Accidents Investigation Branch

Department of Transport

Report on the accident to Embraer Bandeirante G-OAIR at Hatton, near Peterhead on 6 November 1982

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The Rt Honourable Nicholas Ridley MP
Secretary of State for Transport

1 November 1983

Sir

I have the honour to submit the report by Mr C C Allen, an Inspector of Accidents, on the circumstances of the accident to Embraer Bandeirante G–OAIR which occurred at Hatton, near Peterhead, on 6 November 1982.

I have the honour to be
Sir
Your obedient Servant

G C Wilkinson
Chief Inspector of Accidents

Accidents Investigation Branch

Aircraft Accident Report No: 6/83
(EW/C806)

Registered Owner:		Clanair Limited
Operator:		Air Ecosse
Aircraft:	*Type:*	Embraer Bandeirante
	Model:	EMB 110–PI
	Nationality:	British
	Registration:	G–OAIR
Place of Accident:		Two kilometres north-east of Hatton, near Peterhead, Scotland Latitude: 57° 26′ 12″N Longitude: 01° 53′ 30″W
Date and Time:		6 November 1982 at about 1355 hrs All times in this report are GMT

Synopsis

The accident was notified to the Accidents Investigation Branch at 1415 hrs on 6 November 1982, and the investigation commenced the same evening.

The aircraft was engaged on a scheduled public transport flight from Prestwick to Aberdeen, with the commander/pilot as the sole occupant. Whilst in the cruise at Flight Level (FL) 70, the left-hand engine lost power; attempts to re-start the engine were unsuccessful, and the commander elected to continue the flight to Aberdeen. Shortly after the power loss, the right-hand generator went off line, and could not be re-set. The commander attempted to carry out a Surveillance Radar Approach (SRA) to Aberdeen Airport, but this was unsuccessful. Having lost contact with Aberdeen, the commander elected to descend below cloud but was unable to establish his position and made a precautionary landing in a field. The aircraft sustained substantial damage; the commander was uninjured.

The report concludes that the accident was caused by the complete loss of the aircraft's electrical power in adverse weather conditions. A contributory factor was the commander's mismanagement of the electrical system under conditions of high workload.

1. Factual Information

1.1 History of the flight

On the day of the accident the commander had departed from Aberdeen at 0925 hrs, had operated sectors to Prestwick and Belfast, and had then returned to Prestwick. His final sector was scheduled as Prestwick to Aberdeen. The weather throughout the day had been poor, with low cloud, rain and strong gusting winds predominant; however, the first three sectors had been operated on schedule and without incident. There were no reported technical defects to the aircraft.

Start-up clearance for the final sector was given at 1215 hrs, and take-off clearance from Prestwick at 1220 hrs on an Instrument Flight Rules (IFR) flight plan to Aberdeen, with a requested cruising level of FL 70 and with Edinburgh nominated as the diversion airfield. The take-off and departure procedures were normal, and the aircraft was subsequently cleared to FL 70 and to route direct Glasgow to Perth along Advisory Route DB 22 under the control of Scottish Airways. The commander stated that on reaching cruising level (1229 hrs) the aircraft was initially flying in layered cloud and, as the temperature indicated less than plus 5°C, he had the engine anti-ice systems selected ON. After a short while the aircraft flew into clear air between layers of cloud and he decided to switch the anti-icing systems OFF. At about 1232 hrs, with the aircraft on automatic pilot, he noticed a progressive fall in the torque indication of the left-hand engine. The automatic pilot was disconnected and the immediate re-light drill was carried out, without success. A second attempt was then made, using the RE-START WITH STARTER method. At the time that this re-start sequence was initiated the commander recalls a dimming of the cockpit lights, but did not notice any rise in the gas compressor speed (Ng) and accordingly did not re-introduce the fuel supply to the engine. Instead, assuming it to be unserviceable, he completed the engine shut down procedure according to the check list.

