tended to take a wider view of the safety situation and some have introduced such training earlier than required by CAP 160. Birmingham and Manchester ATC units have both taken this view and have commenced emergency training programmes. A number of controllers had completed the initial continuation package, but the Birmingham radar controller had not undergone the course at the time of the accident. Guidance on aircraft emergencies is contained within the Manual of Air Traffic Services (MATS) Part I Section 5. Subjects covered include Aircraft Emergencies - General Principles, Recognising Emergency Situations, Selection of Controlling Agency and Controller's Responsibilities.

1.18.2 Action taken on ice-related events

Vulnerability of turboprop aircraft in conditions of severe airframe and engine icing has long been a concern, not least because the flight levels at which these particular types of aircraft fly coincide with the conditions most likely to produce heavy ice accretion.

In the UK there have been four ice-related reportable accidents recorded since 1980 and these were all caused by airframe ice accretion. However, in three of these the airframe ice protection system consisted of inflatable boots and the shortcomings of such a system have been described in the accident reports. In the fourth, a Britannia, it is believed that the hot air and electrical system functioned effectively, but the melted ice then flowed back onto the leading edge of the (unprotected) control tabs and re-froze. There is little comparison to be drawn with the subject accident.

Considerable efforts have been made to identify the exact conditions which produce 'severe' engine icing, but neither Rolls-Royce nor the Meteorological

Office have been able to identify all water droplet sizes, water vapour contents, or specific temperatures where these conditions might arise. Since 1976 there have been 11 Dart engine failure incidents which were reported as being ice-related, but were not subjects of an AAIB investigation, and these are listed in Appendix H. There were also two incidents in 1991 which were the subject of an AAIB investigation and a number of Safety Recommendations were made.

The first, concerning a Fokker F27 aircraft, recommended an increased use of igniters in conditions of potential engine icing. In consequence, Rolls-Royce issued a Notice to Operators (No 1118) advocating the increased use of igniters. However, BWA did not incorporate these amendments in their manuals because they believed that the problems giving rise to this amendment were exclusively confined to the F27 and did not affect Viscount aircraft because of the different nacelle design. They therefore saw no reason to amend their Operations Manual. The Recommendation and the CAA response is detailed in Appendix J paragraph 1.

The second concerned an ATP aircraft and made three recommendations which, together with the CAA responses are also shown in Appendix J paragraph 2.

Recognising that there are still unresolved problems in this area, the CAA have contracted three projects. These are listed in the CAA Safety Regulation Group Research Programme; 1994/95 which was published in May 1994; and the 1993 JAA Member States research Summary Document which was published in January 1994. They are:

- 1) The Meteorological Office to define a 'Probabilistic Icing Atmosphere'. (Commenced July 1994)
- 2) UK Industry to conduct a cost benefit study for an 'Advanced Ice Detection Study'. (Commenced April 1994)
- 3) The funding of a '3D Ice Accretion Modelling Programme'. (To commence April 1995⁵)

The CAA are also correlating their own efforts with those of The Netherlands, Germany and France and, latterly, Italy, Sweden and Spain into several other areas of research into the occurrence of ice accretion on aircraft: These include methods of predicting ice accretion, improvement of ice protection systems,

⁵ The CAA has since stated "The Authority has no immediate plans to fund Item 3 because the project has yet to be fully defined by UK industry. When the project is so defined, the Authority will then consider whether it will fund some part of this project."

prediction of 3D ice shapes, the choice of wing section for commuter type aircraft and the modelling of performance dissipation in freezing conditions.

1.18.3 Operator's Emergency Checklist

Because a significant factor contributing to the accident was that the first officer had not used the checklist, a possible reason for this was examined. Therefore a behavioural psychologist made an assessment of the presentation of the operator's Viscount Emergency Checklist. Detailed comments are listed in Appendix K. In summary it was found that:

'Overall, the checklist gives the impression of having been reproduced more from considerations of expediency rather than ease of use or utility. It has apparently not been specifically designed for the purpose and is rather a collection of pages poorly reproduced from the manual in a careless fashion which takes no account of the importance of the information or the conditions under which it is going to be used.'

At the time of the accident, the operating company was in the process of reviewing its Viscount checklists.

