AIRCRAFT ACCIDENT REPORT 2/96

Air Accidents Investigation Branch

Department of Transport

Report on the accident to EMB-110 Bandeirante, G-OEAA at Dunkeswick, North Yorkshire on 24 May 1995

This investigation was carried out in accordance with *The Civil Aviation (Investigation of Air Accidents) Regulations 1989*

London: HMSO

First published 1996

ISBN 0 11 551845 2

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Department of Transport
Air Accidents Investigation Branch
Defence Research Agency
Farnborough
Hampshire GU14 6TD

31 May 1996

The Right Honourable Sir George Young
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 EMB-110 Bandeirante, G-OEAA, at Dunkeswick, North Yorkshire on 24 May 1995.

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 Accident Investigation Branch
AC	Alternating Current
ADF	Automatic Direction Finder
agl	above ground level
AH	Artificial Horizon
AIC	Aeronautical Information Circular
amsl	above mean sea level
ANO	Air Navigation Order
AOC	Air Operator's Certificate
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
BCAR	British Civil Airworthiness Requirements
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
C of A	Certificate of Airworthiness
C of M	Certificate of Maintenance
CPL	Commercial Pilot's Licence
CRM	Crew Resource Management
CT	Control Transformers
CVR	Cockpit Voice Recorder
CWS	Caution and Warning System
DA	Design Authority
DC	Direct Current
DRA	Defence Research Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDR	Flight Data Recorder
GCU	Generator Control Unit
GFT	General Flying Test
HSI	Horizontal Situation Indicator
ICAO	International Civil Aviation Organisation
IMC	Instrument Meteorological Conditions
IR	Instrument Rating
JAR	Joint Airworthiness Requirements
LATCC	London Air Traffic Control Centre
LOFT	Line Oriented Flying Training
MAP	Multiple Alarm Panel
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
MTBUR	Mean Time Between Unscheduled Removal
OM	Operations Manual
PNI	Pictorial Navigation Indicator
QNH	Altimeter setting for height above mean sea level
RMI	Radio Magnetic Indicator
RT	Radio Telephony
RVR	Runway Visual Range
SARP	Standards and Recommended Practices
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF omnidirectional radio range
UTC	Universal Time Coordinates

EMB-110 Bandeirante, G-OEAA Instrument Panel

Air Accidents Investigation Branch

Aircraft Accident Report No: 2/96 (EW/C95/5/6)

Operator:	Lambson Aviation Limited [trading as Knight Air Limited]
Aircraft Type and Model:	Embraer Bandeirante EMB-110 P1
Nationality	United Kingdom
Registration	G-OEAA
Registered owner:	Euroair Transport Limited
Place of accident	Dunkeswick Moor, six miles north-east of Leeds Bradford International Airport, North Yorkshire Latitude: 53° 55' North Longitude: 001° 31' West Elevation: 131 feet
Date and Time	24 May 1995 at 1651 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 included:

Mr R StJ Whidborne (Investigator in charge)
Mr B M E Forward (Operations)
Mr D S Miller (Operations)
Mr P F Sheppard (Flight Recorders)
Ms A Evans (Flight Recorders)
Mr A N Cable (Engineering)
Mr R D G Carter (Engineering)
Mr S R Culling (Engineering)
Mr S W Moss (Engineering)

Under the provisions of Annex 13 to the Convention on International Civil Aviation, (Chicago 1944) an Accredited Representative of Brazil (State of Manufacture), advised by representatives of the manufacturer, participated in the investigation. Technical assistance was provided by the manufacturer and maintenance organisations associated with the artificial horizons [1].

[1] Also referred to in the Air Navigation Order as 'Gyroscopic Pitch and Bank Indicator System' and in US nomenclature as 'Attitude Indicators'. The term Artificial Horizon (AH) is used throughout this report except where quoting from regulations.

Shortly after departure from Leeds Bradford Airport on a scheduled flight to Aberdeen, the crew of the aircraft reported a 'problem with the artificial horizon(s)' and arranged to return to the airport. The weather was poor with a low cloud base, precipitation and recent thunderstorm activity. Air Traffic Control (ATC) observed the aircraft on their radar as it climbed to an altitude of 3,600 feet turning continuously left apart from an abrupt right turn while passing 1,700 feet. Despite these turns the crew twice sought confirmation from ATC that the aircraft was 'going straight'. Shortly after reaching 3,600 feet the aircraft entered a steeply descending spiral dive. Due to an airspeed in excess of the design maximum, the aircraft began to break-up, with the wing failing outboard of the right hand engine, tailplane failure, disruption of the fuselage and the early stages of a fuel fed fire. It crashed onto open ground and all of the occupants were killed.

The aircraft had not been struck by lightning, had not experienced total electrical failure and, apart from the artificial horizon(s), there was no other pre-impact airworthiness problem. Malfunction of one or both artificial horizons was a possibility in view of a history of low mean time between unscheduled removal of the instruments which some UK based operators of the Bandeirante had experienced. Continued flight in Instrument Meteorological Conditions (IMC) should have been possible by reference to alternative flight instruments but this would have been highly demanding of the pilots' skills in the prevailing conditions, which included the meteorological affects of recent and adjacent thunderstorm activity.

The following causal factors were identified:

i) One or, possibly, both of the aircraft's artificial horizons malfunctioned and, in the absence of a standby horizon, for which there was no airworthiness requirement, there was no single instrument available for assured attitude reference or simple means of determining which flight instruments had failed.

ii) The commander, who was probably the handling pilot, was initially unable to maintain control of the desired aircraft heading without his artificial horizon, and eventually lost control of the aircraft whilst flying in IMC by reference to other flight instruments.

iii) The aircraft went out of control whilst flying in turbulent instrument meteorological conditions and entered a spiral dive from which the pilot, who most likely had become spatially disoriented, was unable to recover.

Four safety recommendations have been made.

1 Factual Information

1.1 History of the flight

On the morning of 24 May 1995 the aircraft had returned to its base at Leeds Bradford from Aberdeen on a scheduled passenger flight landing at 0844 hrs. The crew, which was not the one later involved in the accident, stated that all of the aircraft's systems and equipment had been serviceable during the flight and, after flight, the aircraft technical log was completed to this effect. Some routine maintenance was performed on the aircraft which was later prepared for a scheduled passenger flight to Aberdeen. It was positioned at the passenger terminal where it was taken over by the crew which was to operate the service, comprising the commander, who occupied the left hand seat, the first officer and a flight attendant. Nine passengers were boarded but, as no seats were specified on the boarding passes, it could not be determined which seats they occupied.

The weather at Leeds Bradford Airport was poor with Runway Visual Range (RVR) reported as 1,100 metres; scattered cloud at 400 feet above the aerodrome elevation of 682 feet and a light south-easterly wind. It was raining and the airfield had recently been affected by a thunderstorm. The freezing level was at 8,000 feet and warnings of strong winds and thunderstorms were in force for the Leeds Bradford area.

The crew called ATC for permission to start the engines at 1641 hrs. Having backtracked the runway to line up, the aircraft took-off from Runway 14 at 1647 hrs and the crew was instructed by ATC to maintain the runway heading (143°M). Radar returns, displayed in the control room, indicated that the aircraft began to turn to the left shortly after becoming airborne. One minute and fifty seconds after the start of the take-off roll and as the aircraft was turning through a heading of 050° and climbing through 1,740 feet amsl, the first officer transmitted to Leeds Bradford aerodrome control: "KNIGHTWAY 816[2] WE'VE GOT A PROBLEM WITH THE ARTIFICIAL HORIZON SIR AND WE'D LIKE TO COME BACK." The aerodrome controller passed instructions for a radar heading of 360° and cleared the aircraft to 3,000 feet QNH[3]. These instructions were read back correctly but the aircraft continued its left turn onto 300° before rolling into a right hand turn with about 30° of bank. About 20 seconds before this turn reversal, the aircraft had been instructed to call the Leeds Bradford approach controller.

The aircraft was now climbing through an altitude of 2,800 feet in a steep turn to the right and the approach controller transmitted: "I SEE YOU CARRYING OUT AN ORBIT JUST TELL ME WHAT I CAN DO TO HELP". The first officer replied: "ARE WE GOING STRAIGHT AT THE MOMENT SIR" The controller informed him that the

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2 Knight Air Limited's RT designator and flight number.
3 An altimeter pressure setting to give height above mean sea level.

aircraft was at that time in a right hand turn but after observing further radar returns he said that it was then going straight on a south-easterly heading. The first officer's response to this transmission was: "RADAR VECTORS SLOWLY BACK TO ONE FOUR THEN SIR PLEASE".

The controller then ordered a right turn onto a heading of 340°. This instruction was correctly acknowledged by the first officer but the aircraft began a left hand turn with an initial angle of bank between 30° and 40°. This turn continued onto a heading of 360° when the first officer again asked "ARE WE GOING STRAIGHT AT THE MOMENT SIR" to which the controller replied that the aircraft looked to be going straight. Seconds later the first officer asked: "ANY REPORT OF THE TOPS SIR". This was the last recorded transmission from the aircraft, although at 1652 hrs a brief carrier wave signal was recorded but it was obliterated by the controller's request to another departing aircraft to see if its pilot could help with information on the cloud tops.

At this point, the aircraft had reached an altitude of 3,600 feet, having maintained a fairly constant rate of climb and airspeed. The ATC clearance to 3000 feet had not been amended. After the controller had confirmed that the aircraft appeared to be on a steady northerly heading, the aircraft immediately resumed its turn to the left and began to descend. The angle of bank increased to about 45° while the altitude reduced to 2,900 feet in about 25 seconds. As the aircraft passed a heading of 230° it ceased to appear on the secondary radar. There were four further primary radar returns before the aircraft finally disappeared from radar. The aircraft's track and height plot, together with ATC instructions, is shown by diagram in Appendix A.

There had been a recent thunderstorm in the area and it was raining intermittently with a cloud base of about 400 feet and a visibility of about 1,100 metres. Residents in the vicinity of the accident site reported dark and stormy conditions. Several witnesses described the engine noise as pulsating or surging and then fading just prior to impact. Other witnesses saw a fireball descending rapidly out of the low cloud base and one witness saw the aircraft in flames before it stuck the ground. All of the occupants died at impact. From subsequent examination it was apparent that, at a late stage in the descent, the aircraft had broken up, losing a large part of the right wing outboard of the engine, and the right horizontal stabiliser. There was some disruption of the fuselage before it struck the ground.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	3	9	-
Serious	-	-	-
Minor/None	-	-	

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other Damage

The aircraft crashed into a field of standing cereal crop, part of which was subsequently destroyed having been condemned as unfit for harvesting.

1.5 Personnel information

1.5.1

Commander:	Male, aged 49 years	
Licence:	Airline Transport Pilot's Licence (ATPL) Valid to 20 November 2004	
Aircraft ratings:	EMB-110	
Instrument Rating:	Valid to 15 August 1995	
Base Check:	Valid to 17 October 1995	
Line Check:	Valid to 20 May 1996	
Medical Certificate:	Class One issued on 30 March 1995 Valid to 30 September 1995	
Flying experience:	Total flying:	3,257 hours
	On type:	1,026 hours
	Last 90 days:	157 hours
	Last 28 days:	36 hours
	Last 24 hours:	2 hours
	Previous rest period:	19 hours

Crew Resource Management (CRM) training had been completed on 15 October 1994.

1.5.1.1 Operational experience

The commander began his flying career 1972 at Sherburn in Elmet airfield and obtained a Private Pilot's Licence (PPL) in August of that year at the age of 26 years. He added an IMC Rating in November 1976 and by January 1980 had qualified as an Assistant Flying Instructor on Group 'A' (single engined) aeroplanes. He qualified for a night rating in February 1988. An initial Instrument Rating (IR), (including a General Flying Test (GFT) with a section on flight by reference to 'limited panel'), was issued on 12 February 1992. A Commercial Pilot's Licence (CPL) was issued on 28 January 1991 and upgraded to an ATPL on 21 November 1994.

The commander had been a light aircraft instructor at Barton airfield from at least July 1987 until April 1993 when he converted to the EMB-110. By June 1993 he had qualified as a first officer on the EMB-110 and was employed by the operator. He began command training in December 1994 and, after a short leave break, completed the training in February 1995. He remained as a first officer, awaiting a command vacancy, until 18 April 1995. A final command line check was successfully completed on 21 April 1995 whereupon he flew as commander of EMB-110s. Thereafter, his crew included the first officer, whose details are set out in the next paragraph, on three separate occasions before the accident flight (10, 18 and 19 May 1995).

1.5.2	First officer:	Male, aged 29 years	
	Licence:	Commercial Pilot's Licence Valid to 24 November 2004	
	Aircraft ratings:	EMB-110	
	Instrument Rating:	Valid to 27 May 1996	
	Base Check:	Valid to 27 October 1995 (Initial)	
	Line Check:	Valid to 4 June 1996 (Initial)	
	Medical Certificate:	Class One issued 18 October 1994 Valid to 31 October 1995	
	Flying experience:	Total flying:	302 hours
		On type:	46 hours
		Last 90 days:	46 hours
		Last 28 days:	46 hours
		Last 24 hours:	1 hours
		Previous rest period:	19:25 hours

In accordance with the training Manual, CRM training was scheduled to be given after completion of his second routine Base Check.

1.5.2.1 Operational experience

The first officer had learned to fly at Sherburn in Elmet, Yorkshire and obtained a PPL on 18 July 1992. In April 1993 he completed an IMC rating course; this included 'limited panel' training.

He qualified for a Basic CPL in July 1994, after the requisite training had been carried out at Oxford, and upgraded to a 'frozen ATPL'[4] on 8 November 1994 having completed further training at a flying college at Prestwick. An initial IR was issued on 4 November 1994. On 18 April 1995, the first officer began training on the EMB-110, completing a final line check on 4 May 1995 and flying as a first officer with the operator.

1.5.3 Training and testing

1.5.3.1 Instruments ratings and IMC ratings

The requirements for professional pilots' IR are set out in Civil Aviation Publication 54 (CAP 54). The flight test syllabus does not include 'limited panel' instrument flying. This ability is tested once only during the initial GFT for a CPL or ATPL.

Private pilots may be issued with an IMC rating (described in CAP 53 and which is considerably more limited in its provisions than an IR) having passed a flight test which includes:

> '(b) Limited Panel Instrument Flying
>
> i.e. assuming failure of the gyroscopic pitch and bank indicator and gyroscopic direction indicators: Straight and level flight, climbing and descending, turns onto given headings, recovery from unusual attitudes.'

The privileges of an IMC rating may not be exercised unless the rating contains a valid Certificate of Test (C of T). The period of validity of the C of T is 25 months from the date of the last satisfactory test. The flight test required after initial qualification for the purpose of revalidating the rating will include item (b) above.

1.5.3.2 Recovery from Unusual and Extreme Attitudes using Limited Panel Technique

Air Publication 3456 is the Basic Flying Handbook of the RAF. Part 2 Section 2 Chapter 9 deals with Instrument Flying. Whilst a Service publication, and not necessarily available within civil aviation, paragraph 47 contains the following comprehensive description of Limited Panel Technique:

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4 'Frozen' ATPL means that all the ground examinations have been passed and issue of an ATPL merely awaits accumulation of the required amount of flying experience.

'With an unserviceable artificial horizon, the turn needle is used as the master indication of bank to level the wings. However, before the turn needle can be relied upon, it is necessary to remove any 'g' force which will cause it to over-read unduly. This 'g' force should invariably be reduced using the body muscle sense as a yardstick, since to extend the scan to an accelerometer might require a head movement and thus increase the risk of disorientation. On propeller-driven aircraft it will be necessary to reduce any extreme unbalance by centralizing the slip ball. However, time should not be wasted obtaining accurate balance; once any excessive 'g' force has been removed and the aircraft is roughly in balance, a positive aileron movement should be made to centre the turn needle. This corrective roll should be checked before the turn needle is actually centred, the amount of anticipation required varying with air speed and rate of roll.