At 1235 hrs the commander reported to Scottish Airways that he had shut down the left engine and that his speed was reducing to 140 knots. In response to a question from the Airways controller, he further stated that he did not wish to declare an emergency situation at that time. Shortly after this the right-hand generator dropped off line. The commander made several attempts to re-set the generator, which did on one occasion come back on line for a period of about 20 seconds, but finally would not re-set. A systematic check of the aircraft's entire electrical installation, including the switching on and off of all equipment, failed to resolve the situation. After these checks the commander noticed that the gyroscopic flight instruments appeared to be unstable, and that warning flags were showing intermittently on the navigation instruments. He informed Scottish Airways of the problem and that he was uncertain of his position (1248 hrs). Shortly afterwards the Scottish Airways radar controller was able to establish the aircraft's position as 6 nautical miles from Glen Esk on a bearing of 240 degrees (see Appendix 1). On being informed of the latest Aberdeen weather conditions, the commander stated that he was not prepared to make an approach there unless under radar surveillance, since he no longer trusted the aircraft's Instrument Landing System (ILS) equipment. A SRA to runway 17 having been offered and accepted, at 1255 hrs control of the aircraft was transferred to Aberdeen Approach. The aircraft's position was positively identified as 5 miles north of Glen Esk on the airway centre line, and the flight was cleared to descend to 4,000 feet. During this hand-over of control the commander had successfully contacted his company operations office to advise them of his problem, using the No 2 Very High Frequency (VHF) communications transceiver.

The commander continued to fly the SRA approach under the control of Aberdeen approach radar, with a temporary interruption between 1259 hrs and 1301 hrs, during an unsuccessful change of radio frequency. Although the commander cannot recall the precise moment, there is little doubt that the flaps were lowered to the TAKE-OFF position during this approach. At about 1302 hrs the commander's RTF speech transmissions failed completely and the aircraft transmitted carrier wave only. The situation was at once recognised by the approach controller, who established that the commander was receiving ground transmissions and would acknowledge by two 'clicks' on the aircraft's transmitter. The radar controlled approach continued, using the 'click' acknowledgement method, until 1309 hrs, when the aircraft was approaching the runway extended centre line at a range of about 8 miles from touch-down. At this point there was a temporary loss of radar contact due to weather 'clutter'. The radar controller advised an overshoot, and suggested that the aircraft should climb to 3,000 feet on an easterly heading. The ATC transcript indicates that the commander started to follow these instructions to re-position the aircraft for a second approach and that he attempted to follow them, with increasing difficulty, until about 1317 hours, when all communication was lost. The aircraft then continued orbiting in an apparently random manner until about 1330 hrs, when it settled on a south-easterly heading towards the sea. The commander remembers only that after reaching 3,000 feet he waited for the compass indications to settle down; he was uncertain of his position and considered all the aircraft's flight instruments to be totally unreliable. Accordingly he decided to attempt to turn the aircraft towards the east and descend through cloud over the sea, with the intention of making visual contact with land and subsequently navigating visually along the coastline back to Aberdeen. The commander later stated that he broadcast his intentions with an open transmission on the International Distress frequency, 121.5 MHz. This call does not appear to have been received by any ground station, and the frequency is not monitored by Aberdeen Air Traffic Control.

At 1337 hrs the Bandeirante was observed, on radar, crossing the coast on an easterly heading over Hackley Head, some 12 miles north of Aberdeen. The aircraft descended below the cloud and the commander saw a stretch of coastline where a river entered the sea. Believing this to be close to Montrose, he headed north towards, as he thought, Aberdeen. However, it soon became obvious to him that the coastline was unfamiliar and, being concerned about the aircraft's fuel state, he turned the aircraft inland in order to find a suitable field in which to make a precautionary landing. The aircraft re-crossed the coast at 1340 hrs, just north of the Bay of Cruden, and at 1344 hrs it was observed on radar, in a left-hand orbit, north of the bay.

The commander reports that he selected two fields, with a southerly aspect, close to a main road. He lowered the landing gear using the emergency manual system, and then made a slow shallow turn onto a base leg, but lost sight of the fields due to the poor visibility. A second circuit revealed a further field with a southerly aspect, and the aircraft was subsequently landed in this field at about 1355 hrs. The landing was heavy and the aircraft bounced. On the second touch-down the nose landing gear collapsed, allowing the nose section and propellers to strike the ground before the aircraft eventually came to rest. The commander, who was uninjured, switched off the electrical master switch and vacated the aircraft. When it became apparent that there was no danger of fire he re-entered the aircraft, completed the shut down sequence, and later reported the accident by telephone from a nearby farmhouse.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	—	—	—
Serious	—	—	—
Minor/none	1	—	

1.3 Damage to aircraft

The nose landing gear up-lock mechanism was torn from the airframe mounting, causing the nose landing gear to pivot rearwards and severely damage the rear of the nose gear bay and the lower fuselage. The underside nose fuselage area and nose landing gear bay were severely damaged in the subsequent impact. The right-hand propeller and engine were destroyed. The right main landing gear sustained damage consistent with a heavy landing.