In November 1992, the CAA issued a revision to the previously published guidance on the production and use of checklists and incorporated it in CAP 360 (Air Operators' Certificates) Part One Chapter 4 Section 10. Whilst the guidance is mostly devoted to the checklists' content, rather than presentation, it does state that:

'All checklists or drill cards must be of a quality sufficient to withstand heavy wear and remain legible.'

and:

'On multi-crew aircraft, instructions must be given that checklists are always to be used.'

There is no guidance on the optimum presentation and ease of use under stressful or difficult conditions.

1.18.4 Historical data provided by Rolls-Royce (Dart Project Department)

Rolls-Royce had recorded engine failures, from 1960 to 1991, which had occurred in icing conditions and these numbered 28 in 110 million flying hours. Of these, 13 events were ascribed to incorrect procedures, 5 to a defective system, 5 to late implementation of the protection system and there was insufficient data to ascribe a cause to the remaining 5. Data on re-start attempts showed that Dart engines had been re-started on 90% of the occasions of failures.

2

Analysis

2.1

General

The investigation was hampered by the lack of a serviceable flight recorder and re-construction of the emergency phases of the flight has been based on a detailed analysis of the CVR, detailed examination of the wreckage, in particular the engines and their systems, icing protection and the electrical systems, and ATC records including the radar track plot. The first officer understandably cannot recall all the details of the accident but his assistance in the investigation has been invaluable.

The extreme nature of the meteorological conditions through which the aircraft flew was undoubtedly the initiating factor in the sequence of engine failures and aircraft electrical problems which led to the accident. A further factor was the inability to re-start the engines. Considering the historically low incidence rate of inability to re-start Dart engines, it is likely that on this occasion there were reasons other than just the meteorological conditions for this lack of success.

The engines had not suffered from fuel starvation and there was no evidence of malfunction which would have been responsible for either the power failures or the inability to re-start. The inoperative generator of No 1 engine was an allowable defect since multiple engine failures were not envisaged.

Single or double engine failures by themselves should not prove catastrophic to a four engined aircraft in the cruise. Proper emergency drills should ensure a successful completion of the flight. In this accident the situation grew steadily worse from the moment of the first engine failure through successive failures and their effect on airframe ice protection systems to the inability to restore adequate power and then to loss of height and, ultimately, control. Tragically, even this progression of problems need not have prejudiced a safe landing at the nearest airfield given better management of the emergencies by the crew.

This analysis looks first at how the meteorological conditions were likely to have caused the engine failures before examining the subsequent flight path of the aircraft. Crew performance is then analysed before human factors, including Crew Resource Management (CRM) and regulatory supervision, are discussed. Engine and system failures are examined including the almost total loss of electrical power shortly before the impact.

2.2

Meteorology

The aircraft encountered very severe icing conditions in the thick cloud during the earlier part of the descent and, with regard to the BCARs relevant at the time of the aircraft's certification, the 'continuous (exposure) maximum' conditions were undoubtedly exceeded for a period of over 11 minutes in the frontal nimbostratus.

From then on, the meteorological conditions were such that they would not have reduced the build-up of snow or ice already formed on the airframe and the engines and may instead have added to it. A 2,500 feet thick, nearly isothermal 0°C layer between 3,500 feet and 1,000 feet, containing freezing rain and some ice pellets almost certainly resulted in icing on the unprotected starboard wing and the failed engines. Glaze ice would then have formed when the temperature fell below 0°C. It is most likely that this contributed to the eventual loss of control.

It is apparent that conditions in excess of those envisaged by BCARs and JARs will, on infrequent occasions, be encountered. The research project to define a 'Probabilistic Icing Atmosphere' referred to in paragraph 1.18.2 will contribute towards the definition of future requirements.

2.3

The flight path

Because of the number of variables present and the lack of flight recorder data, it was not possible to compare the earlier part of G-OHOT's descent with standard rated performance. Nevertheless, some comparison can be made with that part of the flight path which followed the attempt to level the aircraft at its assigned altitude of 2,500 feet.

2.3.1

The loss of control

The aircraft had been cruising in temperatures of about minus 20°C, so that the airframe had been subjected to a lengthy cold-soak. The first officer recalls that ice or snow was re-forming on the windshield immediately behind each sweep of the wiper blades throughout the descent and the Meteorological Office states that the likelihood of airframe icing was high.