The third stage of the recovery should be made using the information displayed on the altimeter - the only instrument which indicates level flight accurately and almost instantaneously throughout the entire speed range. Positive elevator should be applied against altimeter movement, ensuring that the ailerons are kept neutral. The control deflection should be maintained until the altimeter slows almost to a standstill, then a check movement made to hold a constant pitch attitude. The aircraft will then be in an approximate straight and level attitude; the power can then be adjusted, and all the instruments interrogated to achieve accurate flight and to assess their serviceability, including re-erection of the artificial horizon.'

1.5.3.3 Flight simulator training

In a report on an accident involving a BAe Jetstream 32 aircraft in October 1992 in which the aircraft crashed shortly after take-off following a simulated single engine failure, the AAIB recommended that the CAA should positively encourage the development and use of flight simulators. The CAA responded that 'The Authority.....will continue to positively encourage the development and use of flight simulation in all areas where the actual aircraft can be replaced by a realistic simulator. This will be regardless of the aircraft's Performance Classification.'[5]

There was no suitable full flight simulator in the UK for EMB-110 pilot training. Because the high cost of full flight simulator training outweighs the relative economic operating cost of using the actual aircraft, this is a normal situation for this type of aircraft which is operated in limited numbers in the public transport role.

1.5.3.4 Crew Resource Management

Since January 1995 the CAA has required all pilots flying for the purposes of public transport to have attended a course on Crew Resource Management (CRM). CRM training is described as a natural development from the Human Factors Flight Crew Licence examinations introduced by the CAA's Flight Crew Licensing Department.

5 AAIB Bulletin 11/93 and CAA FACTOR F3/94

Aeronautical Information Circular (AIC) 143/1993, issued on 23 September 1993 includes the following definitions relating to CRM courses:

'3.2 Crew Resource Management Training is **not**:

a quick fix that can be implemented overnight;

a training programme administered to only a few specialised cases;

a scheme that occurs independently of other on-going training activities;

a scheme where crews are given a specific prescription on how to work with others on the flight deck;

another form of individually centred crew training;

a passive-lecture classroom course;

an attempt by management to dictate cockpit behaviour or to expose individual's weaknesses

GOOD CRM REQUIRES AN APPRECIATION OF HUMAN FACTORS

3.3 Crew Resource Management Training **is**:

a comprehensive scheme for improving crew performance;

a scheme that addresses the entire crew population;

a scheme that can be extended to all forms of crew training;

a scheme that concentrates on crew members' attitudes, and their behaviour and their impact on safety;

an opportunity for individuals to examine their behaviour and make individual decisions on how to improve teamwork, within the aircraft and with outside agencies;

a scheme that uses the crew as a unit of training.'

1.5.3.5 Aetiology of spatial disorientation in flight

Spatial disorientation is described in Aviation Medicine (2nd edition)[6]. The following edited extract highlights its relevance to this particular accident:

'Pilots have described many different types of spatial disorientation that occur in different flight conditions. Not surprisingly, the mechanism underlying the disordered perceptions is commensurately varied. It is convenient to discuss aetiology under two main headings, even though they are not mutually exclusive: (1) when erroneous or inadequate sensory information is transmitted to the brain (an input error); and (2) when there is an erroneous or inadequate perception of correct sensory information by the brain (a central error).

6 Aviation Medicine 2nd Edition. Air Cdre J Ernsting and AVM P King (eds) , London 1988

Input error

External visual cues

Disorientation is very uncommon when the pilot has well-defined external visual cues; but when he attempts to fly when sight of the horizon is degraded by cloud, fog, snow, rain, smoke, dust or darkness he quickly becomes disorientated unless he transfers his attention to the aircraft instruments. The ability to maintain control of an aircraft without adequate visual cues is quite short, typically about 60 seconds, even when the aircraft is in straight and level flight at the time vision is lost, and shorter still if the aircraft is in a turn. In such circumstances, loss of control occurs because the non-visual receptors give either inadequate or erroneous information about the position, attitude and motion of the aircraft.'

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer:	Empresa Brasileira De Aeronautica SA
Aircraft type:	EMB-110P1
Constructor's serial number:	110-256
Date of manufacture:	1980
Engines:	2 Pratt & Whitney PT-6A-34 Turboprops
Certificate of Airworthiness:	UK Transport Category (Passenger) First issued 2 April 1980 Expiry 19 April 1996
Certificate of Maintenance Review:	Expiry 4 September 1995
Certificate of Release to Service:	Valid to 15,377 hours (includes agreed 60 hour extension)
Total airframe hours at accident:	15,348

1.6.2 Weight and balance

Maximum permitted Take-off Weight:	5,700 kg
Zero Fuel Weight:	4,711 kg
Fuel load (less 30 kg for Start / Taxi):	696 kg
Actual Take-off Weight:	5,407 kg

1.6.3 Loading

The Load Sheet was signed by the commander at 1634 hrs on 24 May 1995. The aircraft had been refuelled to a total load of 726 kg (1,600 lbs). This had been erroneously entered in the load sheet as 272 kg which figure was in fact the sector fuel (Leeds to Aberdeen) of 272 kg (600 lbs). The calculated take-off weight entered on the form was therefore some 454 kg (998 lbs) less than it was in reality. If the correct figure had been calculated (5,407 kg as shown above) the weight would still have been within the permitted weight limit and centre of gravity range, being approximately 22% of the Mean Aerodynamic Chord.

1.6.4 Certification

The basis of the UK certification was that the aircraft had been certificated to Brazilian requirements and such UK Special Conditions as the CAA derived from their evaluation of the aircraft during May 1977. The basis of the Brazilian certification of the EMB-110P was Federal Aviation Regulation (FAR) Part 23 up to amendment 23-7. The standard of UK requirements used during the CAA evaluation were those which would have been applied had the aircraft been offered for certification in the UK and included BCAR Section K (Light Aircraft) to issue 5.

1.6.5 Aircraft history and maintenance records

The operator had maintained G-OEAA since 1993 and had first used it on a scheduled flight on 31 January 1994. Prior to that the aircraft had been operated by several companies and had been maintained by many different maintenance organisations.

The aircraft records contained no deferred defects relevant to the accident and, prior to the accident flight, the aircraft had undergone the inspection phase of a routine servicing package called up on an opportunity basis from the scheduled servicing cycle.

1.6.6 Aircraft electrical system

In the EMB-110, electrical power is supplied by a 28V DC electrical system and, in addition, there are 115V and 28V AC systems supplied by static inverters.

During normal operation the 28V DC system is powered by two DC generators, one driven by each of the aircraft engines; either generator is capable of powering the aircraft's electrical system alone and they also act as DC starter motors for the aircraft engines. If both of the DC generators are inoperative, and there is no external power supply attached, the DC system is powered by a 24V battery.

The supply of each generator to the 28V DC main bus bar is controlled by a generator control unit (GCU) and the majority of the aircraft's electrical services are supplied from this bus bar. The Emergency bus bar is normally supplied by the 28V DC main bus bar but, with cockpit selection of Emergency electrical power, the Emergency bus bar is disconnected from the 28V DC main bus bar and is supplied solely by the battery.

The distribution bus bars of the AC electrical system, both 115V AC and 26V AC, are supplied by two static inverters (No 1 and No 2) which are connected to the 28V DC main bus bar. Supply is normally by the No 1 inverter but the No 2 inverter will supply the distribution bus bars if the No 1 inverter becomes disconnected or faulty.

1.6.7 Flight and navigation instruments

In EMB-110 aircraft, the group of flight instruments in front of each pilot position is conventional and consists of an airspeed indicator, altimeter, vertical speed indicator, artificial horizon, 'turn and slip' indicator and a Pictorial Navigation Indicator (PNI), which includes gyro magnetic compass information. In addition, further navigation information is available on a Radio Magnetic Indicator (RMI) with Automatic Direction Finding (ADF) and VHF Omni-directional Receiver (VOR) displays and a standby compass.

Of the principal flight and navigation instruments, the airspeed indicators, altimeters and vertical speed indicators are simple and conventional, working directly from airframe pitot and static pressure sources. The altimeters' altitude encoding operation and the secondary radar transponders, which use the altimeter information, are supplied by the 28V DC main bus bar. Both 'turn and slip' indicators are supplied from the 28V DC main bus bar, as are the PNI and the artificial horizon on the first officer's instrument panel.

On the commander's instrument panel, both the PNI and the artificial horizon are supplied from the 28V DC Emergency bus bar. In the case of the artificial horizon, this DC supply is converted to 115V AC by a dedicated inverter mounted close to the instrument.

1.6.8 Artificial horizons

The two artificial horizons in EMB-110 aircraft are of the generic type found in turboprop aircraft of this weight category and are similar to the pneumatically-driven instruments found in light aircraft. The artificial horizons in G-OEAA had been manufactured by AIM (Aircraft Instrument Manufacturing) in 1979 (commander's) and 1980 (first officer's) respectively as part of their '500 Series Horizon Reference Indicator' product line applicable to a range of aircraft models.

The gyroscope rotor in these instruments is an AC synchronous motor, operating from a 115V AC 400Hz three-phase supply. In the case of the commander's artificial horizon this supply is from a dedicated PC-50 power inverter, powered from the 28V DC Emergency bus bar; in the case of the first officer's artificial horizon the supply is from an inverter contained within the instrument case and the instrument is powered by the 28V DC main bus bar. Another difference is that the commander's instrument includes transformer pick-offs for the autopilot. In G-OEAA the auto pilot originally fitted had been removed. There was no airworthiness requirement for one to be fitted to UK registered EMB-110 aircraft.

In both types of instrument, the only direct indication of instrument malfunction is a solenoid-operated failure flag which appears on the face of the instrument when insufficient voltage is being supplied to the rotor.

Appendix B shows a generic diagram of the AIM 500-series artificial horizon, with the autopilot pick-offs, as found in the commander's instrument, but without the internal inverter contained within first officer's instrument. The 115V AC 400Hz synchronous motor is contained within the rotor assembly and generally operates in the range of 22,000 to 23,000 RPM. The rotor assembly is self-erecting by a system of pendulous vanes, through which airjets from small impellers in the motor could be directed, and is suspended in bearings mounted in the gimbal assembly. The rotor assembly is allowed ± 85° freedom in pitch, guarded from 'gimbal lock' by a stop screw and gimbal stop. The gimbal assembly itself is suspended from bearings in the rear of the instrument so that the whole assembly has complete freedom about the instrument's longitudinal axis.

Display of the aircraft's attitude is derived from the gimbal assembly which is mechanically linked to a small moveable horizon 'mask', the upper half of which is painted to represent the sky and the lower half black to represent the ground. In front of the moveable horizon mask is a fixed symbol of an aeroplane and it is the relative displacement between this fixed symbol and the moveable horizon mask that depicts the aircraft's angular displacement in roll and pitch. In addition, a dial ring moving past a small pointer shows the degree of bank.

1.6.9 Turn-bank indicators

The two turn-bank indicators in the EMB-110 are of the generic type often referred to as 'turn-and-slip' indicators. This type of indicator contains two independent mechanisms. A simple ball in a liquid filled tube indicates the degree of co-ordination (or 'slip') between the aircraft's rate of turn and angle of bank and a gyroscopic-controlled pointer shows the aircraft's rate of turn.

The pointer is driven by a 'rate gyroscope' which acts about a single-axis. This 'precession' (or 'output') axis of the gyroscope is the same as the longitudinal axis of the instrument and thus of the aircraft. The precession forces from the aircraft's turn are balanced by a restraining spring which, with no precession force, is centred and indicates no turn. It is the resulting displacement of this restraining spring which controls the pointer which moves against a simple scale showing rate of turn. Because it is centred by a spring, the mechanism needs no erecting device or correction from random precession. It is, therefore, unnecessary for the rotor to rotate at high speed and variations in the rotation speed only result in changes in the degree of pointer deflection from the centre, not the sense of the turn.

A feature of these instruments is the simplicity of design and operation. From this simplicity comes an inherent degree of mechanical reliability distinctly higher than that which may be achieved with an equivalent standard of artificial horizon.

1.6.10 Warning systems

The warning systems of EMB-110 aircraft includes a Multiple Alarm System, analogous to the Caution and Warning Systems (CWS) found in similar aircraft. The system is designed to warn the crew of malfunctions occurring in the systems most critical to safe flight.

The Multiple Alarm Panel (MAP) is mounted on the instrument panel and consists of 14 indicator captions, each light having two bulbs. The captions are as follows:

FUEL	FUEL
OIL	OIL
HYDRAULIC	LANDING GEAR
GENERATOR 1	GENERATOR 2
INVERTER 1	INVERTER 2
26 VOLTS AC	CIRCUIT BREAKER
OXYGEN	HYDR FLD

1.6.11 Pictorial Navigation Indicators (PNIs)

The aircraft is equipped with two KCS-55A gyromagnetic compass systems. Each system consists of a directional gyro, a magnetic flux detector, slaving and compensatory units and, as the cockpit display, a KI-525A PNI. The two systems are designed to operate independently, the commander's being powered by the 28V DC Emergency bus bar, and the first officer's by the 28V DC main bus bar.

The function and display of the KI-525A PNI combines radio navigation information with compass heading information. Separate failure warning flags indicate radio navigation system failure and compass failure.

1.7 Meteorological information

1.7.1 General situation

An aftercast by the Meteorological Office at Bracknell reported that, at 1700 hrs, a thundery trough was moving steadily northwards across the Leeds Bradford area at 12 to 15 kts. The visibility was generally 1,500 metres in rain and the cloud was scattered at 1,000 feet with a broken base at 2,500 feet and embedded cumulonimbus with tops at 29,000 feet. The weather was described as moderate thunderstorms with rain.

The meteorological observation taken at Leeds Bradford airport at 1659 hrs (eight minutes after the accident) recorded a surface wind of 120°/04 kts, a visibility of 1,200 metres, an RVR of 1,100 metres on Runway 04, scattered cloud at 400 feet, a further layer of scattered cloud at 900 feet and broken cumulonimbus at 2,000 feet. The weather was described as thunderstorms and rain.

The Meteorological Office rainfall radar indicated that, at 1645 hrs, the area to the north-east of Leeds Bradford airport was experiencing rainfall at a rate of between one and four millimetres per hour. Four millimetres per hour equates to moderate rain in meteorological terms.

At the time and site of the accident the visibility was estimated from the aftercast as 1,200 metres in light rain with an overcast sky. It was calculated from the airport observation that the cloud base over the accident site was about 500 feet. Witness observations indicated that there had been a thunderstorm in the area but that it had cleared just prior to the accident. They also reported that conditions in the accident area were 'very black' due to the thundery conditions.

1.8 Aids to navigation

Not relevant.

1.9 Communications

RT exchanges between the aircraft and the ATC aerodrome and approach controllers at Leeds Bradford were recorded. A condensed version of the transcript showing exchanges between the first officer and ATC is at Appendix C. Examination of the two VHF radio communication selectors found in the wreckage showed one station selected to Leeds Bradford Approach on 123.75 MHz and the other on the ATIS[7] frequency of 118.025 MHz.

Colleagues of the flight crew identified the first officer, by his voice, as the only one to make radio transmissions from the aircraft throughout the flight. In all of these transmissions he sounded calm and collected.

Using frequency spectrum analysis techniques, an attempt was made to discover whether the first officer had declared a single or double horizon failure in his transmission "....A PROBLEM WITH THE ARTIFICIAL HORIZON SIR.....". However, his use of the word 'SIR' totally obscured the ending of the word 'HORIZON(S)'.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

The EMB-110 was first issued with a type certificate on 15 September 1977. If the maximum weight authorised had exceeded 5,700 kg, the provisions of Scale S(i) of Schedule 4 to the ANO (2) 1995 would have required it to carry either a four channel CVR or an FDR. Since the maximum weight authorised was 5,700 kg there was no requirement to carry any flight recorders.

Under the provisions of Scale S(iv) of Schedule 4 to the ANO (2) 1995, all multi-engined turbine powered aircraft not exceeding 5,700 kg and carrying more than nine passengers for which an *individual* Certificate of Airworthiness was first issued on or after 1 June 1990, are required to carry both CVR and FDR. The individual Certificate of Airworthiness for G-OEAA was first issued by the CAA on 2 April 1980 and therefore the provisions of Scale S(iv) did not apply.