1.4 Other damage

Minor damage was caused to a crop of winter barley.

1.5 Personnel information

Commander:	Male, aged 42 years
Licence:	Airline Transport Pilot's Licence valid until 1 April 1991
Aircraft ratings:	PA28, PA32, PA23, DHC–6 Twin Otter, EMB–110 Bandeirante
Instrument ratings:	18 December 1981, valid until 17 January 1983

Last medical examination:	3 October 1982, valid until 2 March 1983 with no restrictions
Flying experience:	
Total hours as pilot:	4,800
Total hours in command:	4,550
Total hours on type:	1,700
Total hours in preceeding 28 days:	46 (of which 18 were on type)
Total hours in preceeding 24 hours:	3.20
Rest period before duty on day of accident flight:	17 hours

The commander had completed a company base check flight on 28 June 1982 and his performance was assessed as satisfactory in all respects. A further base check was flown after the accident, on 10 November 1982, and again his performance was assessed as satisfactory.

1.6 Aircraft information

1.6.1 Leading particulars

Type:	Embraer EMB–110 P1 Bandeirante
Constructor's Number:	110222
Date of Manufacture:	August 1979
Certificate of Registration:	The registered owners were Clanair Ltd
Certificate of Airworthiness (C of A):	UK Transport (Passenger) category, first issued by the Civil Aviation Authority (CAA) on 10 October 1979 and valid until 9 October 1983
Certificate of Maintenance:	Renewed on 1 November 1982 at 4,867 airframe hours, and valid until 29 November 1982 or a further 200 flying hours, whichever was the sooner
Total airframe hours:	4,912.53
Engines (2)	Pratt and Whitney PT6A–34
Propellers (2):	Hartzell HCB3TN–3C

Total engine hours (both):	4,912.9
Maximum weight authorised for take-off:	5700 kg (12,566 lb)
Actual take-off weight:	4387 kg (9,673 lb)
Maximum weight authorised for landing:	5450 kg (12,015 lb)
Estimated landing weight:	4179 kg (9,212 lb)
Estimated fuel remaining at time of accident:	302 kg (666 lb)
Type of fuel:	JET A–1 (AVTUR)

Centre of Gravity (CG)

The CG limits at the actual take-off weight were between 5.3% and 31% mean aerodynamic chord (MAC), with the CG at 17.5% MAC. The CG remained within the aircraft's weight and centre of gravity envelope throughout the flight.

1.6.2 *Engine anti-ice systems*

The air inlet of each engine is provided with an electrical anti-ice protection system which, when selected, activates electrical heater elements which are bonded to the air inlet lips of each engine. In addition, an inertial separation system is installed at each engine air inlet, in order to deflect the airflow so as to minimise the ingestion of frozen water or snow particles during flight in icing conditions. Instructions concerning the operation of the engine anti-ice system are included in the Aircraft Flight Manual as follows:

The system should be turned on:

- whenever the OAT is at or below +5° C and when visible moisture is present
- whenever ice formations are visible, or
- at the first evidence of ice formation on any other section of the aircraft.

A cautionary notice warns that: 'Engine air inlet anti-ice system should not be switched on unless the inertial separation system has been turned on'.

The two pressure sensing pipes that allow the engine fuel control unit (FCU) and propeller governor to sense compressor discharge pressure are provided with heating elements which are controlled by the pressure (Px) switch. This heating must be selected ON during operations with ambient temperatures below +5° C. The relevant switch was found in the ON position during the examination of the aircraft after the accident.

1.6.3 *Engine starting/re-light system*

The engine starting system consists basically of a starter/generator, a starter relay, a generator control unit (GCU), and a spring loaded, centre off, starting switch. An engine start can be performed either by using an external power source, the aircraft battery, or the aircraft battery aided by an 'on-line' generator. The system is supplied from the 28 volt main bus-bar and is activated by momentarily pressing up the starting switch, located on the overhead panel, to the START position. Once activated, the start cycle is controlled by relays and the GCU, and is automatically stopped by the GCU sensing circuit when the gas generator speed reaches 45% to 50%. In the case of an unsuccessful start (or for maintenance purposes), the start cycle must be manually interrupted by moving the starting switch to the INTERRUPTION position. A green indicator light, mounted on the overhead panel next to the starting switch, illuminates whenever the start circuit is energised.