Ice or snow was forming on the aircraft throughout the descent and, as the airframe was almost totally unprotected throughout this period, the rate of accretion would have been high. Furthermore, as these conditions persisted almost all the way down to ground level, there was little opportunity for the considerable deposits to have melted off.

Following the consecutive failures of engine Nos 2 and 3, cold air would have passed through the heat exchangers and entered the ducting, with unpredictable internal icing effects, and the airframe external surfaces would have been unprotected. Five minutes later, when No 2 engine was re-started and, assuming that the heat exchangers and ducting were not obstructed, ice shedding may have occurred on the left wing but the heating effect was probably diluted in the tail area and non-existent in the right wing. This condition, leading to asymmetric drag and lift, persisted for the eight minutes before impact.

The commander's attempt to level the aircraft at the assigned altitude of 2,500 feet by raising the nose of the aircraft resulted in the loss of 45 kt. Therefore, in order to maintain flying speed, descent was continued at an airspeed, calculated from the radar plot, of about 138 kt. Even at this speed directional control was lost and the drag from the unfeathered propellers of the failed engines (Nos 3 and 4) would have exacerbated the situation, as did the 0% setting of the fuel trimmers which considerably limited the maximum power available from the live engines. Since it appears that G-OHOT lost directional control at a much greater speed than the 120 kt demonstrated in the flight test (see paragraph 1.16), the difference is probably explained by the presence of a significant quantity of ice or snow on the fin. Furthermore the significant quantity of ice or snow had also increased the all-up weight of the aircraft and impaired the aerodynamic performance of the wings such that a climb using the available (but limited by fuel trimming and the omission of synchronisation deselection) power of two engines was no longer possible.

2.4 Operational performance

2.4.1 Flight planning

The meteorological forecasts available to the crew and the decision to advance the despatch time of the flight in anticipation of bad weather should have alerted the crew to the probability of encountering severe weather. There is no evidence from the aircraft's track or from ATC communications that any avoidance was made. During the flight from north to south it was necessary to traverse the frontal system and the warning of severe icing in nimbostratus cloud should have triggered the need for some alternative course of action when such conditions were encountered. A suitable routing might have been considered during the planning stage but, in flight, such avoidance would have been difficult to achieve without using the weather radar, which was not in operation at the time. This was a serious and surprising omission from the effective operation of the aircraft,

although the commander was known to make little use of weather radar. It is difficult to understand why such an essential aid for the avoidance of severe weather conditions was not used.

2.4.2 The initial descent

Because of the Viscount's performance and the frequent practising of double engine failures during training, such failures might be considered by crews more as an 'abnormal' event than as an 'emergency'. In these conditions the aircraft is usually controllable and, provided it is not close to its maximum weight, able to sustain a climb. It is therefore likely that, upon the failure of the second engine, when the commander instructed the first officer to "GET AN IMMEDIATE DESCENT DECLARE AN EMERGENCY", he was mindful of the fact that, having lost Nos 2 and 3 engines, the aircraft no longer had any airframe ice protection and needed therefore to vacate the icing environment if at all possible.

2.4.3 Emergency drills

Use of the Emergency Checklist is specified in the OM but the first officer recalls that it was not used, even for the first engine shutdown drill when there was little pressure on the crew. Furthermore, the spoken drill used for the attempted re-start of No 2 engine did not conform with the Emergency Checklist. Thereafter, with the pressure on the crew increasing rapidly, still no reference was made to the Emergency Checklist and consequently omissions and errors of procedure were made, including the following:

- a) propeller synchronisation - not de-selected thus reducing the power available on the live engines;
- b) correct airspeed re-start envelope - not verified;
- c) fuel trimmers - not re-set for the attempted re-starts, thus reducing the chances of success;
- d) airframe de-icing system of Nos 2 and 3 engines - not closed, thus allowing the worst possible airframe icing to occur;
- e) electrical system - omission of emergency actions, resulting in the loss of several electrical services;
- f) propellers - those of the two failed engines were not feathered. However, No 3 may have been in the process of being re-started and it may not have been possible to feather No 4 fully because of reduced electrical power supply.

At no time did the first officer comment upon the incorrect airspeed. The commander made no comment about the Emergency Checklist not being used and he appeared not to have monitored the (incorrect) actions of the first officer. Use of the Emergency Checklist is designed to assist in such circumstances and it is unfortunate that the first officer, who was known to have reservations about its design and layout, did not use such aid as it could have given him.