7 Automatic Terminal Information Service; continuous broadcast of recorded non-control information in selected high- activity terminal areas.

Joint Airworthiness Requirements (JAR) OPS 1.700 and 1.715 require all aircraft in this category with a first Certificate of Airworthiness (C of A) date after the JAR OPS adoption date to be fitted with a CVR and FDR. Additionally, JAR OPS 1.705 requires that all such aircraft with a first C of A date after 1 January 1990 will be required to be retro-fitted with a CVR of 30 minute duration.

Part 1 of Annex 6 to the Convention on Civil Aviation contains Standards which shall be adopted by contracting States, regarding the operation of international public transport flights. It includes a section on the equipment to be fitted but there is no Standard or Recommended Practice regarding the fit of recorders to this category of aircraft. However, in early 1995 a group of specialists was formed under the auspices of the International Civil Aviation Organisation (ICAO) to recommend amendments to Annex 6. The group is considering a proposal that ICAO should include a Recommended Practice that all multi-engined turbine powered aircraft with an authorised weight not exceeding 5,700 kg should be fitted with a CVR.

1.12 Wreckage and impact information

Appendix D shows a plot of the aircraft wreckage which comprised:

a. the main impact site with the burned remains of the fuselage, the starboard engine and most of the flying surfaces, was contained within a 14 acre field. The central axis was aligned with a heading of 345°;

b. the surrounding area of approximately 350 x 250 metres containing aircraft structure, components and furnishings;

c. a 'paper trail' of insulation material and lightweight items from inside the cabin, this extended for approximately 3 km into 19 other smaller fields on a heading of 330°.

1.12.1 Pre impact break up

The distribution of wreckage described above showed that there had been an in-flight break-up of the aircraft prior to impact but at a relatively low height. The overall spread of the wreckage was not large compared with that typically found in cases of airborne structural failure. The more extensive 'paper trail' was the result of wind drift on very light debris but also indicated that the fuselage was disrupted before the impact, since most of these objects originated from within the cabin. Many of the occupants, some still in and others separated from their seats, were found outside the main impact area suggesting extensive disruption of the fuselage. However, the debris pattern contained very few sizeable fuselage skin pieces making it unclear how this had occurred.

The wreckage distribution, although compact for such an extensive airborne failure, showed which major structural items had separated before impact. Some of these had separated into several pieces during detachment including:

a. the right wing and aileron from a point just inboard of the aileron

b. the right tailplane and elevator about one metre from the aircraft centreline

c. the left elevator

d. the right engine cowling

e. the left aileron

The structural wreckage was laid out at the AAIB facility at Farnborough. This did not give a clear indication of the sequence of failure but did reveal the existence of a heavy slash from the right hand (No 2) propeller in the fuselage side on the aft frame of the right hand crew emergency exit. Fragments of the structure and a tip from one propeller blade were found in the debris field (see Appendix D). Much of the fuselage skin had been destroyed during the post-impact fire but a section from the crown aft of the cockpit demonstrated an unusual mode of separation along the longitudinal manufacturing lap joint in the form of hoop-tensile tearing. Some portions of the structure which had separated in-flight showed signs of sooting indicating that they had been briefly exposed to some airborne fire. The vertical fin, although apparently remaining attached to the bulk of the main wreckage, had received a heavy blow on its leading edge, forcing back its attachments but without failing them completely before impact. The right wing outboard leading edge had been detached from the torque box, which had itself also detached from the inboard wing by a heavy blow, and had been recovered in two pieces.

1.12.2 Wreckage drift plot

An analysis of the wreckage distribution, was made in order to equate the 'as found' locations of various key items of debris to a sequence of failure and height of break-up. Using estimated drag coefficients for each item combined with its known weight, the terminal velocity was calculated using a specially developed computer programme. With an approximate forward/vertical velocity of the aircraft at the time of separation, modified by the aftercast wind data from the time of the accident, and using conventional ballistic theory, an iterative process was followed until a height and sequence of failure was deduced which aligned with the known location of each piece of wreckage. This process estimated the height at which the aircraft began to break up as between 1,500 and 2,000 feet agl.

1.12.3 Aero-elastic oscillations

A conclusive sequence of break-up following conventional logic regarding the directions of failure suffered by the major structural members was not apparent from the wreckage analysis. Evidence of aero-elastic flutter on the failed components, particularly the detached flying control surfaces was sought. The classic signs of multiple load reversals such as low-cycle fatigue were absent, although there were some signs of single gross load reversal prior to failure. However, close metallurgical examination of the four machined brackets securing the tailplane to the rear fuselage, which did not appear to have failed completely prior to impact, did show clear evidence of low-cycle, high strain fatigue in both fore and aft and vertical directions. This indicates conclusively that aero-elastic oscillation had occurred and also implies that the aircraft must still have been in an airworthy state, albeit at speeds well above those for which it had been designed and tested. Any other sequence, such as failure of some other major structural component, under which the aircraft would have had the time or ability to accelerate to the tailplane flutter speed is highly unlikely. Thus the aircraft must have achieved a speed in excess of its design diving speed (V_D)[8] during the final left turn recorded on the airport Watchman radar. Although the entire tailplane had started to oscillate aero-elastically, it did not reach the point of failure but instead appears to have caused separation of the elevators followed by failure of the right tailplane section outboard of the fuselage.

A propeller slash on the right side of the fuselage was not the result of any detachment of the right engine or its propeller prior to ground impact. It might have occurred during a rapid pitch-down of the aircraft, when the gyroscopic precession forces could have distorted or partially failed the engine mounting frame to the left. It is also possible that the fuselage structure deformed outwards into the propeller arc, following rupture of the upper seam, which seems to have occurred for reasons stated above. There was insufficient conclusive evidence as to which of the two mechanisms was responsible for the slash.

1.12.4 Instruments

Analysis of the MAP caption bulbs indicated that, at impact, there was electrical power supply on the 28V DC main bus bar.

1.12.4.1 Artificial horizons

Both artificial horizons had been severely damaged in the final impact with the ground but the majority of the component parts were identified as follows:

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8 One of the speeds used in establishing structural strength.

	Commander	First Officer
Power supply	115V AC	28V DC
AIM Part No	110P2-9001-20	110P2-9001-10
EMBRAER No	504-0005-901	504-0010-910
(Other Part No)	(251ECFB)	(500DCFM)
Serial No	1728	5247
Manufactured	5 September 1979	7 July 1980
Installed Note; at accident, aircraft hours were 15,348	25 January 1995 at 14,955 aircraft hours	22 December 1994 at 14,865 aircraft hours

After initial examination at an approved overhaul facility in the UK, for strip examination the artificial horizons were taken to JET Electronics & Technology Inc. in the US who, although not the original manufacturer, had acquired the AIM 500 Series product line. JET was thus responsible for any continuing design changes, manuals and service information. The component parts were later examined at the UK's authorised service centre for this manufacturer and tests performed on other, similar, artificial horizons.

1.12.4.2 Examination of artificial horizons at JET

The main feature of the examination at JET was the damage to the instruments from the impact forces: although most artificial horizon items were recovered, there was limited information as to how each instrument had been behaving at impact. Although parts of the 'pendulous' vane systems were identified, it was not possible to determine from which artificial horizons they came. Examination of the power on/off solenoids from the G-OEAA instruments (S/N 1728 and 5247) showed that both solenoids operated correctly but the disruption of the instruments meant that there was no evidence as to the actual position of the power on/off flag at impact.

The damage to the gyroscope rotors was similar between the two instruments. In each artificial horizon rotor assembly the top locating nut had been deformed downwards, showing that both artificial horizons had been approximately erect when subjected to the same inertial impact forces on the gyroscope rotor. Dismantling of the rotor assemblies showed clear witness marks within the housings to demonstrate that both rotors were rotating at impact. Both motors ran satisfactorily at speed when electrical power was applied. Previous tests at JET to investigate 'coasting' times for this type of instrument (*ie* operating time following removal of electrical power) had shown that all the sampled instruments would still give accurate attitude information for at least three minutes after removal of power. This was confirmed by AAIB at a UK overhaul facility.

On the commander's artificial horizon the mountings of the autopilot 'pick-off' transformers were loose. The detailed examination is described in 1.12.4.3.

The best indication of artificial horizon attitude indication at the point of impact was the contact between the head of the 'gimbal stop' screw and the gimbal arm. In the assembled instrument these parts are very close and at impact each screw head had made a clear impression on the inner face of the gimbal arm. Measurement showed the commander's artificial horizon (Serial No 1728) as having 23° nose-down at impact and the first officer's artificial horizon (Serial No 5247) at 15°. The indications of the displayed roll attitudes were less clear and less accurate. However, in the first officer's artificial horizon, damage between the gimbal assembly and a circuit board showed approximately 20° of right roll. In contrast, the commander's artificial horizon, evidence of damage between a gimbal balance weight and a board-mounted turret lug showed approximately 0° of roll indication.

1.12.4.3 Examination at DRA Farnborough

In view of the damaged mountings, on the commander's artificial horizon, of the autopilot 'pick-off' transformers for the pitch and roll channels, the Structural Materials Centre at the DRA Farnborough were requested to examine these components in detail to determine whether or not these mountings might have been loose before the accident. This would have allowed the transformer coils to migrate and thus, at some point, interfere with their corresponding armature plates. With an operating autopilot system this migration would become apparent as the autopilot would cease to operate, whereas with G-OEAA not having an autopilot there would be no such cue.

Examination at the DRA, however, indicated that neither screw had been turning in its hole and showed no evidence that the mounting attachments had been loose.

1.12.4.4 Artificial horizon failure modes

The description of this type of artificial horizon in sub paragraph 1.6.9 shows that the only unambiguous (or 'hard') failure mode is a failure of the required electrical power supply to the instrument. This results in the appearance of the failure flag across the instrument face.

Examination of repair records from several operators' instruments shows that this type of artificial horizon will more often fail in service for reasons other than loss of electrical supply and that some reported failures resulted in 'no fault found' diagnosis at the repair agency. These are more subtle ('or soft') failures than disruption of power from the aircraft's electrical supply system; failures are most commonly attributed to deterioration in the mechanical bearings or some other form of mechanical interference. Other failure modes included loss of a balance weight or 'hanging up' of an erection vane. The identification of the failure in these incidents is generally by erratic behaviour of the display or by indications of attitude which can be interpreted as unrealistic by reference either to other flight instruments or to external visual references. In more sophisticated (and thus expensive) systems, this monitoring between similar instruments may be achieved by the use of signal comparators.

A feature of the flight path of G-OEAA was that reasonable control in pitch attitude was maintained and that the problems reported were with control of roll attitude. Because of the 'precession' characteristic of a gyro, this would suggest interference in the 'pitch' portion of the mechanism, such as deterioration in a pitch bearing or slight interference between the display masks. These modes would result in failures predominantly in roll display, with less effect on pitch information.

1.12.4.5 Turn-bank indicators

Both turn-bank instruments (Serial Nos 3710 and 4008) were recovered from the wreckage and, after initial examination, were taken to an approved overhaul facility for stripping. The autopilot 'pick-off' transformer coils indicated that No 3710 was the commander's instrument and No 4008 the first officer's.

The cases of both instruments had been crushed and in each instance the resulting damage had caused the rotors to move from their bearings and come into contact with the enclosing gimbal. This contact had resulted in abrasive markings on the gimbal and on the rotors, indicating that the rotors were rotating at impact. Despite the disruption, there was no evidence of damage before impact.

The pattern of damage on No 4008 did not present any evidence as to the turn indication at impact. On No 3710, however, the position of the gimbal indicated a turn to the right. This is consistent with the indications that the right-hand wing had separated before impact, that the left-hand engine was still developing power and that, therefore, the aircraft was rolling and yawing to the right.

The simple design of the instruments gives confidence that, at impact, both turn-bank indicators were still functioning.

1.12.4.6 Pictorial Navigation Indicators (PNIs)

Both KI-525A PNIs were identified at the accident site, separated from the instrument panel. The faces of both instruments had been severely damaged, demolishing the compass cards and indicators, but the bulk of the instrument mechanisms had been retained within the instrument cases. In each instrument, despite the impact damage, the mechanism from the slave Control Transformers (CT) was still intact. Thus, by comparison with a serviceable unit it was possible to 'read' the position of these transformers as a position of the compass card at impact. The readings were 356° and 004°, close to the heading of the fuselage at actual impact with the ground.

As well as being powered separately, the aircraft's two gyromagnetic compass systems had separate directional gyros and magnetic flux detectors. The probability that, with rapid changes of the fuselage heading, both systems could agree so closely with each other and with the fuselage heading is unlikely to have been random and this is positive evidence that, at impact, the commander's PNI was still correctly powered by the 28V DC Emergency bus bar and the first officer's by the 28V DC main bus bar.

1.12.5 Engines

Both engines had severe impact damage including the separation of the reduction gearbox forward housing and accessory gearbox and, for the right engine, separation of the power section and gas generator case. Strong circumferential rubbing and machining were displayed by the centrifugal impellers and shrouds, the compressor turbine disks and interstage baffles due to axial contact under impact loads and external case distortion. The compressor blades and shrouds, the compressor turbine blades and shroud, the compressor turbine blades and power turbine housings, and the power turbine blades and shroud displayed strong circumferential rubbing, deformation, and fracturing of the rotating components due to radial contact under impact loads and external case distortion.

There were no indications of any pre-impact anomalies or operational malfunction in any of the engine components examined, to the extent possible regarding impact damage. Both engines had rotational signatures of the engine internal components which were characteristic of the engines developing a level of power at impact which approximated to a middle power range. There were no indications of any anomalies or distress to any of the engine components that would have precluded normal operation prior to impact.

1.13 Medical and pathological information

All the occupants died as the aircraft broke up and struck the ground.

Both pilots were medically fit and properly rested prior to the flight. No pre-existing conditions that could have caused or contributed to the accident were discovered during post mortem examinations.

1.14 Fire

1.14.1 Pre-impact

As a result of the loss in flight of the outboard section of the right wing a quantity of fuel, approximately half the fuel on board, was released. This fuel was ignited by an unidentified source of ignition and was seen by several eye witnesses who described the descent of either a fireball or the aircraft in flames. Many items originating from inside the cabin and recovered from the 3 km 'paper trail' exhibited burn or scorch marks. These included business stationery and pages from publications in the aircraft library and indicated that, during the time of the airborne fire, the cabin had been breached and its lightweight contents were passing through the external fuel fire.

1.14.2 Post-impact

The main impact site covered an area of approximately 55 x 18 metres and had been the scene of a heavy fuel fire. Surrounding the main site was an area, which contained barley contaminated with fuel, which increased the overall area to 80 x 50 metres. See Appendix D.

The remains of the port wing were recovered from the impact site and had a pattern of deformation characteristic of that produced by the impact of a wing with the ground at a time when the wing fuel tank was intact and full of fuel. The wing fuel tank had subsequently ruptured and released the fuel for the ground fire.

1.15 Survival aspects

The accident was not survivable.

Due to the proximity of the accident site to the county boundary, Emergency Services from both North and West Yorkshire attended. The police established a Casualty Bureau which acted as an information point for all enquiries relating to casualties. The Social Services Major Incident Response Team were in attendance to provide support to bereaved relatives and traumatised local residents. Selected representatives from the National Police Major Disaster Advisory Team were also contacted and provided advice to the local police. In support of the Emergency Services, several facilities were provided, many of them co-ordinated through the County Emergency Department.

1.16 Tests and research

1.16.1 Radar trials

After take-off the aircraft was observed on the Claxby radar (53° 26' North; 000° 18' West; 666 ft amsl) and a Watchman aerodrome radar which was primarily used for information on traffic within the airport control zone. Both radars were displayed in the control tower and recorded on VHS video tape. The Claxby radar was digitally recorded by London Air Traffic Control Centre (LATCC) at West Drayton. Only the latter contained height information derived from the aircraft's ATC transponder with Mode C. The final secondary radar return (Claxby) was at an approximate altitude of 2,900 feet. Thereafter four primary returns (with no height information) were observed on the Watchman radar.