1.6.4 *Engine re-light drills*

The recommended drills in the event of an engine flame-out in flight are described in the Aircraft Flight Manual, and listed in the in-flight check lists. The drills include an immediate re-light procedure, and a re-start procedure using the starter/generator. The immediate re-light drill should be used after an engine failure when the Ng has not fallen below 50%. In this case the in-flight ignition switch is selected to IN-FLIGHT IGNITION and, if the engine re-starts, power can be restored. The alternative drill, RE-START WITH STARTER is used when, following an engine failure, the Ng has fallen below 50%, and is as follows:

GENERATOR	OFF
SHUT-OFF VALVE	ON
POWER LEVER	IDLE
PROPELLER LEVER	FEATHER
FUEL CONDITION LEVER	FUEL CUT-OFF
FUEL BOOSTER PUMPS	ON/AUTO
Perform normal start	When Ng stabilises:
PROPELLER	UNFEATHER
GENERATOR	ON
ICE & RAIN PROTECTION	REVIEW PRECAUTIONS

The Flight Manual and Normal check lists include the warning that:

> 'The starting cycle is automatic and does not require subsequent action, provided the engine accelerates normally and continually, and reaches the stabilised low idle speed. If the ignition light does not turn off after 45% Ng the starting switch must be immediately positioned to INTERRUPTION in order to avoid starter damage.'

At the date of the accident, this warning was not included in the in-flight Emergency drills check lists. However, shortly after the accident, the CAA advised all Bandeirante operators that check lists should be amended to include the warning.

The commander cannot remember whether, after the left engine failed to start, on using the RE-START WITH STARTER drill, he selected the starting switch to the INTERRUPTION position.

1.6.5 *DC electrical system*

1.6.5.1 *General description*

During normal operation DC electrical power is supplied by two engine-driven DC generators. When both of the generators are inoperative, DC power is supplied by the aircraft's battery. The DC generation system for each engine consists of a DC starter/generator capable of supplying 200A at 28V DC, a reverse current relay (RCR), a GCU, two line protection relays, a volt/ammeter and a switch.

1.6.5.2 *Emergency operation*

In the event of the loss of both generators, the drills to be carried out are listed in the in-flight check list Emergency drills, and described in more detail in the Aircraft Flight Manual. The immediate actions, as set-out in the in-flight check list are as follows:

GENERATORS	RE-SET

If they fail to re-set, turn off and proceed:

EMERGENCY BUS BAR SWITCH	EMERGENCY
UTILITY LIGHTS	ON
IGNITION AND FUEL PUMPS (MAIN AND AUXILIARY)	OFF UNLESS REQUIRED FOR STARTING THE ENGINES
BATTERY ENDURANCE	30 MINUTES

Once the emergency bus-bar switch has been selected to EMERGENCY the electrical services that remain energised are restricted to the following:

- Pilot's horizon
- Pilot's gyrocompass system
- Pitot static heating system
- Ignition
- Auxiliary fuel pumps
- VHF 1
- VOR/ILS/MKR 1
- Audio control panels (both)
- Utility lights
- Emergency lights system
- Landing gear actuation
- Landing gear position indicator
- Shut-off valves

The Aircraft Flight Manual also includes the following note:

> 'In case other services aboard the aircraft are required beyond those supplied by the emergency bus-bar, turn off all equipment which is not essential and return the switch to NORMAL. In this condition the battery endurance may be penalised.'

The in-flight emergency check lists include the information that the aircraft battery should adequately supply the emergency bus-bar services for 30 minutes; the check lists do not include the warning that, after a double generator failure, if the emergency bus-bar switch is not immediately selected to EMERGENCY, the battery endurance may be penalised. The 30 minute endurance is based on the assumption of a five minute delay in crew response.