The psychologist's view of the Emergency Checklist, given in detail at Appendix K, is that:

'Users will become familiar with, and make use of, less than optimal material. However, Emergency Check Lists are, presumably, not in very frequent use and when they are used, the situation is, by definition, likely to be abnormal and possibly stressful. Individuals under stress often have difficulty in absorbing information. Information is frequently missed and errors are made. It is therefore particularly important that any material likely to be needed under abnormal or stressful conditions be tailored to the purpose. This document infringes most of the basic human factors considerations in the design and presentation of visual information.'

The air re-start drills are relatively straightforward and the physical actions easily committed to memory. However, the Emergency Checklist does contain vital drills of verification, listed in sub paragraphs a) to d) above, which are less easily recalled from memory, hence the need for an Emergency Checklist. This must present timely and correct information to a crew which may be operating under conditions of stress or high workload. The traditional flip card or loose leaf folder with typed action lists has many shortcomings. There is no guidance on optimum presentation and ease of use given in CAP 360 (paragraph 1.18.3 refers). Operators devise their own formats based upon either traditional or personal preference. This is an area where specialist advice can improve the presentation of vital information on the flight deck in both paper and electronic form. It is therefore recommended that the CAA should commission research into the most effective form of presentation of emergency reference material which may be required on a flight deck. This should include both manual Checklists and electronic screen displays. Suitable advice from human factor specialists should be included in guidance material which should be promulgated in a publication such as CAP 360. [Safety Recommendation 94-40]

2.4.4 RT communications

When the commander initially instructed the first officer to "GET AN IMMEDIATE DESCENT DECLARE AN EMERGENCY", the first officer requested only the descent and did not mention any emergency. It was not until four minutes later, when the

commander instructed him to "TELL THEM ABOUT BIRMINGHAM", that he declared the emergency, but did not use the correct pro-words. Neither of these omissions was corrected by the commander. This is a frequent aspect of emergency situations in which there is a reluctance to use the specified pro-words, perhaps in the belief that the emergency does not warrant it or the hope that the situation might improve. This is generally a false optimism which is likely to prejudice appropriate responses by those able to assist. It is therefore recommended that the CAA should consider further reminding pilots and operators about the correct meaning and use of the 'Distress Message'. The correct use of pro-words together with information about what actions will be taken by ATC on receipt of a distress message should be covered. The fact that the message can be easily cancelled, if the situation of the aircraft improves, should also be emphasised. [Safety Recommendation 94-22]

2.4.5 Choice of diversion airfield

At 1937 hrs, when the first officer informed ATC that an emergency existed, the decision to divert to Birmingham had already been made. Although the level of activity on the flight deck was high, there was a lack of geographic orientation, which denied the crew awareness that East Midlands was considerably closer than Birmingham. This is understandable given the normal reliance on positions based upon aeronautical beacons rather than ground features. Based on subsequent track miles flown by the aircraft, if the crew had chosen to change the diversion to East Midlands Airport, the aircraft would have almost certainly been able to land there.

It is therefore unfortunate that the crew did not ask ATC for 'a diversion to the nearest suitable airfield' and that ATC did not advise the crew of the relative distances to the other diversion airfields. Improved training in the handling of emergencies by ATC should include this aspect (refer to paragraph 1.18.1).

2.5 Human factors

Several factors together placed the aircraft and crew in an irretrievable situation and no single factor can be said to have caused the accident. These factors fall into the categories, 'active failures' and 'latent failures', which inter alia are described in the 1993 ICAO Circular 240-AN/144, 'Human Factors Digest No 7 Investigation of Human Factors in Accidents and Incidents'. An 'active failure' is an error which has an immediate adverse effect and such errors are usually made by operational personnel. A 'latent failure' is a result of a decision or action made

well before the accident and these failures usually originate at organisational level. Both types of failure are apparent in the circumstances of this accident; Operational Performance, discussed in the previous paragraph, and Management and regulatory supervision which is discussed below.

2.5.1 Regulatory supervision

Prior to the accident, routine inspections had indicated little of significance to cause safety concerns to the Flight Operations Inspectorate of the CAA which was content with the continuance of the operator's AOC provided no major increase in operator activity or re-equipment (new aircraft types) occurred.