In order to establish the lowest altitude at which both primary and secondary radar returns could be obtained from a representative target in the vicinity of the accident location, an EMB-110 aircraft was flown in a series of left hand orbits over the accident site at progressively lower altitudes. From observation of the radar display in the control tower, the lowest secondary return was observed at an altitude of 700 feet, and the lowest primary return at an altitude of 600 feet.

The Claxby radar head revolved at 7.5 rpm producing a return every 8 seconds. The Watchman radar revolved at 15 rpm producing a return every 4 seconds. From these data it was possible to estimate the average rate of descent of the spiral dive following loss of control as about 8,500 feet per minute.

1.17 Organisational and management information

1.17.1 History of the operator

The operating company was originally formed in 1985 but was subject to a number of take-overs the last of which was in 1991. At the time of the accident, the company employed 85 staff of which 20 were full time pilots and two were employed on a part-time basis. The company held an Air Operators Certificate (AOC) and undertook both scheduled and charter flights. The scheduled route structure involved four destinations daily; all served from Leeds Bradford and flown by four EMB-110 aircraft. These were:

<u>Monday to Friday</u>

Aircraft 1: two return flights to Aberdeen
Aircraft 2: two return flights to Southampton and one return flight to Aberdeen
Aircraft 3: two return flights to Belfast
Aircraft 4: two return flights to Isle of Man (three on Friday)

The company held a Joint Aviation Requirement 145 approval to undertake maintenance on a wide range of aircraft types and also operated a flying school for both commercial and private training.

1.17.2 Minimum Equipment Lists

1.17.2.1 Air Navigation Order

ANO (2) 1995 Schedule 4 lists the equipment required. Scale E was applicable to this flight and specified:

'(i) (b) ..... a slip indicator and either a turn indicator or, at the option of the operator, an additional gyroscopic bank and pitch indicator.

(ii) A gyroscopic bank and pitch indicator.

(iii) A gyroscopic direction indicator.

(iv) A sensitive pressure altimeter adjustable for any sea level barometric pressure which the weather report or forecasts available to the commander of the aircraft indicate is likely to be encountered during the intended flight.'

Under the provisions of Article 16 of the ANO (2) 1995, no aircraft registered in the UK may commence a flight if any of the equipment required by or under the Order is not carried or is not in a fit condition for use, unless a Permission to do so has been issued by the CAA. The CAA carries out its obligations under the terms of this Article by authorising the use of Minimum Equipment Lists (MEL). Each type of aircraft (exceeding 2,730 kg) will, in general, have a CAA approved Master Minimum Equipment List (MMEL). The MMEL will deal with items of equipment which may be safely permitted to be unserviceable under certain conditions. It will not necessarily include those items which are essential for safety under all conditions. The MEL may not be less restrictive than the appropriate CAA approved MMEL and may have to be more restrictive to reflect operators' circumstances and capabilities.[9]

1.17.2.2 Master Minimum Equipment List

The MMEL relating to the Embraer EMB-110 which was maintained by the CAA in Revision 1 dated 30 November 1990 lists:

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9 A full description of MMEL and MEL may be found in CAP 549, the Second edition (extant at the time of the accident) was published in April 1992 ISBN 0 86039 516 2. A Third edition was published in January 1996 ISBN 0 86039 647 9.

'34 NAVIGATION[10]

4. Pilots Artificial Horizons

(2) Number Installed 2

(3) Number required for despatch 1

(4) Remarks or Exceptions *[11] As required by Air Navigation Legislation. The right side instrument may be inoperative for day VFR operations'

The CAA wrote to all AOC holders on 15 December 1993 concerning 'MMEL Policy Changes'. Operators were authorised to submit appropriate MEL amendments to reflect the following change in the MMEL alleviation (viz. column 4): *The aircraft may continue the flight or series of flights but shall not depart an airport where repairs or replacements can be made'* has been changed to : *'Repairs or replacements are carried out within 3 calendar days'*.

1.17.2.3 Minimum Equipment List

Volume 2(D) Section 6 of the operator's Operations Manual (OM) included the operator's Minimum Equipment List (MEL). It stated:

'34 NAVIGATION

4. Gyroscopic Pitch & Bank Indicator System

(2) Number Installed 2

(3) Number required for despatch 1

(4) Remarks or Exceptions *(O)[12] For two pilot operations, either indicator may be inoperative

REPAIRS OR REPLACEMENTS ARE CARRIED OUT WITHIN THREE CALENDAR DAYS.'[13]

1.17.2.4 Civil Aviation Publication (CAP) 360

The purpose of this publication is to explain the administrative procedure for the issue and variation of Air Operators' Certificates (AOCs) and to indicate

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10 The information is portrayed in the tables in a slightly different format but is reproduced here for clarity and brevity. The numbers in brackets refer to column numbers.

11 This symbol in Column 4 indicates that if the specified item is inoperative, a placard must be placed on or adjacent to the affected unit, component or control such that it is clear to the operating crew that it or it's associated system is inoperative.

12 The use of this symbol in Column 4 indicates that an appropriate procedure (or change to an existing procedure) must be established, published and utilised to maintain the required level of safety while operating under the terms of the (M)MEL.

13 OM printed in upper case as shown.

requirements to be met by applicants and certificate holders in respect of equipment, organisation, staffing, training and other matters affecting the operation of aircraft.

Part One, Chapter 4, paragraph 1.9 describes the statutory responsibility of operators and the role of the regulatory authority (CAA)

> 'It is most important for operators to appreciate that it is their responsibility under the relevant statutory provisions to provide adequate instructions and accurate information to their operating staff. Inspectors will check manuals lodged with the Authority and will suggest amendments, where they appear to be necessary. The primary purpose of these checks will be to verify the adequacy of the operator's systems and procedures for keeping instructions and information under review and for issuing timely amendments, as necessary. There can be no question of the Authority or its Inspectors assuming responsibility for the detailed information provided in manuals. This responsibility rests with the operator who should designate a suitably qualified person to see that it is properly discharged.'

Describing the procedure to be adopted when qualifying newly hired or promoted pilots, paragraph 5.9.5 states:

> 'On completion of the sectors under supervision a line check is to be administered. If no flying 'under observation' is required (see paragraph 5.9.6), successful completion of a further line check and acceptance by the operator of such a check will release a pilot to the line. The subsequent rostering together of two such newly qualified pilots should[14] be avoided where possible.'

1.17.2.5 Operations Manual

The duties of the commander and first officer (co-pilot) are set out in Volume 1 Section 1 of the airline's Operation Manual. They include the following extracts:

> 'DUTIES OF THE PILOT IN COMMAND
>
> 1. In general terms he is solely responsible for all matters relating to the safe conduct of any flight he has been authorised to undertake. He may delegate to the co-pilot, pilots assistant or cabin staff as appropriate
>
> FIRST OFFICER'S RESPONSIBILITIES
> *inter alia*:
>
> h) During flight, maintaining the navigation PLOG, operating the radios and navigation aids, reading the check list, operating the controls as required and maintaining a look-out.'

14 In CAP 360 the word 'should' is used to indicate that the operator has a degree of latitude, partcularly where the nature of the operation affects the degree of compliance. The use of 'should' must not, however, be taken to mean that nothing need be done.

1.18 Additional information

1.18.1 Post accident reports

The day after the accident a claim that the accident had been the result of sabotage was investigated by the police and found to be without foundation.

Shortly after the accident a number of anonymous allegations relating to the operator's quality of maintenance and in particular to the serviceability of the artificial horizons, including a claim that one of them was known to be unserviceable before the accident flight, was made known to the investigation. No evidence was found to substantiate these claims.

1.18.2 Artificial horizon reliability

An assessment was made of the Mean Time Between Unscheduled Removal (MTBUR)[15] of the artificial horizons fitted to both pilots' positions on the aircraft (see paragraph 1.12.4.1).

Examination of the technical records from G-OEAA produced a total of 41 entries concerning replacements of either the commander's or first officer's artificial horizon over the 15,347 flying hour life of the aircraft. These included the histories of the two instruments fitted to G-OEAA at the time of the accident. The data from which the MTBURs were derived does not include the first officer's horizons before 1984 as the second pilot only became mandatory on public transport work in 1984. However, first officer's data from after 1984 is included in this survey. The entries included 21 artificial horizons which were identified by serial number when fitted and removed from the aircraft, and from which times to removal could be calculated. These 21 artificial horizons had an MTBUR of 257 hours.

This figure was sufficiently low that the technical records from three other EMB-110s were examined to provide corroboration. The total flying hours for the three aircraft, up to 19 June 1995, was 51,860 hours, and a further 51 artificial horizon histories were identified representing over 25% of the total aircraft flying hours. These additional histories covered a period of approximately 15 years of use of each aircraft with a variety of operators and maintenance organisations. These data included the hours flown on the instruments currently fitted to the aircraft and gave an overall MTBUR of 260 hours for the 72 instrument changes. A table showing these histories is at Appendix E.

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15 Throughout this report the term 'unscheduled removal' is used to indicate occasions on which any artificial horizon has been rejected as unserviceable for any unspecified reason. In several cases no apparent defect was recorded by the repair organisation.

A further feature of the statistics was the presence of a significant early removal pattern in which 25% of the artificial horizons had been changed within 40 hours of being fitted. However, at the time of the accident the horizons fitted to G-OEAA had been installed for 393 hours (the commander's) and 483 hours (the first officer's). At that point the statistics indicate that their average remaining time to unscheduled removal would have been 225 and 188 hours respectively.

Statistical analysis was necessarily confined to UK based EMB-110 installations. Information was sought from the UK repair organisations and some other operators to compare the service history of AIM 500 series artificial horizons installed in other aircraft types. This was inconclusive and, in the absence of detailed records from numerous and varied aircraft operators, no meaningful comparison could be made. Furthermore, installations in other aircraft included features such as different anti-vibration mountings which altered the operating environment of the instruments.

1.18.2.1 Certification Requirements

The BCAR Section under which the aircraft was certificated did not stipulate the reliability requirements that the artificial horizon should meet in order to ensure that the occurrence of a double failure was a statistically remote event.

1.18.2.2 Environmental Considerations

Consideration was given to the possibility that environmental factors, peculiar to the EMB-110, had been responsible for the reduced MTBUR experienced in the UK. A vibration survey of the instrument panel adjacent to both instruments was carried out on an aircraft which was about to undergo propeller balancing due to excess vibration. Vibration transducers were mounted close to the instruments and monitored panel vibration in three axes (fore and aft, vertical and horizontal). This was done for three phases of flight (take-off roll; climb out and top of climb). The results obtained showed that, whilst the background vibration level was low, some frequency spikes associated with the propeller rpm and its harmonics were present. The maximum value achieved by these peaks was 0.25g at 18 Hz in the fore and aft direction. This was well below the design limit defined in the Federal Aviation Administration (FAA) Technical Standard Order C4 c which requires 1.5g in the range 5 to 50 Hz, and 5.0g in the range 50 to 500 Hz.

A similar test was carried out by the aircraft manufacturer on 20 September 1995 on EMB-110 serial No 110-498, using a ground run test, which they considered the most critical condition of vibration on the panel. Two vibration accelerometers were installed on the front instrument panel: one at the centre, and the other as near as possible to the commander's artificial horizon. Ground runs were performed at the following conditions:

a. Take-off power, 100% propeller speed, 1790 lb ft torque.

b. Climb power, 91% propeller speed, 1600 lb ft torque.

c. Maximum cruise power, 83% propeller speed, 1300 lb ft torque.

For these three conditions the maximum measured level of acceleration obtained was 0.07g for take-off power on the ground; this was much lower than the maximum allowed for the artificial horizon.

In addition to the two tests detailed above, the Design Authority (DA) ran an artificial horizon whilst mounted on a vibration test table. A resonant survey was carried in the three operational axes of the instrument at acceleration levels considerably higher than either the aircraft manufacturer or the AAIB had measured in their instrument panel testing. No deviations in excess of 1.5° were observed.

1.18.2.3 Instrument panel design

The EMB-110 has two main instrument panel configurations, both of which are secured by simple anti-vibration mountings. The standard configuration is a one piece panel; a factory fitted option was subsequently introduced which comprised a main instrument panel with an anti-vibration mounted hinged sub-panel containing the primary flight instruments for each pilot. The manufacturer has stated that the main reason for introducing this option was to provide full access to each instrument. They acknowledge that the design does also give better vibration insulation.

Two UK registered aircraft were identified with the sub panel option fitted, and their technical records were searched for artificial horizon entries to determine whether the improved vibration insulation properties had any significant effect on artificial horizon histories. In total 22 entries were identified yielding 6 quantified histories; these included one of 3,947 hours, but also three below 33 hours. The aircraft records were not as comprehensive as those from the original four aircraft. The results obtained, though indicating the presence of an early failure problem, were not able to produce quantified results with a degree of confidence that could be compared with that of the data from the original four aircraft.

1.18.3 Artificial horizon maintenance

The artificial horizon fitted to the EMB-110 had no specified overhaul life and was treated as an 'on condition' item, that is, it was left in the aircraft until reported as unserviceable. As there was no requirement for the instrument to be ground tested, the majority of unserviceability reports were raised in the aircraft's technical log by the flight crew.

When reported as unserviceable the artificial horizon was sent to one of several UK repair agencies for repair or overhaul. Whilst all the repair agencies were approved by the CAA, only one was a Service Centre authorised by the DA. All repair agencies had access to the instrument technical manuals, which detailed the procedures for the replacement of components and testing.

However, there was no requirement for the Repair Agency to embody a Service Bulletin unless the Bulletin had been declared mandatory by the CAA, or they had been requested to incorporate it by the customer. It would therefore have been possible for bulletins, regarded as providing product improvements by the DA, to remain unembodied by repair agencies.

The DA considered that this practice had led to the long term decline in the condition of the artificial horizon fitted to the UK EMB-110 fleet, both in terms of mechanical degradation and in the non incorporation of Service Bulletins which were aimed at product improvement. The DA has subsequently published Service Letter SL 124 dated 26 October 1995 to provide a revised definition of the overhaul requirement.

It was noted that the artificial horizons seen in the survey did not have special packaging, transportation or handling procedures. The DA commented that such procedures were vital to ensure that the instrument was serviceable when it was installed in an aircraft.

1.18.4 Trend monitoring

The terms of reference of the operator's Quality Manager at Leeds contained the following responsibilities:

> 'Reliability monitoring in respect of both aircraft and components, defect analysis in respect of aircraft undergoing maintenance so that any adverse trends are identified and responded to promptly.'

The Quality Manager discharged this duty by maintaining a log of repeated defects for each aircraft. The artificial horizon reliability statistics presented in paragraph 1.18.1 were obtained from data covering four aircraft over a period of approximately 15 years. Most of the log books and technical records containing these data were not in current usage and a significant proportion of the archival material was not held by the operator.

The four EMB-110 aircraft whose records were used to provide the data were first maintained by the operator on the following dates:

G-OEAA	19 March 1993
G-OEAB	19 March 1993
G-JBAC	21 January 1994
G-BVRT	25 August 1994

Thus the only evidence readily available to the operator of the MTBURs of his artificial horizons was provided by unscheduled removals from these aircraft after their acquisition. The evidence accumulated over time is shown by the table:

Date	Hours to Removal	Date	Hours to Removal
25 March 1993	322	9 September 1994	310
26 May 1993	207	2 December 1994	169
4 June 1993	1087	10 December 1994	270
1 July 1993	499	19 December 1994	21
24 September 1993	824	20 December 1994	101
31 March 1994	873	23 December 1994	267
7 April 1994	491	4 January 1995	367
17 May 1994	617	26 April 1995	20
27 July 1994	not known	4 May 1995	52

This shows that, in the period before the accident, the operator had experienced 18 removals, with eight from one aircraft. The MTBUR of 382 hours provided by these figures, (not withstanding that the data contained some early failures) did not identify any adverse trend over the period preceding the accident during which the operator maintained the aircraft.