1.6.6 *Airworthiness requirements regarding power sources for attitude reference instruments*

Because the Bandeirante's basic aircraft attitude indication system is totally electric, the United States Federal Aviation Administration originally required the fitment of a third vacuum powered attitude indicator, or a dedicated emergency battery, separate from the aircraft's electrical system, to power the indicator. In practice, this requirement was met by the installation of an additional battery, separate from the main electrical system, as an alternative power source for the P1 attitude indicator. Subsequent lack of adverse service experience resulted in a relaxation of this requirement.

The fitting of a standby attitude indicator or, alternatively, a separate power supply, was not required by the UK certificating authority.

1.7 Meteorological information

1.7.1 Synoptic situation

Low pressure over the Atlantic and an anticyclone over western Russia were maintaining a mild, moist southerly airflow over the area. A weak warm front over north-west Scotland was moving slowly away to the north-west. Surface winds were generally 150°/20 to 25 knots with gusts to 35 knots.

1.7.2 Forecast conditions

Before the aircraft departed from Prestwick the commander had obtained the forecasts for Aberdeen and Edinburgh, valid from 0700 hrs to 1600 hrs. That for Aberdeen is as follows:

Surface wind:	160°/22 knots gusting to 32 knots
Visibility:	3000 metres, intermittent moderate rain
Cloud:	8 oktas stratus at 400 feet

Intermittently, between 0700 hrs and 1200 hrs, becoming

Visibility:	1500 metres
Cloud:	8 oktas stratus at 200 feet

1.7.3 Actual weather conditions

The following weather report for Aberdeen was passed to the commander by the Scottish Airways controller at 1253 hrs:

> Surface wind 170° at 25 knots, gusting 35 knots. Visibility 3000 metres, rain, 2 oktas at 600 feet, 4 oktas at 700 feet, 8 oktas at 900 feet, temperature plus 10°C.

Additional weather reports recorded at Aberdeen were:

1320 hrs Surface wind 150°/22 knots, visibility 3500 metres, recent rain, 5 oktas at 800 feet, 8 oktas at 900 feet, temperature plus 10° C, dew point plus 08° C.

1350 hrs Surface wind 160°/23 knots maximum 33 knots, intermittent light rain, 5 oktas at 800 feet, 8 oktas at 900 feet, temperature plus 10°C, dew point plus 08°C.

The estimated height of the 0°C isotherm *en route* was 7,500 feet.

1.7.4 *Significant meteorological phenomena (SIGMET)*

The following SIGMET report was issued at Prestwick airport prior to the aircraft's departure.

> Aberdeen Strong Wind Warning valid 0630 to 2200 hrs: "The strong south-easterly winds mean speed 25 knots gusts to 35 knots will continue".

The commander was also passed the following SIGMET:

> Prestwick SIGMET No 1 valid 1130 to 1530 hrs: "Local severe turbulence forecast below 6,000 feet land area south of Scottish Flight Information Region east of 005°W, extending westwards".

The accident occurred in daylight.

1.8 Aids to navigation

Throughout the accident flight there were no reports of unserviceability to either the radar or navigational facilities on Advisory Route DB 22.

A comprehensive selection of pertinent maps, airways charts and flight information documents was carried on the aircraft.

1.9 Communications

VHF communication was satisfactory on all frequencies between the aircraft and ground stations from the time of the commencement of the flight until about 1302 hrs, when the speech transmissions from the aircraft failed. The commander continued to acknowledge receipt of transmissions, using carrier wave only, until about 1313 hrs. From the evidence of the RTF recording it appears probable that he continued following the Aberdeen Approach radar controller's instructions until about 1317 hrs, when all communication was lost.

Subsequently, the radar controller continued to transmit position reports and instructions to the aircraft until it disappeared from radar cover whilst making the precautionary landing. These transmissions contained sufficient indication of the aircraft's position to make it possible to provide, from the transcript, an assessment of its track until shortly before the landing. The assessment is shown at Appendix 1.

1.10 Aerodrome information – Aberdeen Airport

Aberdeen Airport is licensed for public use, and equipped with all the approach and landing aids normally associated with a major airport. On the day of the accident, due to the prevailing weather conditions, the runway in use was 17. There are published airfield and runway approach procedures to this runway embracing all available aids. These consist of ILS, VOR, NDB, and SRA. All the navigational, approach and radar aids were serviceable at the time of the accident flight.

1.11 Flight recorders

Neither were fitted nor required.