This accident has shown a weakness in flight deck drills, from the unsatisfactory operator's Emergency Checklist, lack of standardisation, training and CRM education. Little of this had been detected, or reported, by the assigned FOI and preventative measures could not have been initiated in time to reduce the chances of this accident occurring. Acknowledgement is made of the difficult task faced by the assigned FOI who must, in limited time, attempt to check and advise on many varied operational aspects. Although there was a prescribed structure to individual check items, individual FOIs had to use their own judgement on those areas most deserving of their attention. After the accident the IDA, which was conducted by a team of inspectors, was able to identify the reported weaknesses, which were brought to the attention of the operator.

2.5.2 Crew Resource Management

Although this section of the report has highlighted the shortcomings in the performance of the crew, mitigating circumstances must include the difficult operating conditions at the time. The initial emergency quite quickly compounded itself. As it progressed, more and more services were lost, including crew intercommunications, flight deck lighting and an adequate electrical supply. The commander became increasingly pre-occupied with hand flying the aircraft by reference instruments in turbulent conditions, while the first officer was left on his own to cope with the several emergencies. Although the opportunity for discussion existed, there was hardly any between the two pilots about the options available to them and the best course of action.

It is significant that neither crew member had received initial CRM training although both were scheduled to do so. It cannot be known what effect, if any, such training might have had on the crew's performance but there is no doubt that

the situation could have been better managed. One of the aims of CRM training is to bring an awareness of the need for teamwork and feedback during the handling of emergencies. Considerable emphasis is placed on the need for commanders to make the best use of resources including all the available advice and the vital need to maintain an overview of the problems without becoming immersed in the detailed handling of the situation. To this end the use of autopilots and interaction with other crew members is emphasised.

2.6 Aircraft systems

2.6.1 Engine re-start performance

Since their introduction, the Dart 530 engines have maintained a long record of successful re-starts in the air, if not on the first attempt, then almost always on the second. On this occasion the failed engines, which were thus unprotected from icing, remained in almost continuous conditions of icing down to ground level and therefore the intake airflow was most likely to be severely disturbed, or even choked, by snow or ice when the re-starts were attempted.

Other circumstances which may have prejudiced the success of the several attempts to re-start Nos 3 and 4 engines included the persistent icing conditions, incorrect airspeed, and 0% fuel trimmer settings.

When the first re-start was attempted on No 2 engine, amongst the other omissions from the checklist, there was no (spoken) action taken to reset the fuel trimmer to an appropriate setting, from the previous selection of 0% (fully weak). Assuming this action to have been forgotten during this drill, it was unlikely to have been remembered by the first officer during subsequent attempts when there was greater urgency and this is confirmed by the 0% position found in the wreckage.

2.6.2 Igniter units

Following an engine failure, a functioning ignition source is required for an air start. On Nos 2 and 3 engines at least one igniter, and on No 4 engine both igniters, were shown to be serviceable subject to an adequate electrical supply. In fact No 2 engine was eventually re-started. The evidence from No 3 engine suggested that the igniter in No 7 can position (outboard igniter unit) may well have been operating at impact. If the inboard unit on No 3 had not been operating because of the welded contact points this may have been caused by prolonged use

during the accident flight or the low supply voltage condition towards the end of the flight. On the CVR recording a pulsating 'fizzing' noise could be detected, caused by interference from the operating igniters. This slowed, became erratic and appeared to stop before the impact. Although this may conflict with the evidence of ignition found in No 3 engine, it is not known which igniters were causing the interference heard on the CVR, some may have been barely audible. Although there were deficiencies in the igniters as found it cannot be shown that igniter performance prejudiced the attempts to re-start the engines.

2.6.3 Fuel

Although all the prescribed checks were not carried out when the aircraft was refuelled prior to departure, evidence from the bowser and airfield tank records, from previous aircraft usage and from gauge indications after the crash shows that there was no significant discrepancy in fuel load at takeoff. The engine failure and re-start sequence and circumstances do not appear to be indicative of fuel starvation; there was no report of the crew seeing a low fuel pressure warning, No 2 engine was eventually re-started and run up to produce some thrust, and wreckage analysis indicated the presence of fuel at the engines at the time of the crash. Finally the evidence from fuel samples from the aircraft and from the supply also gives no indication that there was a problem with fuel quality.