1.18.5 Alternate attitude indication systems

In the early 1980's the aircraft manufacturer received comments from some EMB-110 operators concerning the difficulties in maintenance of the Pilot's (110P2-9001-20) artificial horizon. In response the manufacturer offered operators a new artificial horizon under Service Bulletin No. 110-34-046 which comprised the Jet Electronics and Technology Model RAI-303B (Part No 501-1291-01) for UK certificated aircraft. The indicators were associated with a remotely mounted vertical gyro, model VG 208C, and this new configuration was intended to increase the instrument reliability. Aircraft serial numbers from 110-338 and upwards had this modification factory incorporated.

No operators in the UK had reportedly retrofitted this installation under the Service Bulletin, but some experience was gained through the use of aircraft with the factory installed system. The two units in the system, the vertical gyro and the remote indicator, were many times the cost of the original instrument and the additional cost was not recouped by a proportional increase in reliability. Furthermore, the installation only affected the commander's instrument, the first officer's artificial horizon remained the same. Some aircraft were de-modified and reverted to the original installation.

1.18.5.1 Alternate artificial horizon (first officer's panel)

On 24 February 1995 the operator applied to the CAA to remove the first officer's gyro, AIM part No 504-0010-910, and substitute an RCA gyro part No RCA 26BK6 on the four EMB-110 aircraft operated by them. The CAA gave their approval on 25 April 1995, and the first substitution was made on 29 June 1995, at which time it was realised that the presentation of the RCA gyro was incompatible with the original AIM gyro in the commander's position, and the RCA gyro was removed 14 flying hours later on 6 July 1995.

The application did not give a reason for the substitution, but the operator has stated that it was made because of the poor availability of the original first officer's gyro arising from its low MTBUR. The application concerned the first officer's gyro only because it was directly replaceable with another off the shelf item, whereas the commander's gyro included autopilot pick offs which made it specific to the EMB-110.

1.18.6 Other accidents and incidents

An EMB-110 operated by another UK company suffered two double artificial horizon failures in 1995. The first, on 4 June 1995, involved a double instrument failure; and the second, on 24 August 1995, was caused by a total electrical failure. On 20 October 1990 a Partenavia P68B aircraft crashed shortly after take-off when its single artificial horizon malfunctioned.

These occurrences were examined for the operational implications of a total loss of single reference attitude information resulting from whatever cause. Although there is no close similarity to the circumstances of the accident to G-OEAA, it does indicate that a loss of both horizons is not a remote possibility. Furthermore, loss of even a single horizon highlights the requirement for both an alternative and stand-by instrument in order that a sound diagnosis of the erroneous indication can be made.

1.18.6.1 Double artificial horizon failure on EMB-110, G-OCSZ, on 4 June 1995

The pilot's report on the first incident stated that when he was lined up on the runway at Southend en route to Luton he noticed that the first officer's artificial horizon had not erected properly so he used the fast slave device, which seemed to function correctly. Once airborne and in a normal climb, he noticed that the commander's artificial horizon was indicating 10° nose down and the first officer's had toppled. Within about 10 seconds the commander's artificial horizon had also toppled so the aircraft was levelled using the natural horizon and a visual circuit was carried out to land.

The aircraft records show that the two artificial horizons involved in the first incident had the following histories:

Position	Serial No.	Date Fitted	Hours flown at 4 June 95
Commander's	5319	10 April 1994	1,972.59
First officer's	5173	16 March 1994	2,055.33

1.18.6.2 Total electrical failure on EMB-110, G-OCSZ, on 24 August 1995

A report on an incident involving a massive over voltage (greater than 90 Volts DC) caused by the failure of a Generator Control Unit (GCU) was published in AAIB Bulletin 12/95[16]. The GCU contained a voltage regulation board and an over voltage protection circuit; a dormant failure of a resistor in the over voltage protection circuit, plus a subsequent (and unrelated) short circuit in a capacitor in the voltage regulation board, allowed the generator field current to become uncontrolled and the generator output voltage to rise substantially. This high voltage operated the No 2 GCU reverse current relay and took the No 2 generator off line. As both artificial horizons were fed from a common DC bus bar, they both lost power and the failure flags were displayed. The flight was in Visual Meteorological Conditions (VMC) and the aircraft was recovered safely.

1.18.6.3 Accident to Partenavia near East Midlands airport.

On 20 October 1990 at 0331 hrs, a Partenavia P68B aircraft, registration G-BMCB, departed East Midlands airport for a positioning flight to Manchester. The aircraft crashed shortly after departure from Runway 27, fatally injuring the single pilot on board. The accident investigation determined that the most likely cause of the accident was due to the pilot losing control of the aircraft when the single and only artificial horizon failed.

16 AAIB Bulletin Ref: EW/G95/08/23

The report [17]also stated that the commander had not been required by regulations to demonstrate 'partial panel' IF ability since passing the general flight test for a Commercial Pilot's Licence (CPL) at the training college. Moreover, the type of turn co-ordinator fitted to the aircraft, which had a moving aircraft symbol display, was subtly different to the needle types fitted to the training college's fleet. The following recommendation was made to the CAA as a result of the investigation:

> 'It is recommended that Scale E of Schedule 4 of the ANO Section 1/102 be amended to require duplicate gyroscopic bank and pitch indicators in aircraft flying for the purpose of public transport under IFR or at night Table 4 sub-sub-paras(2)(b)(i) and (ii). Moreover each indicator should be driven by a separate or duplicated power source and, for single pilot operations, both indicators should be clearly visible from the left hand pilot's seat. This proposal might best be met by replacing the electric turn and slip instrument with a topple resistant electric artificial horizon complete with slip indicator (as permitted by the proviso to Scale E of the ANO Schedule 4).'

The CAA response was:

> 'The authority does not accept this recommendation. Following consultation with industry, it is considered that the requirement to fit a second artificial horizon would not be justified, as a third horizon would also be necessary to allow positive identification of the failed instrument in the case where there is no warning flag indication. Furthermore it was considered that in this case, fitment of a second (or third) horizon would have done little except alert the pilot at a very late stage in the train of events, and a turn and slip indicator was actually available to the pilot. This position was supported by the relevant JAA Working Group, who are not prepared to consider an amendment to the relevant requirement in JAR(OPS), which the UK will be adopting as a member state.'

17 AAIB Bulletin Ref: EW/C1179.

2 Analysis

2.1 General

2.1.1 Sources of evidence

Evidence available to the investigation was limited to that obtained from eye witnesses, radar and ATC tape recordings, detailed examination of the wreckage, training and maintenance records, and some limited testing and research of the badly damaged flight instruments. A notable lack of evidence resulted from the absence of either a CVR or FDR since the date of original type certification and the issuing date of G-OEAA's individual Certificate of Airworthiness pre-dated the requirement for recorders to be fitted to aircraft in this weight category (not exceeding 5,700 kg). In the circumstances of this accident a record of inter-crew communication would have proved invaluable and enabled a detailed analysis of the crew's actions and interaction. Therefore, an appropriate recommendation for the carriage of CVRs by this class of aircraft is made, in paragraph 2.10, later in this report.

2.1.2 Elimination of some possible causes

The following possibilities have been considered and discarded in the light of the available evidence:

a. Neither pilot suffered from any incapacitation which would have affected his ability to perform his duties. None was reported to ATC by the first officer and none was discovered at post mortem examination.

b. The aircraft had not been struck by lightning. There was no evidence in the wreckage of electrical arcing or signs of burning associated with a lightning strike. None had been reported by the crew. Evidence that the aircraft's electrical system was functioning until seconds before the impact was provided by the transponder transmissions and the illuminated bulbs found in the Multiple Alarm Panel. These latter facts also ruled out the possibility of a total electrical failure such as that experienced by another EMB-110 and described in paragraph 1.18.5.2 above.

c. Despite the poor weather conditions prevailing at Leeds Bradford, conditions were above the prescribed operating minima for take-off. Continuous flight in IMC was necessary shortly after take-off; this is a normal and frequent situation. Manual flying of the aircraft would have been made more difficult in the stormy and turbulent conditions, but there is no evidence that meteorological phenomena were prime causal factors.

d. There was no evidence of unlawful interference with the aircraft or its systems. Contrary claims soon after the accident proved to be unfounded following Police inquiries.

e. The structural failure that had occurred, mainly in the right wing and horizontal stabiliser, was the result of manoeuvring beyond the design limits of the aircraft following the loss of control and shortly before impact. Examination of the wreckage showed no pre-existing or causative failure.

f. Examination of both engines showed them to have been at a medium power setting with power being delivered to the propellers. It is unlikely that thrust asymmetry had contributed to the ultimate loss of control.

g. Other than the two artificial horizons, of which at least one reportedly had a 'problem', examination of the remaining flight instruments showed them to have been in a serviceable condition before the accident.

h. There was no evidence to support the possibility that one artificial horizon was known to be faulty before the aircraft was crewed for the accident flight. No unserviceability had been logged prior to the flight; the crew who had operated the aircraft in the morning stated that there was no unserviceability or anomaly; and examination of the instruments recovered from the wreckage showed that in both case the gyros had been rotating which meant that electrical power had been available and failure flags would not have been displayed. However, a 'soft' failure was still a possibility.

Having eliminated these possibilities, the remaining evidence is examined for the most likely causes of the accident. The flight path indicates that the aircraft had a marked tendency to turn left throughout the flight. Control of the aircraft's heading was the major problem, suggesting either erroneous or absent information concerning the aircraft's roll attitude. Other factors, including the poor in-service record of the artificial horizons fitted to some UK operated EMB-110 aircraft, suggest that inadequate or confusing attitude reference was the initiating event leading to directional control problems and, ultimately, complete loss of control.

2.2 Aircraft handling

Loss of adequate attitude reference was apparent to the crew early in the flight. Despite an ATC instruction to maintain the runway heading, the aircraft turned left as soon as had it become airborne. By the time it had turned through 90° the first officer was able to report a problem with the artificial horizon. It is not clear from his radio call which artificial horizon (his own or the commander's) was involved or if the problem referred to both of them. His habit of addressing ATC as 'Sir' obscured the single or plural description in his transmission "....A PROBLEM

WITH THE ARTIFICIAL HORIZON(S) SIR.....". Detailed analysis of the ATC tape recording by frequency inspection could not determine this.

In the absence of CVR information it cannot be known for certain which pilot was the handling pilot throughout the short flight. Strong evidence is provided by the fact that the first officer continued to operate the RT throughout the flight and, since the OM allocates this task to the non handling pilot, the commander was most likely the handling pilot. Furthermore, the commander retained the ultimate responsibility for control of the aircraft irrespective of which pilot was actually handling the controls. Based on this deduction that the commander was the handling pilot, the left turns were the result either of inadequate attitude reference being available to the commander or his inability to retain attitude control solely by use of the remaining flight instruments, which were serviceable.

2.2.1 Analysis of which artificial horizon had failed

The first officer's report to ATC of a 'problem with the artificial horizon(s)' shows that the crew had either diagnosed an artificial horizon malfunction and could not decide which one was faulty, or they realised that both artificial horizons could not be relied upon. With only two horizons fitted, the immediate problem facing the crew was to decide which one was presenting erroneous information. Until this question had been resolved, information from both horizons had to be regarded as suspect. A standby artificial horizon was not fitted, since airworthiness requirements did not specify it, and, in its absence, the crew needed to resolve this conundrum by a systematic analysis of all the flight instrument indications.

By initially placing one artificial horizon 'wings level' and observing the behaviour of other flight instruments the handling pilot could see if the aircraft was in level flight. If it could be established that it was not, then control would be handed to the non handling pilot whose artificial horizon should have been set 'wings level' to see if that instrument was indicating correctly. In the prevailing turbulent conditions this would have been a demanding procedure, and any crew faced with this dilemma would have needed all their available skills as well as close co-operation between the pilots.

It is most unlikely that the commander attempted to fly by reference to the first officer's artificial horizon (assuming it to be serviceable) by looking to his right across the flight deck, since to have handed control to the first officer would have been the more sensible option. The first officer's two queries to ATC as to whether the aircraft was going straight might have been part of this analytical process, but other explanations are given in paragraph 2.3 below. The controller's assessment of the aircraft's track was based on his observation of two or three returns on his screen at four second intervals. Thus it was not easy for him to give an accurate answer to this unusual request.

2.2.2 Flight by reference to 'limited panel'

With no reliable artificial horizon attitude reference, indications were available from alternative flight instruments; notably the PNI and turn and slip indicators with cross reference to the airspeed indicator, vertical speed indicator and altimeter. This technique, commonly referred to as 'limited panel' (see paragraph 1.5.3.2) does not form part of a professional pilot's recurrency training and testing, although it is included in the less enabling IMC rating for private pilots. This casts some doubt on the abilities of a professional crew, such as that assigned to G-OEAA, to adopt this emergency procedure without the benefit of frequent training and testing. Nevertheless, a two pilot operation, with each pilot having his own full set of flight instruments, includes a degree of redundancy that is not available to a single pilot (private or professional) and it may be judged that there should be sufficient redundancy to reduce significantly the need for recourse to 'limited panel'.

With a third artificial horizon available as a standby in the event of failure of one or both primary instruments, the necessity of recourse to 'limited panel' is greatly reduced. A recommendation for a third independently powered artificial horizon to be fitted to aircraft types such as the EMB-110 was made on 19 October 1995 (see paragraph 2.9 2 below and Recommendation 4.2). The safety benefit of such a measure in terms of preventing the failure modes associated with this accident outweigh any potential benefit to be derived from improved training in limited panel techniques for professional pilots. Use of a standby artificial horizon requires no additional training or skill on the part of pilots. 'Limited panel' training is recurrently expensive, highly demanding of pilot skills and cannot guarantee a successful outcome in circumstances similar to this accident. Furthermore, when simulating an instrument malfunction by covering up the affected horizon, the powerful visual cue afforded by a faulty horizon, which is presenting an apparently true picture, is not present. Full flight simulators cannot replicate the important vestibular and motion sensing cues with sufficient realism. For these reasons no recommendation relating to further 'limited panel' training has been made.

The commander managed to retain control of the aircraft for some four minutes before he eventually lost control. Reconstruction of the flight profile from radar recordings showed that greater control was exercised in pitch than in bank and this was manifest in the inability to 'keep straight'. Continuation of the climb to 3,600 feet suggests an attempt to gain VMC conditions, with a natural horizon, above the cloud tops. That this intention was in the minds of the crew is indicated by their request to ATC for information about the cloud tops. Subsequently a descent was initiated, perhaps with the intention of regaining the ATC clearance altitude of 3,000 feet, very shortly before the ultimate loss of control.

2.2.3 Disorientation

The final departure from controlled flight probably resulted from the aircraft being in an extreme and unusual attitude with its attendant confusion of 'g' forces, abnormal airspeed, wind and engine noise and irreconcilable flight instrument indications. The incorrect indication of the commander's artificial horizon may therefore be deduced, assuming that the instrument had not 'toppled'. When the commander set his artificial horizon in a wings level attitude, the aircraft itself turned to the left. For the aircraft to fly straight it would have showed a right bank by the appropriate amount of the erroneous indication. The artificial horizon is the primary reference for attitude when there is no natural horizon and it would take a conscious and determined effort to ignore such a compelling cue, even when it had been diagnosed as erroneous, and deliberately to maintain it in an attitude which was quite unnatural to him. These conditions are highly conducive to a condition of spatial disorientation being experienced by a pilot, often described as 'the leans' (see paragraph 1.5.3.5 for a description of this condition). If the handling pilot had become spatially disorientated it would explain the aircraft's departure from controlled flight.

2.3 Human factors

2.3.1 Operational experience

The commander, with considerable experience of EMB-110 operations having flown as a first officer since June 1993, was recently promoted as aircraft commander. At the time of the accident he had some three weeks of experience in command of EMB-110 aircraft which, under the regulations, required two operating pilots. As such the description 'commander' has wider connotations than the term 'pilot in command'. His experience as an instructor of student pilots on light aircraft, whilst useful in a general sense, had little bearing on airline command.