1.12 Wreckage and impact information

1.12.1 On site examination

The field in which the accident occurred was planted with a young crop which, combined with recent heavy rainfall, made the surface conditions very soft. The landing run of the aircraft was made towards moderately rising ground, with a significant rise occurring about 30 degrees left of the landing heading at a distance of some 600 metres. The evidence from the ground impact marks indicated that the aircraft initially touched down firmly on the main landing gear, followed, after 6 metres ground run, by the nose landing gear. After 10 metres of three point ground run, the aircraft became airborne again before contacting the ground for the second time, nose gear first, and with considerable downwards force. The nose gear remained in contact for approximately 9.50 metres before the main gear touched for the second time. During the ground run on the nose gear alone, this gear collapsed and a nose gear door was torn from its mounting point. The aircraft continued the ground run for a further 33.50 metres before coming to rest. The witness marks indicated that, at impact, the aircraft's attitude was slightly nose-up, wings level, but rolling to the right, and on a heading of 222° magnetic. The left propeller was feathered and not rotating, and the right propeller was rotating under moderate power. The total ground run was 60.35 metres and the aircraft configuration: landing gear DOWN, flaps 28° (TAKE-OFF position).

After the landing the pilot completed a normal shut down sequence; thus when the aircraft was first examined in detail after the accident all electrical switches were found in the OFF position. The flap selector was in the TAKE-OFF position, and the normal landing gear selector was selected to DOWN. The emergency landing gear selector's wire locking was not broken, and the emergency manual gear lowering pump had been operated. Both main fuel shut-off selector switches were selected to OPEN, all fuel pumps had been switched OFF, and the crossfeed selector was CLOSED. The fuel flow integrator showed a reading of 333.1 lbs. The navigation/communications equipment had all been switched off.

The battery open circuit terminal voltage was measured and found to be 16 volts. This measurement was taken approximately 18 hours after the accident. At approximately the same time, with the emergency bus-bar selected, the battery master switch was selected ON;

the emergency bus-bar magnetic indicator went to the in-line position, the P1 artificial horizon OFF flag disappeared from view and the horizon gyroscope started to spin up. The P1 directional gyroscope started to operate, and the landing gear position lights illuminated, showing green for the main gear and red for the nose. The battery voltage indicated on the aircraft voltmeter was 12 volts. The following day, a fully serviceable battery was fitted to the aircraft, the main and emergency bus-bars selected in turn, and all indications were normal. The fuel contents gauges registered 480 lbs (218 kg) in the left wing and 300 lbs (136 kg) in the right wing. However, as the aircraft attitude was considerably nose down, these readings were not considered to be accurate. All the fuel pumps were, in turn, switched on momentarily, and indications of fuel pressure were observed. Each invertor was selected in turn and found to function normally. The flap position indicator registered 28°, the normal TAKE-OFF selection. External examination of the aircraft confirmed that the flap, trim and fuel valve settings agreed with the cockpit selections.

Both engines were externally examined on site. The left engine was undamaged and no disconnect or failure of the system's controls or components was observed. The left propeller and free turbine were found to rotate without restriction. The right engine was severely damaged, consistent with the propeller striking the ground under moderate power. Both engines' inertial separator plates were found to be retracted and their air intakes unrestricted.

1.12.2 *Subsequent detailed examination*

The aircraft was recovered from the accident site, underslung beneath a helicopter, and airlifted to Aberdeen Airport. The engines, starter/generators, and battery, were removed for more detailed examination, and the airframe was dismantled and transported to Norwich Airport for repair.

1.12.2.1 *Left engine*

The left engine was removed from the aircraft, each control and system connection being examined prior to disconnection. The fuel control unit (FCU) and the engine driven fuel pump (EDP) were removed from the accessory gearbox and the spline drives were examined for integrity and found to be serviceable. All pressure sensing pipes were removed, checked for cracks, and found to be serviceable. All of the fuel components and filters were examined and no water or other contaminant was found. The FCU and EDP were bench tested in the 'as-found' condition and found to be serviceable. The items removed from the engine were re-fitted and the engine, less its starter/generator, was placed on a test bed. The engine started normally and a full engine run test schedule was then carried out, followed by a hot start: all the engine specifications were achieved.

1.12.2.2 *Fuel system*

The left fuel system was examined and no fault was found except that the filler cap seal was in a poor condition. An internal examination of the fuel tanks showed them to be in good condition and very clean. The main fuel filter was examined and no water or other contaminant was found. Fuel flow checks were performed and found to be satisfactory.