2.6.4 Electrical system performance

Prior to the failure of No 2 engine the electrical systems load was assessed as 400 Amperes (A), this current being supplied by three generators each of which was normally rated at 375A; the No 1 engine generator was unavailable throughout the flight. The loss of No 2 engine should not have led to any change in the operation of the system since there was still adequate generating capacity, and no such effect was evident on the CVR. Post-accident testing of the No 4 generator, with a similar regulator, indicated that it should have been capable of instantly meeting the load (400A or more) with no drop in voltage. However, with the failure of No 3 engine a change in the operation of the electrical system was apparent from the short break in the CVR recording and the indication that two inverters, identified as the Emergency Inverter and a Main Busbar inverter, were running when the recording resumed.

It is apparent therefore that there was a temporary drop in Main Busbar voltage following the loss of No 3 engine sufficient to energise the EPAC relay and the

flashing LOW VOLTAGE lights would have illuminated briefly. The EPAC would then remain activated, unless the GEPS was switched to No 4, even when the Main Busbar voltage recovered from this temporary (and undiscovered) interruption and the low voltage indicator lights went out. The Main Busbar, supplied by No 4 generator, would remain separated from the essential services on the Emergency Busbars. The batteries would supply all the essential services, including those on Busbars 1A and 3A which would otherwise have been supplied by one of the emergency generators, and not just those on Busbar 2A.

If the crew had been aware of this brief indication then the correct procedure would have been to pull the gang bar down and select the GEPS to the No 4 engine generator. This would have provided generator power to Emergency Busbars 1A and 3A and battery power to 2A only. It would have also removed power from the Main Busbar disabling items such as the Main Inverter and leaving only the Emergency Inverter running. CVR evidence indicates that two inverters were running after the failure of No 3 engine. A comparison of Main Inverter and Emergency Inverter frequency traces following the failure of No 3 engine shows the Main Inverter to be stable but the Emergency Inverter showing a slight decay. This indicates that there was a decay in GEB voltage before No 4 engine failed. It is therefore concluded that the Main Busbar must have had an adequate and stable voltage supply from No 4 generator, and that the GEB must have been live and was being supplied from the batteries (not an emergency generator) whose output was already showing signs of deterioration some five minutes after No 3 engine had failed. With an otherwise intact system, for the GEB to be live on battery power, the GEPS could not have been selected to No 4 and the EPAC must have operated. The first officer has stated that he made no electrical selections and the situation described above confirms both that the gang bar was not pulled and that the GEPS was not selected to No 4.

Four 25 Ampere-hour (Ah) batteries were fitted to the aircraft which, taking into account incomplete charging effects and battery ageing, could be assumed to have a combined capacity of 80Ah at a nominal discharge rate of 25A per battery. From an estimate of the applicable electrical loads, after the operation of the EPAC relay the batteries would have been supplying 150A to the GEB and No 2A Emergency Busbar and the No 4 generator would have been supplying 250A to the Main Busbar. At this high discharge rate the batteries should have been able to supply 150A for periods of 28 minutes, however, it was apparent from the CVR recording that the GEB voltage (supplied by the batteries) had started to decay only five minutes after the loss of the No 3 engine. No reason

for such a rapid decrease in battery supply could be identified. A fused lead from one of the batteries was found but the circumstances in which it had failed and suffered electrical arcing could not be identified.

Since only one inverter was running before the engine failures, it is evident that the GEPS had previously been selected to 'OFF' and the GEB was initially unpowered. Furthermore, if the GEPS had been pre-selected to either emergency generator then the EPAC would have been disabled.

Following the subsequent failure of No 4 engine the batteries would have remained connected to the GEB and No 2A Busbar. Post-accident testing indicated that the GEB voltage was 18V at this stage and reduced gradually to 12V at impact, causing the radios, intercom, flight deck and instrument lighting and other emergency services to fail. Following the reinstatement of the No 2 engine at 1938 hrs, the CVR shows that the Main Busbar inverter and other Main Busbar services, such as the landing lights, were working. This was to be expected as, without the activation of the gang bar, the No 2 generator would have remained connected to the Main Busbar, powering it in place of No 4 generator but separated from the essential services on the Emergency Busbars.