The first officer was new to airline operations, this being his first position with a scheduled operation having completed a final line check some twenty days before the accident. Given their respective qualifications and validations, there was nothing to prevent this particular combination of pilots being assigned to operate the flight, but ideally such a combination would be avoided so as to provide a balance of experience between the two flight crew members. Indeed CAP 360 states this precise combination should be avoided (see paragraph 1.17.2.4). With little airline command experience, the commander may not have appreciated the potential assistance of the first officer, who himself was so newly qualified as to inhibit any forceful intervention. Thus the crew's capability to deal with this serious emergency may not have been maximised.

2.3.2 Crew co-operation

The first officer's two enquiries of ATC about the aircraft's direction has two explanations. Initially, at least, the flight instrument information presented to the crew was confused. Both PNIs and the turn and slip indicators would have showed the aircraft turning. The commander was possibly not responding to these cues because the artificial horizon display was so compelling as to inhibit 'limited panel' instrument flying.

It is possible that the first officer had a clearer view of the problem than the commander who was probably working to the limits of his capacity, flying in turbulence with confusing instrument indications. The first officer's problem was how to help him without overloading him or unnecessarily challenging his authority. Asking ATC to confirm that the aircraft was 'keeping straight' when the commander was maintaining what he thought to be 'wings level' by reference his artificial horizon could have been a sensitive and constructive approach. The repetition of the question a short time later suggests either that the commander at least, remained confused and disoriented or the crew was attempting some process of elimination to identify the faulty instrument.

The first officer's habit of addressing air traffic controllers as 'Sir' is of no significance and, although not approved in RT phraseology, it is frequently heard in RT exchanges. As such it is often imitated and thus by example adopted as common practice. Unfortunately it deprived this investigation of a clear indication of whether one or both artificial horizons had a problem when it was reported to ATC. Despite detailed analysis of the ATC tape recording, it was not possible to be certain of the first officer's meaning. If his sentence had ended with the word 'horizon' or 'horizons' the nature of the reported problem would have been more clear.

2.4 Pilot training

2.4.1 Instrument ratings

The loss of an artificial horizon should not be catastrophic and reference to 'limited panel' should ensure a continuing ability to control the aircraft in stable flight. However, recourse to this alternative procedure requires recurrent practice if it is to be effective. The commander, a CPL/ATPL holder since 1991 would not have been tested in his instrument flying abilities using 'limited panel' during recurrent proficiency checks. In any case, having to fly by reference to 'limited panel' in difficult and turbulent weather conditions would tax the ability of most pilots.

By far the more effective prevention of this undesirable situation is through the provision of a standby artificial horizon. There is no training or recency requirement for pilots to make use of this essential back-up in the event of a primary instrument failure. The necessity to resort to 'limited panel' is greatly reduced. It is for these reasons that a recommendation for a third independently powered artificial horizon to be fitted to this class of aircraft has been made (see paragraph 4.2).

2.4.2 Simulator training

Regional airlines operating small twin turboprop aircraft have little access to full flight CAA approved simulators which can be incorporated into their training schemes. This is mainly for economic reasons whereby small aircraft fleets do not justify the expense of running and maintaining an approved simulator and it is more economical to conduct routine conversion and proficiency training in the actual aircraft. There is no EMB 110 full flight simulator in the UK.

Despite the limitations described in paragraph 2.2.2 above, use of a simulator for training has many advantages. Several emergency situations can be practised which, for the risk of hazarding an actual aircraft, would not wisely be performed in flight. Furthermore, subtle combinations of related failures, combined with benign or obscure indications can add greatly to realism. This in turn increases the confidence of pilots under training to deal effectively with emergency situations.

Simulated flight training is also an integral part of Line Oriented Flying Training (LOFT) and CRM. The air transport industry and the CAA have already recognised this and, in particular, the problems of the smaller operators acquiring the use of these essential training aids. In response to an AAIB recommendation, the CAA stated in 1994 that it 'will continue to positively encourage the development and use of flight simulation in all areas where the actual aircraft can be replaced by a realistic simulator.' A further recommendation is therefore unnecessary.

2.5 Operational and maintenance quality

2.5.1 Defect management

The anonymous reports referred to in paragraph 1.18.1 were considered. Information received in this manner will always deserve circumspect treatment unless it can be authenticated and corroborated. For the allegations of known pre-flight unserviceabilities to be true it would have required that either an artificial horizon had been declared unserviceable in the technical log, and the defect had been deferred in accordance with the operator's MEL; or an operating pilot had observed an unserviceable artificial horizon and had not entered the defect in the technical log. At the time of the accident the company's MEL allowed the aircraft to operate with either of the artificial horizons inoperative for three calendar days but there was no such deferred defect in documentation relating to G–OEAA. With knowledge of the MEL there would have been no inhibition in writing up such a defect. The discrepancy between the MMEL and MEL is examined in the following paragraph 2.6. A careful examination of the technical records and stores documentation revealed that, at the time of the accident, both the commander and the first officer versions of the artificial horizon were available, either in stores or fitted to an aircraft which was undergoing long term maintenance in the hangar. The removal and fitting of an artificial horizon can be carried out in a short time; there would therefore have been no logical reason why either course of action described above should have occurred.

From the examination of the wreckage and strip examination of both artificial horizons it is clear that two were installed in the aircraft's instrument panel at the time of the accident and both were receiving electrical power since positive evidence of rotation in the gyroscopes was found (see paragraph 1.12.4) and the failure flags were not displayed.

2.5.2 Trend monitoring

The fact that the operator's trend monitoring system did not detect an abnormally low MTBUR for the artificial horizons is understandable. Not all the archival data was kept by the operator and the day-to-day work of the Quality Manager concerned the current state of his fleet and the work done by his company rather than that of other operators and maintenance organisations.

The maximum number of artificial horizon unserviceabilities on an individual aircraft over the period available for review was eight, and this had not caused the operator to raise a quality alarm. However, there was evidence that action, albeit to no avail, had been taken as a result of the reduced availability of artificial horizons arising from their poor MTBUR.

2.6 Minimum Equipment Lists

The definitive list of required navigational equipment is contained in the MMEL, promulgated by the CAA in consultation with the aircraft manufacturer. This list in turn refers to the scale of equipment specified for particular types of aircraft operation defined by the ANO (2) 1995. For the EMB-110, being operated for the purpose of public transport; and when flying under Instrument Flight Rules and by night, Scales D and E are required. Scale D requires either a turn and slip indicator or an artificial horizon; and Scale E requires the addition of an artificial horizon. Thus at least one artificial horizon must be fitted with the option of another one in place of a turn and slip indicator.

The MMEL for the EMB-110 required two artificial horizons to be fitted but allowed the *right side* instrument to be inoperative for day VFR operations. The MEL, included in the operator's OM, also required two artificial horizons to be fitted but, for two pilot operations, allowed *either* indicator to be inoperative subject to repairs or replacements being carried out within three calendar days. This discrepancy had its origin in a misinterpretation, by the operator, of the CAA letter to AOC holders allowing the existing alleviation *'The aircraft may continue the flight or series of flights but shall not depart an airport where repairs or replacements can be made'* to be changed to : *'Repairs or replacements are carried out within 3 calendar days'*. The misinterpretation was that, in the case of artificial horizons, the latter alleviation did not in fact replace the former. The MMEL remained unchanged as *'The right side instrument may be inoperative for day VFR operations'*.

The operator believed that the MEL, contained in his OM, had CAA approval. This was a reasonable assumption that approval of the MMEL (see paragraph 1.17.2) might also apply to the MEL, since it formed part of the documentation which is a pre-requisite for issue of an AOC. Nevertheless, as CAP 360 makes clear: 'there can be no question of the Authority or its Inspectors assuming responsibility for the detailed information provided in manuals.'

The CAA Permission relating to Article 16(2) of ANO (2) 1995 required any amendment which had the effect of rendering the MEL less restrictive than the relevant MMEL to have CAA approval before coming into effect. The lack of approval for the difference between the MMEL and MEL could have come to light during routine inspections of the operator by the assigned Flight Operations Inspector of the CAA Safety Regulation Group, but periodic reviews of the Operations Manual by the operator should also have revealed the discrepancy. It is therefore recommended that the CAA should require AOC holders periodically to verify their MEL with the MMEL. [Recommendation 96-6]

2.7 Analysis of the pre-impact break up

The small spread of wreckage pointed to a combination of low break-up height, a steep angle of descent, and a very rapid failure sequence. Analysis showed that the height at which the fuselage rupture occurred could not have been lower than about 1,500 feet agl. This is due to the length of the 'paper trail' on the ground, which would require at least this height to drift such distance in the prevailing winds. The aircraft had been heading in a northerly direction just prior to its departure from controlled flight. The wreckage distribution then gave rise to several inconsistencies which could only be explained if the aircraft was in a steep dive at high speed and if the entire break-up sequence occurred very rapidly.

A sequence of break-up which matches both the debris pattern and the physical examination of the structure in every respect remains obscure. Nevertheless the initiating factor for the sequence was excessive airspeed occurring at a height between 1,500 and 2,000 feet agl. There were indications of a brief airborne fire, probably as a result of fuel released from the disrupted right wing, but no evidence was found to suggest any structural problems pre-existed the overspeed condition which led to the eventual break-up.

2.8 Aircraft electrical system

Although the aircraft was not equipped with an FDR, information about the aircraft electrical system was available from a number of sources, including the PNIs, transponder and multiple alarm panel. Examination of the PNI instruments showed that, at impact, the compass cards of these independent systems agreed closely with the heading of the fuselage derived from the wreckage trail.

The altitude encoding operation within the altimeters and the radar transponders which use the altimeter information, are supplied by the 28V DC main bus bar (see paragraph 1.6.6). The final return on secondary radar was at 2,900 feet, after the aircraft had descended from 3,600 feet in about 25 seconds. Thus, up to and beyond the time the aircraft departed from controlled flight, the 28V DC main bus bar was still operating.

Trials had established that a secondary return could be observed as low as 700 feet (see paragraph 1.16) but the last recorded one of G-OEAA had been at 2,900 feet. Given an average rate of descent of 8,500 feet per minute, there was insufficient time for a further observation by the secondary radar between the aircraft's departure from controlled flight and the height at which it is estimated to have begun to break up. Therefore loss of secondary returns from the transponder does not indicate any electrical problem prior to the break up.

The readings of the bulbs from the Multiple Alarm Panel are open to a range of interpretations, depending on the state of disruption at the point of impact. The number of filaments which were lit at impact are a clear indication of continuing 28V DC supply.

These systems provide overwhelming evidence that there had been no failure of the 28V DC bus bars to cause the problems with the artificial horizon.

2.9 Artificial horizons

2.9.1 Probability of loss of attitude information from both artificial horizons

Although both artificial horizons were theoretically independent, experience has shown that there are a number of ways in which a loss of attitude information from both artificial horizons can occur from a common cause. For example, this could follow total electrical failure or from allowing insufficient time for gyro erection after start-up.

The indications from the examination of both artificial horizons from G-OEAA were that the instruments were still functioning at impact but were giving different readings. There is strong evidence that 28V DC electrical power was available to both artificial horizons at least up to the loss of aircraft control and probably up to impact with the ground. There was adequate time for the instrument gyros to have run up between the time power was first applied to the aircraft to the time it began to move. It is therefore most likely that at least one of the artificial horizons was malfunctioning due to one of the 'soft' failure modes described in 1.12.4.4. For other causes of total loss of attitude information, such as lightning, fire or explosion, there is no evidence at all.

For independent failures of the two artificial horizons to have been responsible for the crew's inability to control the aircraft's heading, the second failure needs to have occurred at some point between the first application of electrical power, at the outset of the flight, and a point in the air when control could reasonably have been passed to the first officer. Given some 10 minutes on the ground and 4 minutes in the air and an average MTBUR of 207 hours (commander's 225.33 hours and first officer's 188.57 hours), the probability of this occurring would be approximately 8.05×10^{-4}. This indicates that, although the possibility of independent double failure of the artificial horizons cannot be discounted, it is distinctly lower than the probability of a single artificial horizon failure.

Current JARs state that catastrophic events should be extremely improbable, defined as occurring at a rate less that one in 10^9 hours. The evidence obtained from the technical records of UK operated EMB-110 aircraft indicates that the MTBUR is 260 hours and the presence of a significant early failure pattern in which 25% of the artificial horizons had been changed within 40 hours of being fitted. These factors mean that statistically a double artificial horizon failure would not be a remote event.

In order to address the low MTBUR and early failure characteristics of EMB-110 artificial horizons demonstrated by the statistics the CAA should:

1. Require the Design Authority to define an overhaul standard applicable to the artificial horizons. This standard should include the satisfaction of relevant Service Bulletins and should be incorporated in the artificial horizons' technical manuals.

2. Initiate a campaign to return the artificial horizons in the UK EMB-110 fleet to an acceptable technical standard by overhaul in a Design Authority approved facility. This should be carried out as soon as possible.

3. Specify, for UK registered EMB-110 aircraft, a periodic overhaul at a suitable frequency in order to maintain the standard aimed at by the previous two recommendations.

4. Require the Design Authority to define suitable packaging, handling, and storage requirements to ensure the off aircraft integrity of their artificial horizons.

[Recommendation 95-34 made 19 October 1995]

The improvements listed in the above recommendation should raise the MTBUR of the artificial horizons in the UK fleet to those levels achieved by foreign operators. Since the accident, the CAA have issued Emergency Airworthiness Directive 002-11-95 mandating the manufacturer's overhaul and maintenance instructions.

2.9.2 Standby artificial horizon

Both artificial horizons nominally receive power from a different power supply but it originates from a single DC busbar. The loss of both artificial horizons can therefore be caused by either the unserviceability of both horizons, or by a total DC power failure. Although the EMB-110 was not originally certificated in the UK to the JAR requirement that catastrophic events should occur at a rate less that one in 10^9 hours requirement, such levels of reliability are clearly desirable and can be achieved by the use of triple redundancy. Such a system could also overcome the dependency of the present artificial horizons on a single DC busbar, and provide a comparator system in the event of a single artificial horizon failure.

Following an accident to a Partenavia P68B aircraft being operated by a single pilot using a single artificial horizon which failed (see paragraph 1.18.6.3), the AAIB recommended that, in the circumstances of the accident, an independently powered standby artificial horizon should be fitted. This recommendation was rejected by the CAA on the grounds that the requirement to fit a second artificial horizon would not be justified, as a third artificial horizon would also be necessary to allow positive identification of the failed instrument in the case where there is no warning flag indication. This position acknowledges the requirement for a third artificial horizon in the precise[18] circumstances of the accident involving G-OEAA. It is however inconsistent with the current ANO (2) 1995 Schedule 4 Scale E, which specifies one artificial horizon and either a turn and slip indicator or the optional addition of a second artificial horizon. The CAA's view that a third artificial horizon would be required for the purpose of identifying failed instruments is therefore fully endorsed.

Since 1994 FARs have required a third attitude indicator to be fitted to Part 121 turbojet and turboprop aircraft. The FAA stated an intention to issue a Notice of Proposed Rule Making in December 1995 requiring all commuter aircraft with between 10 and 30 seats to be fitted with a third attitude indicator.

Given the desirability of harmonising JAR and FAR requirements it is therefore recommended that the CAA should require a third artificial horizon, operated from an independent power supply and protected from voltage transients affecting the aircraft power supplies, for all aircraft in the Public Transport Category with more than nine seats. [Recommendation 95-35 made 19 October 1995 and since amended to include all aircraft in the Public Transport Category with more than nine seats in accordance with JAR-OPS1.652 (1)].

In January 1996 the CAA wrote to the AAIB stating that it was considering the need for a third artificial horizon as recommended.

2.10 Flight recorders

This investigation is yet another involving a public transport aircraft which has been handicapped by the lack of on board recorded data. Historically the EMB-110 was absolved from the requirement to fit any flight recorders because it was originally certificated at a weight which did not exceed that for which flight recorders were specified. If the C of A for G-OEAA had been issued after 1 June 1990 regulations would have required it to be fitted with a CVR and FDR. Current regulations thus support the desirability of such equipment but the impracticality of retrospective action, including economic considerations, means that considerable time must elapse before the benefits of these prescriptions to accident and incident investigation present themselves.