If the procedure of pulling down the gang bar and selecting the GEPS to No 4 generator had been followed after the failure of No 3 engine then, depending on the nature of the fault which affected the battery supply, the electrical supply may have been protected up to the time that No 4 engine failed. Thereafter, when the indications of electrical problems were more evident to the crew, this action would have been ineffective as the EPAC relay had already operated and no emergency generator was then available. Given that the EPAC relay had not been de-energised through the normal procedure of selecting the emergency generator through the GEPS, it was not then possible to reconnect the Main Busbar and its live generator (No 2) to the Battery Busbar and the essential services by the normal procedure (PMS to 'ON').

2.7 Summary

Many factors contributed to the accident putting the aircraft and crew ultimately into an irretrievable situation.

Two consecutive engine failures (No 2 and 3) deprived the aircraft of any airframe de-icing. A third (No 4) then failed but shortly afterwards No 2 engine

was successfully re-started and this should then have enabled the aircraft to maintain height and continue the flight.

This sequence of emergencies with their attendant consequences was demanding enough of any crew. The situation required clear thinking and decisive action if an accident was to be avoided. In fact the deteriorating situation escaped this particular crew and they never successfully caught up with it. The lack of a contingency plan for the avoidance of the forecast severe icing conditions, the decision to descend immediately following the first engine failure, the early decision to divert to Birmingham and the lack of a decision to change to the nearer diversion of East Midlands, all contributed to the deterioration of the situation. Without reference to the Emergency Checklist, there were important omissions of emergency selections of the electrical system; the airframe de-icing system; the fuel trimmers; and, possibly, the propeller feathering. All of these omissions and their consequences might have been avoided if the principles of CRM had been applied to decision making, monitoring and workload sharing.

The seriousness of the emergencies facing this crew is not underestimated, comprising a rapidly worsening situation at night, in IMC, in severe icing and turbulence, in an aircraft which was heavily contaminated by ice or snow and with engines failing sporadically. It is therefore perhaps understandable that the emergencies were not handled as they might have been for example, on a LOFT exercise in the simulator. Nevertheless, it is commendable that, despite the deterioration of the essential electrical system, especially the flight deck lighting and the crew intercommunications, and the fact that the commander had lost directional control of the aircraft, the first officer had the presence of mind to transmit two 'MAYDAY' messages whilst continuing attempted engine re-starts.

The most significant factor in this accident was the encounter with severe icing conditions. It has been suggested by some in the UK aviation industry that lessons learned during the era when transport aircraft were predominately propeller driven have been diluted with the present day predominance of jet engine aircraft which spend less time at levels where severe icing is likely. This view ignores the considerable number of turboprop and piston aircraft which have operated throughout this period. The more likely explanation is that encounters with extreme icing conditions are comparatively rare events such that prudent avoidance is only necessary infrequently and that successful avoidance is the result of good airmanship.

Despite the long and successful history of operations world-wide, Viscount aircraft and their Rolls-Royce Dart engines have, as have many other turboprop aircraft, a limit to the quantity of ice contamination which the engines can ingest without failing, even though complying with the requirements of BCARs. Although they are infrequent, some meteorological conditions can apparently produce a level of ice accretion greater than that which engines can tolerate and, although the meteorologists have difficulty in identifying these exact conditions, they are able to warn aircrew of most conditions which are certain to cause ice accretion.

3

Conclusions

a) Findings

- (i) Both crew members were medically fit and properly licensed to carry out the flight.
- (ii) The aircraft certification and maintenance documentation was current but the FDR routine readout had not been performed within the prescribed period.
- (iii) The despatch of the aircraft with No 1 engine generator inoperative was allowable in accordance with the Operations Manual and the deficiency would have had no effect on the normal operation of the aircraft since adequate electrical power was available from any one generator.
- (iv) The aircraft was correctly loaded and carried sufficient fuel for the flight.
- (v) The weather radar was serviceable but not in operation throughout the flight. This was a serious and surprising omission from the effective operation of the aircraft and, had it been in use, it might have been possible to avoid the more severe weather conditions encountered.
- (vi) The Nos 2, 3 and 4 engines failed during the descent due to unusually severe meteorological conditions resulting in excessive ice accretion in the area of the engine air intakes. For a considerable period the aircraft was experiencing conditions which exceeded the BCAR for icing conditions which applied originally to the Dart inlet icing protection system.
- (vii) The sequence of emergencies with their attendant consequences was highly demanding. The situation required clear thinking and decisive action if an accident was to be avoided.
- (viii) Although scheduled by the company, neither crew member had received any CRM training and the poor quality of flight deck management evident during the flight contributed significantly to the developing severity of the emergency.
- (ix) The operator's Emergency Checklist was not consulted during the entire process of the multiple emergencies.