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18 In AIM Series 500 horizons the warning flag indication occurs only when there is no electrical power being supplied to the instrument.

JAR OPS 1.705, when promulgated, will require aircraft such as the EMB-110, which first obtained a C of A after 1 January 1990, to be retrofitted with a 30 minute CVR. This recognises the ready availability and relative simplicity of modern recorders. Although a recommendation to this end is therefore superfluous, existing exemptions by virtue of pre-dating the requirement, allow such an unsatisfactory situation to exist for the foreseeable future. The qualifying date of implementation should be removed. It is therefore recommended that the JAA should consider, in the light of developments in flight recorder technology, a requirement for all aircraft certificated in the Transport Category, which are powered by two or more turbine engines and approved to carry more than nine passengers, to be equipped with a four channel Cockpit Voice Recorder of at least 30 minutes duration. [Recommendation 96-7]

2.11 Summary

What should have been a routine flight from Leeds Bradford to Aberdeen, albeit in poor weather conditions, turned into a tragedy because the handling pilot's artificial horizon failed. This should not have proved catastrophic because it is possible to retain control of the aircraft using other flight instruments, even when a standby artificial horizon is not fitted. It requires an ability to fly by reference to 'limited panel' which is demanding and needs regular practice. Professional pilots, unlike private pilots, are not necessarily practised and tested in this aspect under existing requirements.

The most effective preventative measure for the failures which caused this accident would be the provision of an independently powered standby artificial horizon. This in turn would significantly reduce the likelihood of pilots being required to exercise their skill at instrument flight by reference to 'limited panel'. Such a recommendation has been made and, for the above reason, a recommendation for additional training in 'limited panel' by professional pilots has not been made.

In the absence of a CVR, which airworthiness requirements did not require to be fitted to this aircraft, the precise events that occurred in the cockpit during this brief flight cannot be known. It is concluded that, based on the first officer's continued operation of the RT, the commander probably was the handling pilot throughout. This leads to the conclusion that it was his own (the commander's) artificial horizon which was malfunctioning. Whilst it should have been possible to deduce which was the faulty instrument, assuming that both had not failed, and with no standby artificial horizon for comparison, such analysis demanded of the pilots all their available skills together with close co-operation between them. It cannot be known how the crew attempted to resolve their problems other than the RT report of problems with the artificial horizon(s), the predominance of left turns, the attempted climb above the cloud tops and the eventual loss of control.

The particular instruments fitted to some UK EMB-110 aircraft have been shown to exhibit an abnormally low MTBUR but trend monitoring by the operator, based as it was on single aircraft analysis, had not given rise to a major concern. The operator had taken steps to try out an alternative artificial horizon but had found its display incompatible with the existing instruments. An inconsistency between the MEL and MMEL may have created a perception on the part of the operator toward single artificial horizon failure which was less critical than that of the manufacturer and regulatory authority whose MMEL was much more restrictive.

Evidence from the radar recording and that from examination of the wreckage shows that the aircraft went out of control at about 2,900 feet having begun a controlled descent from its maximum achieved altitude of 3,600 feet, possibly attempting to regain its ATC cleared height (3,000 feet). Its airspeed in uncontrolled descent was well in excess of its maximum design speed so as to cause structural break up before the final impact.

3 Conclusions

a) Findings

The crew

(i) Both crew members were medically fit, adequately rested and properly licensed to carry out the flight. Both had recently completed routine tests on their abilities to perform their respective duties associated with the flight to a satisfactory standard.

(ii) In view of the Operations Manual description of the normal allocation of tasks between the handling and non handling pilot, where the non flying pilot is tasked with operating the radios, the commander was probably the handling pilot throughout the flight.

(iii) The commander did not maintain the heading instructions given by ATC because his artificial horizon had failed or malfunctioned. Whilst flying by reference to the remaining flight instruments, which were all found to be serviceable, he lost control of the aircraft having become spatially disoriented.

(iv) With only two horizons installed, information from both horizons had to be regarded as suspect, until the question of which one was presenting erroneous information could be resolved.

(v) The commander was responsible for the overall conduct of the flight. He does not appear to have exercised his option to hand control to the first officer. This may have been because his (the first officer's) artificial horizon was malfunctioning which would have required him to refer to 'limited panel' thereby being as poorly placed as the commander.

The aircraft

(vi) The commander's artificial horizon malfunctioned during or immediately after take-off and it is possible that the first officer's may also have malfunctioned at any time after the aircraft was started for its flight. Examination of the remaining flight instruments showed no evidence of unserviceability before the impact.

(vii) Airworthiness requirements relating to UK registered EMB-110 aircraft did not specify a third independently powered artificial horizon and none was fitted.

(viii) Both artificial horizons were recovered from the wreckage and showed evidence of electrical power to the gyros up to the point of impact. There had been no failure of the 28V DC bus bars to deprive the artificial horizons of electrical power.

(ix) The aircraft had not been struck by lightning and the electrical system was functioning until seconds before the impact.

(x) The loss of secondary returns from the transponder at 2,900 feet did not indicate any electrical supply failure prior to the break up because the final rate of descent was too high for a further return before the aircraft began to break up.

(xi) The airborne structural failure that had occurred was the result of flight characteristics which were beyond the design limits of the aircraft following the loss of control shortly before impact.

(xii) Both engines were at a medium power setting and delivering power to the propellers. Thrust asymmetry had not apparently contributed to the ultimate loss of control.

(xiii) The aircraft was exempted, by virtue of its maximum authorised weight and date of initial type certification, from the carriage of flight recorders.

The operation

(xiv) Meteorological conditions at Leeds Bradford were above the prescribed minima for take-off.

(xv) There was no evidence of unlawful interference with the aircraft or its systems.

(xvi) A discrepancy between the MEL and MMEL allowed the operator to believe that failure of either artificial horizon in IMC conditions was acceptable subject to replacement within three days. The MMEL allowed only the first officer's artificial horizon to be unserviceable and then only in VFR conditions.

(xvii) Trend monitoring by the operator, in tracing the defects of single aircraft, had not shown up the low MTBUR of artificial horizons so as to cause major concern.

(xviii) The crewing combination of the newly promoted commander and a newly qualified first officer should have been avoided, as recommended by CAP 360. Although not proscribed by any regulation, such a combination meant that the crew's capability to deal with a serious and demanding emergency may not have been maximised

(b) Causes

The following causal factors were identified:

i) One or, possibly, both of the aircraft's artificial horizons malfunctioned and, in the absence of a standby horizon, for which there was no airworthiness requirement, there was no single instrument available for assured attitude reference or simple means of determining which flight instruments had failed.

ii) The commander, who was probably the handling pilot, was initially unable to control the aircraft's heading without his artificial horizon, and was eventually unable to retain control of the aircraft whilst flying in IMC by reference to other flight instruments.

iii) The aircraft went out of control whilst flying in turbulent instrument meteorological conditions and entered a spiral dive from which the pilot, who was likely to have become spatially disoriented, was unable to recover.

4. Safety Recommendations

During the course of the investigation the following recommendations were made

4.1 In order to address the low MTBUR and early failure characteristics of EMB-110 artificial horizons demonstrated by the statistics the CAA should:

1. Require the Design Authority to define an overhaul standard applicable to the artificial horizons. This standard should include the satisfaction of relevant Service Bulletins and should be incorporated in the artificial horizons' technical manuals.
2. Initiate a campaign to return the artificial horizons in the UK EMB-110 fleet to an acceptable technical standard by overhaul in a Design Authority approved facility. This should be carried out as soon as possible.
3. Specify, for UK registered EMB-110 aircraft, a periodic overhaul at a suitable frequency in order to maintain the standard aimed at by the previous two recommendations.
4. Require the Design Authority to define suitable packaging, handling, and storage requirements to ensure the off aircraft integrity of their artificial horizons. [Recommendation 95-34 made 19 October 1995]

4.2 The CAA should require a third artificial horizon, operated from an independent power supply and protected from voltage transients affecting the aircraft power supplies, for aircraft in the Public Transport Category with more than nine seats. [Recommendation 95-35 made 19 October 1995, since amended to conform with JAR-OPS1.652 (1)]

4.3 The CAA should require AOC holders periodically to verify their MEL with the MMEL. [Recommendation 96-6]

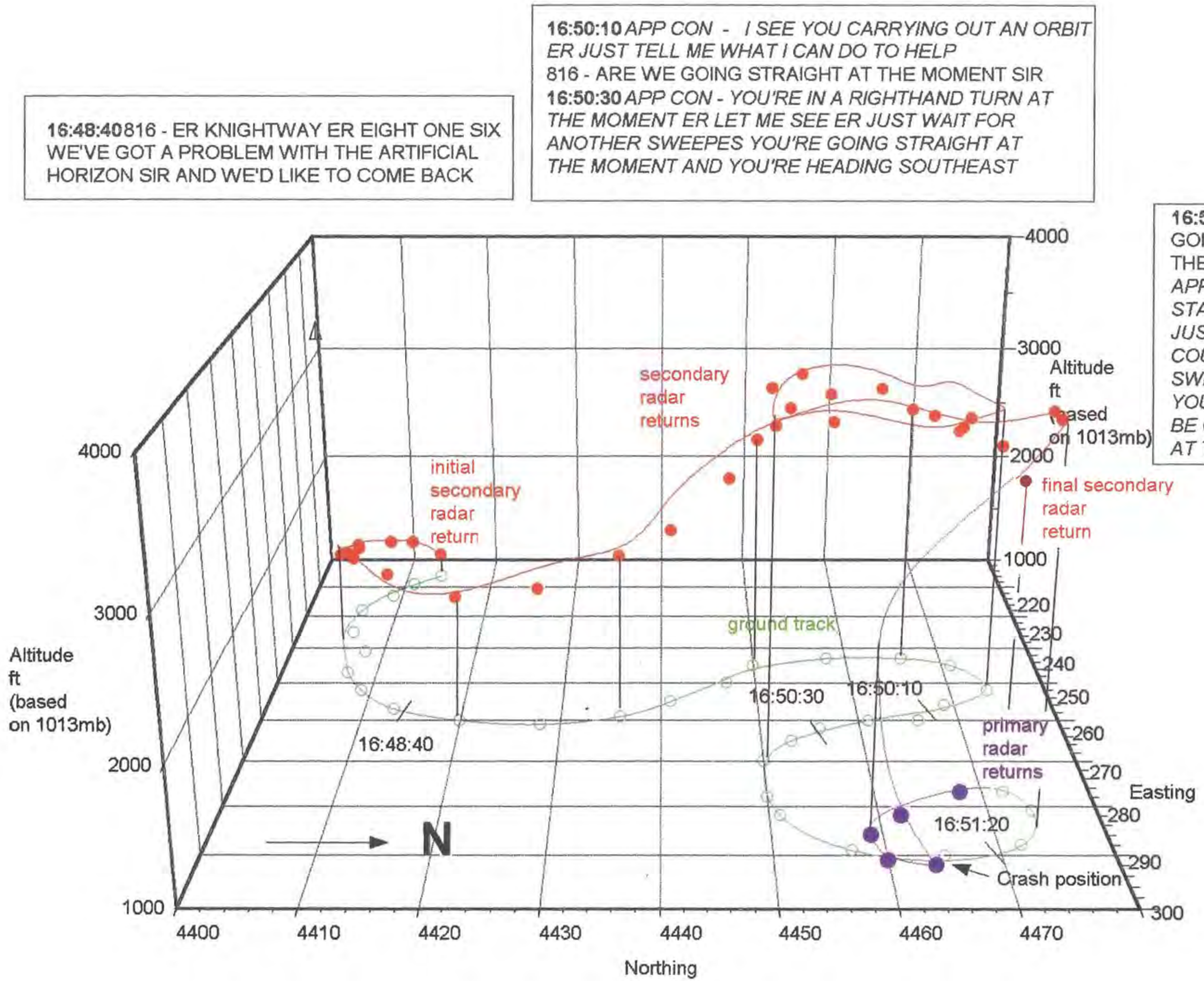
4.4 The JAA should consider, in the light of developments in flight recorder technology, a requirement for all aircraft certificated in the Transport Category, which are powered by two or more turbine engines and approved to carry more than nine passengers, to be equipped with a four channel Cockpit Voice Recorder of at least 30 minutes duration. [Recommendation 96-7]

R StJ Whidborne
Inspector of Air Accidents

May 1996

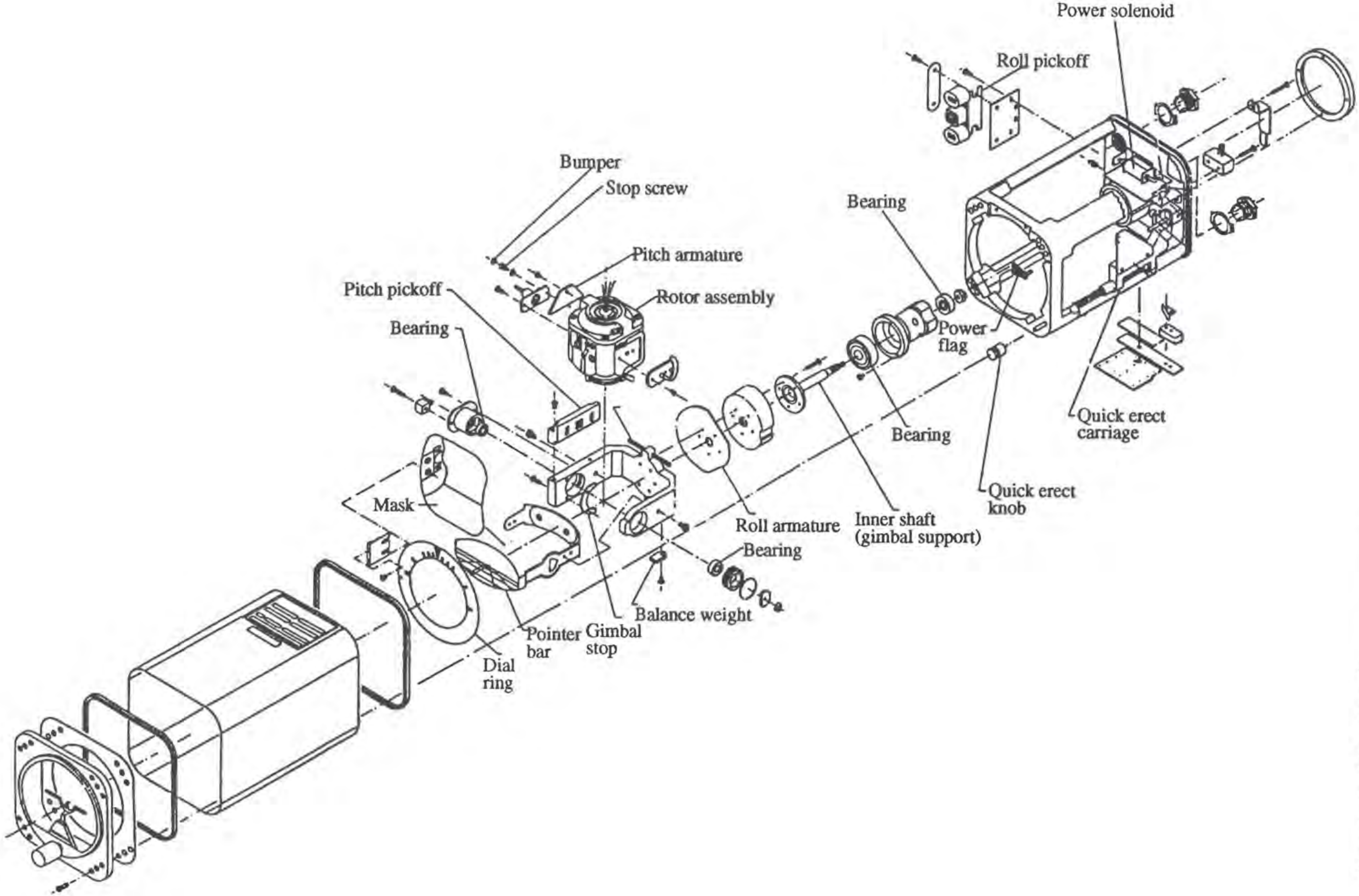
APPENDIX A

TRACK PLOT G-OEAA



APPENDIX B

TYPICAL ARTIFICIAL HORIZON (AIM 500 SERIES)