- (x) The operator's Emergency Checklist was inadequate in its presentation and ease of use under conditions of stress.
- (xi) The commander did not select a diversion which was closest to the point at which the emergency developed (Manchester) or closest to which the aircraft subsequently passed (East Midlands). Had he done so, the chances of landing the aircraft safely at an airport would have been much increased.
- (xii) When declaring the emergency, use of incorrect RT procedure did not ensure the maximum and most effective response from ATC who, in turn, chose not to provide the crew with range information to the closest diversion airfield.
- (xiii) The difficulty in re-starting the engines during the continuous descent in severe icing conditions was almost certainly influenced by a considerable build-up of ice or snow on and in the intakes.
- (xiv) The probability of immediate or subsequent engine re-starts was prejudiced by the fuel trimmers remaining set to zero, maintenance of an airspeed outside the recommended envelope and diminishing electrical power.
- (xv) Some five minutes after No 3 engine had failed the Main Busbar had an adequate and stable voltage supply from No 4 generator. The GEB and essential services were being supplied from the batteries whose output was already showing signs of deterioration.
- (xvi) Although a single generator (No 2) was working during the final minutes of the flight, its power was not directed to the essential services because the emergency procedure for the electrical system had not been properly followed.
- (xvii) The intercom system and flight deck lighting and other electrical services failed some four minutes before impact. This was a result of the rapid decay in battery power for which no complete explanation was found.
- (xviii) Although there were deficiencies in the igniters as found it has not been established that igniter performance prejudiced attempts to re-start the engines.

- (xix) The omission from the operator's emergency drills of correct fuel trimmer and propeller-synchroniser selections resulted in a significant reduction of otherwise available power from the two live engines (Nos 1 and 2).
- (xx) The incorrect handling of the airframe de-icing system resulted in a considerable accretion of ice or snow during the descent.
- (xxi) The inability to maintain height was the result of ice or snow on the wings and airframe, drag from the windmilling propellers and the limitation of the available power as a result of (xix) above.
- (xxii) The loss of directional control was caused by a reduction of the airspeed to the point where the authority of the (ice or snow contaminated) vertical stabiliser was less than that needed to overcome the drag from the two unfeathered propellers. Asymmetric contamination of the wings, with the left side receiving most of the hot air from No 2 engine may have also contributed.
- (xxiii) The supervisory and regulatory function of the assigned FOIs did not identify, report and call for correction of the several deficiencies in the company's operating procedures which were subsequently identified by the IDA conducted after the accident.

3(b)

Causes

The following causal factors were identified:

- (i) Multiple engine failures occurred as a result of flight in extreme icing conditions.
- (ii) Incomplete performance of the emergency drills by the crew, as a result of not referring to the Emergency Checklist, prejudiced the chances of successful engine re-starts.
- (iii) Crew actions for securing and re-starting the failed engines, which were not in accordance with the operator's procedures, limited the power available. The drag from two unfeathered propellers of the failed engines and the weight of the heavily iced airframe resulted in a loss of height and control before the chosen diversion airfield could be reached.
- (iv) Poor Crew Resource Management reduced the potential for emergency planning, decision making and workload sharing. Consequently, the crew had no contingency plan for the avoidance of the forecast severe icing conditions, and also was unaware of the relative position of a closer diversion airfield which could have been chosen by making more effective use of air traffic services.

4. Safety Recommendations

It is recommended that:

- 4.1 The CAA should consider further reminding pilots and operators about the correct meaning and use of the 'Distress message'. The correct use of pro-words together with information about what actions will be taken by ATS on receipt of a distress message should be covered. The fact that the message can be easily cancelled, if the situation of the aircraft improves, should also be emphasised. [Safety Recommendation 94-22 - made March 1994]
- 4.2 The CAA should commission research into the most effective form of presentation of emergency reference material which may be required on a flight deck. This should include both manual Checklists and electronic screen displays. Suitable advice from human factor specialists should be included in guidance material to be promulgated in a publication such as CAP 360. [Safety Recommendation 94-40]

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