APPENDIX C

AIR TRAFFIC CONTROL

CONDENSED TRANSCRIPT OF COMMUNICATION BETWEEN LEEDS BRADFORD ATC AND KNIGHTWAY 816 [G-OEAA]

Key: Plain typescript = First officer of G-OEAA
Italic typescript = ATC
(*) = time signal as shown on left hand column

Aerodrome Control 120.300 Mhz

1641:10 LEEDS TOWER GOOD EVENING ITS THE KNIGHTWAY (*) EIGHT ONE ER SIX REQUEST START

KNIGHTWAY EIGHT ONE SIX GOOD EVENING START UP APPROVED RUNWAY THREE TWO FOR DEPARTURE CORRECTION RUNWAY ONE FOUR FOR DEPARTURE

1641:20 COPIED START APPROVED EIGHT ONE SIX (*)

1642:20 LEEDS TOWER (*) KNIGHTWAY EIGHT ONE SIX FOR TAXY

KNIGHTWAY EIGHT ONE SIX HARD RIGHT TURN TAXY TO HOLDING POINT XRAY

1642:30 HARD RIGHT HOLDING POINT XRAY KNIGHTWAY EIGHT ONE SIX(*)

KNIGHTWAY EIGHT ONE SIX ENTER BACKTRACK LINE RUNWAY ONE FOUR

1644:10 ENTER BACKTRACK LINE UP ONE FOUR KNIGHTWAY (*) EIGHT ONE SIX

1645:10 *KNIGHTWAY EIGHT ONE SIX CLEARANCE*

GO AHEAD EIGHT ONE SIX

1645:20 *EIGHT ONE SIX YOUR EVENTUAL ROUTEING WILL BE NEWCASTLE FOR ABERDEEN AFTER DEPARTURE MAINTAIN RUNWAY (*) HEADING UNTIL DIRECTED CLIMB FLIGHT LEVEL NINE ZERO SQUAWK ONE FOUR SIX TWO*

1645:30 OUR EVENTUAL ROUTEING WILL BE (*)NEWCASTLE ABERDEEN CLIMB RUNWAY HEADING TIL ADVISED CLIMB FLIGHT LEVEL NINE ZERO AND SQUAWK ONE FOUR SIX TWO

1645:40 *KNIGHTWAY EIGHT ONE SIX AFFIRM SURFACE WIND IS ONE TWO ZERO FIVE KNOTS CLEAR TAKE (*) OFF*

CLEAR TAKE OFF KNIGHTWAY EIGHT ONE SIX

1646:50 (*) EIGHT ONE SIX ROLLING

ROGER KNIGHTWAY EIGHT ONE SIX

1648:40 ER KNIGHTWAY ER EIGHT ONE SIX WE'VE GOT A PROBLEM WITH THE ARTIFICIAL HORIZON SIR AND WE'D LIKE TO (*) COME BACK

ROGER TURN LEFT RADAR HEADING THREE SIX ZERO

LEFT RADAR HEADING THREE SIX ZERO KNIGHTWAY EIGHT ONE SIX

1648:50 *KNIGHTWAY EIGHT ONE SIX (*) STOP CLIMB AT ALTITUDE THREE THOUSAND FEET Q N H ONE ZERO ZERO TWO*

STOP CLIMB AT THREE THOUSAND Q N H ONE ZERO ZERO TWO KNIGHTWAY EIGHT SIX

1649:00 (*) *EIGHT ONE SIX CONTACT APPROACH ONE TWO THREE DECIMAL SEVEN FIVE*

TO APPROACH ONE TWO THREE SEVEN FIVE KNIGHTWAY EIGHT ONE SIX

Approach Control 123.750 Mhz

1649:50 *KNIGHTWAY EIGHT ONE SIX LEEDS DO YOU READ*

1650:00 EIGHT (*) ONE SIX GO AHEAD

KNIGHTWAY EIGHT ONE SIX SIR I DON'T WANT TO ADD TO YOUR WORK LOAD BUT IF YOU JUST ER SQUAWK ZERO FOUR TWO THREE PLEASE WHEN YOU'VE GOT A MOMENT

1650:10 ZERO FOUR TWO (*) THREE EIGHT ONE SIX

I SEE YOU CARRYING OUT AN ORBIT ER JUST TELL ME WHAT I CAN DO TO HELP

ARE WE GOING STRAIGHT AT THE MOMENT SIR

1650:30 *YOU'RE IN A RIGHTHAND TURN AT THE MOMENT ER LET ME JUST SEE (*) ER JUST WAIT FOR ANOTHER SWEEP YES YOU'RE GOING STRAIGHT AT THE MOMENT AND YOU'RE HEADING SOUTHEAST*

1650:40 ER RADAR RADAR VECTORS SLOWLY BACK TO ONE FOUR THEN SIR (*) PLEASE

RADAR BACK TO ONE FOUR OKAY THEN TURN RIGHT HEADING THREE FOUR ZERO

RIGHT THREE FOUR ZERO KNIGHTWAY EIGHT ONE SIX

1651:00 *IF YOU'RE GOING LEFT CONTINUE LEFT TURN DON'T STOP IT FOR ME YOU CON- CAN CONTINUE GOING LEFT HEADING (*) THREE THREE ZERO*

LEFT THREE THREE ZERO KNIGHTWAY EIGHT ONE SIX

1651:20 ARE WE GOING STRAIGHT AT THE MOMENT SIR

ER JUST STANDBY ER JUST WAIT FOR A COUPLE OF SWEEPS YEAH YOU LOOK TO BE GOING STRAIGHT AT THE MOMENT

1651:30 (*) ANY REPORTS OF THE TOPS SIR

NOTHING REPORTED BUT I'VE GOT A DEPARTURE JUST GONE I'LL CALL HIM

1651:40 *GOLF GOLF OSCAR LEEDS YOU (*) MIGHT BE ABLE TO HELP ME WHA- ER WHAT'S THE CLOUD LIKE AT FOUR THOUSAND*

G-BAGO ER WE'RE STILL IN CLOUD AT FOUR THOUSAND AND WE'RE QUITE HAPPY TO CLIMB TO FIND THE TOPS FOR YOU IF YOU LIKE

1651:50 *(*)GOLF OSCAR YES OKAYI F YOU WOULDN'T MIND DOING THAT PLEASE LET ER DONT COMPROMISE YOURSELF LET ME KNOW IF THERE'S ER THAT IF YOU GET YOURSELF INTO TROUBLE WILL YOU DO THAT CARRYING OUT A RIGHT HAND ORBIT IN YOUR PRESENT POSITION PLEASE GOLF OSCAR*

1652:10 *KNIGHTWAY EIGHT ONE SIX LEEDS DO YOU READ*

KNIGHTWAY EIGHT ONE SIX KNIGHTWAY EIGHT ONE SIX LEEDS DO YOU READ

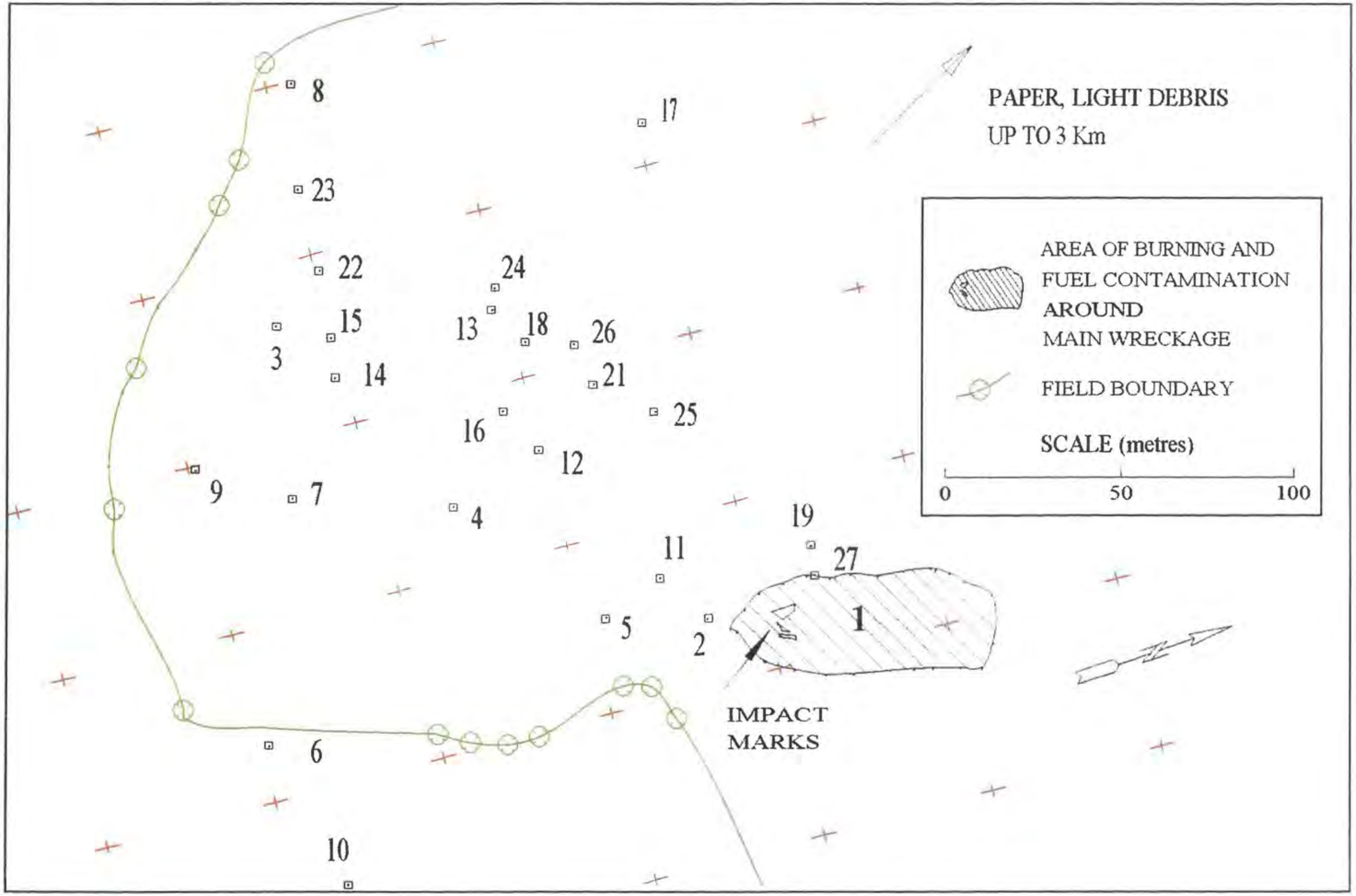
1652:30 *KNIGHTWAY EIGHT ONE SIX KNIGHTWAY EIGHT ONE (*) SIX LEEDS DO YOU READ*

DIAGRAM SHOWING WRECKAGE DISTRIBUTION

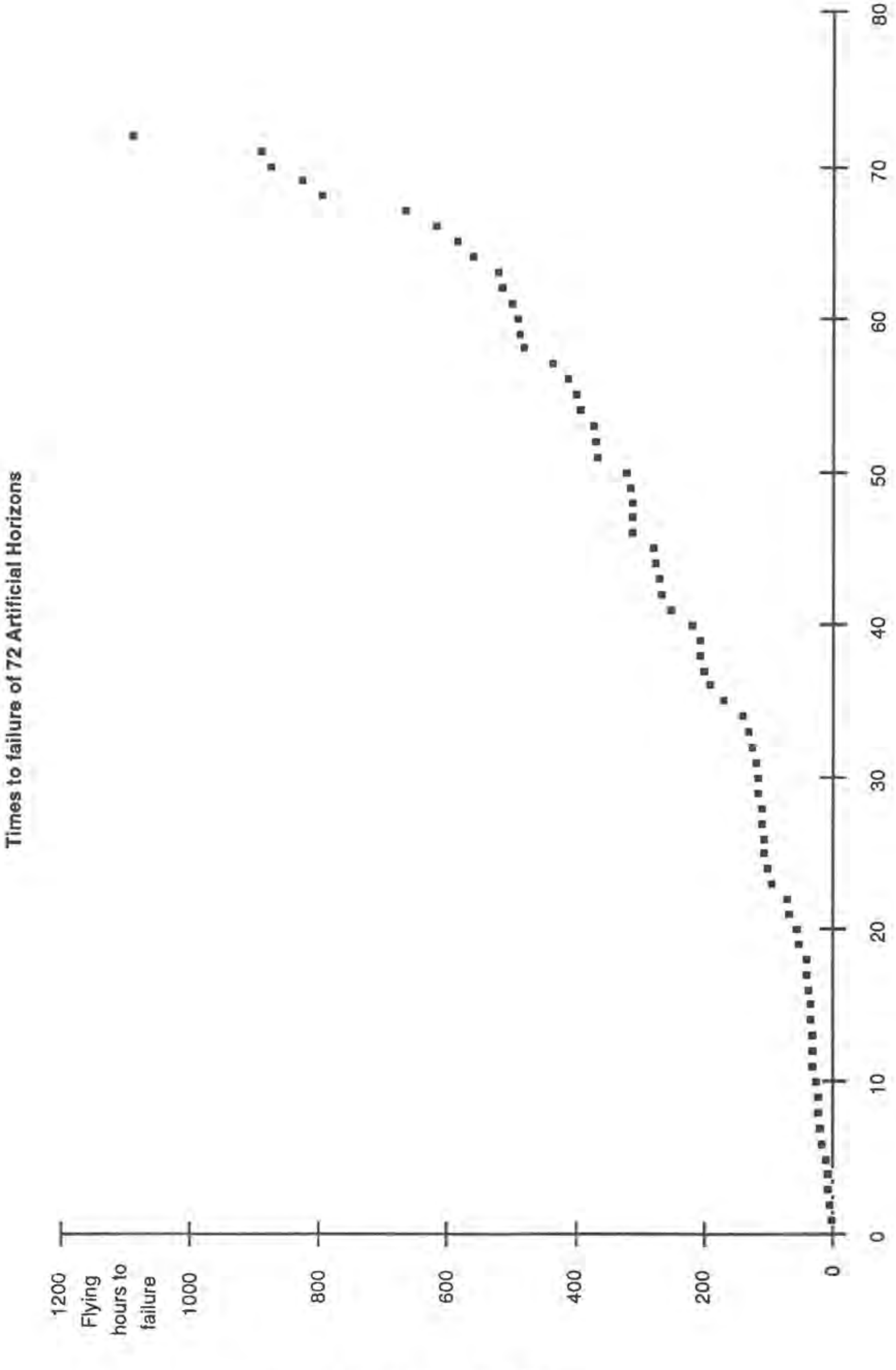
Key:

1	Main wreckage comprising fuselage, fin and rudder, right tailplane, left wing, left engine, right engine and propeller
2	Right wing torque box outboard section
3	Right wing leading edge mid-section
4	Right wing leading edge outboard section
5	Right engine lower cowling including intake
6	Right aileron
7	Right tailplane
8	Right elevator outboard section
9	Right elevator mid- section
10	Right elevator inboard section
11	Left elevator outboard section
12	Left aileron outboard section
13	Left wingtip (approx. half)
14	Fuselage skin panel
15	Right wing aileron shroud
16	Right wingtip
17	Piece of right wing/fuselage fairing
18	Right hand nacelle aft fairing
19	Left propeller
20	Right propeller and reduction gearbox
21, 22, 23 & 24	Pieces of fuselage cut by right propeller
25	Right propeller blade tip
26	Right overwing exit
27	Left overwing exit

G-OEAA DISTRIBUTION OF MAJOR ITEMS OF WRECKAGE



ARTIFICIAL HORIZONS - TIMES TO FAILURE



Printed in the United Kingdom for HMSO
Dd 0302837 6/96 C5 3400 354517 25/35578