1.12.2.3 Starter/generators

Both starter/generators were visually examined and functionally tested. The visual examination of the left starter/generator revealed that it had been severely overheated in the area of the brushes and windings. This had been caused by the unit being subjected to a high current for a period in excess of approximately 2½ minutes. It was not possible to establish whether this had occurred in the starter or in the generation modes. The right starter/generator exhibited evidence consistent with normal usage. Both units were bench tested and found to be within the minimum specifications, except that in the start mode they were both between 5% and 11% below the minimum speed requirement. The left unit was fitted to an engine and found to carry out an engine start adequately.

1.12.2.4 Aircraft battery

The aircraft battery was subjected to a detailed examination, from which it was concluded that it had been serviceable prior to the accident, and that thermal runaway had not occurred.

1.12.2.5 Electrical system

A detailed examination of the electrical wiring and components revealed no indication of a malfunction, short circuit, disconnection or overheating. After the major repair had been carried out to the airframe, the electrical systems were thoroughly tested, both with and without engines running, and no faults could be found except that the generator current limiting circuit in the GCU was not functioning. As the left generator system was not involved in the accident sequence, this fault is not considered relevant.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

There was no fire.

1.15 Survival aspects

At about 1252 hrs, when the commander reported to Scottish Airways that the aircraft's navigational equipment was suspect, the Scottish Airways Supervisor declared an UNCERTAINTY phase; this was up-graded to an ALERT phase at 1325 hrs. The Rescue Co-ordination Centre, Pitreavie, then tasked a Royal Air Force Nimrod aircraft to the Aberdeen area to assist. At 1335 hrs the Airways Supervisor declared a DISTRESS phase. The Nimrod, call-sign Rescue 01, first contacted Aberdeen Approach at 1336 hrs. At this time the controller was monitoring a radar contact that he believed to be the Bandeirante, and transmitting continuous position reports which he hoped might be heard by the aircraft; subsequent investigation confirmed that the radar return was from the accident aircraft. A Royal Air Force Search and Rescue Wessex helicopter was despatched from Leuchars at 1343 hrs; at 1356 hrs the Nimrod arrived over the Bay of Cruden and commenced a search.

The Bandeirante had made its precautionary landing at 1355 hrs. Shortly afterwards the Royal Air Force helicopter landed in the same field, and after the crew had established that casualty evacuation was not required, the helicopter returned to Leuchars. At 1411 hrs it was confirmed that the pilot was safe and that ground agencies were at the accident site; accordingly all search and rescue units were stood down.

1.16 Tests and research

Tests were undertaken on the accident aircraft and its associated systems and equipment as described in the following sub-paragraphs.

1.16.1 Fuel quality and quantity

Fuel samples taken from the aircraft's left-hand fuel system were sent for analysis and found to conform to the required specification and had no water or other contaminant.

The aircraft's fuel flow totalizer receives its power supply from the main bus-bar; thus from its reading an estimate may be made of the time at which this supply was disconnected. On examination, after the accident, the fuel totalizer recorded 333.1 lbs (151 kg). From the aircraft's performance data it was calculated that, for a flight under the accident conditions, and assuming two engines operating for the first 15 minutes and one engine thereafter, 333 lbs of fuel would have been consumed in about 44 minutes from the time that the engines were started. Engine start clearance was granted at 1215 hrs; thus, provided that the battery MAIN/EMERGENCY switch was undisturbed from the MAIN selection, a totalizer reading of 333.1 lbs should have been achieved at about 1259 hrs.

1.16.2 Fuel filler caps

Both fuel filler caps, complete with their wing mounted seals, were tested by immersion in water. It was found that both allowed water to penetrate the seals, the left one at approximately twice the rate of the right.

In 1981 the manufacturer produced a Service Bulletin that provided new and smaller fuel filler caps, with more effective sealing. The reason for the issue of the bulletin was that instances had been reported of water penetration into the wing fuel tanks through the fuel filler caps. The bulletin was not made mandatory and, at the time of the accident, had not been carried out on G–OAIR.

1.16.3 Starting current

An engine start using a 28 volt external power source was carried out, the current being monitored and found to register 1000 amps initially; this rapidly decayed to 450 amps, at which figure it stabilised until the start cycle was de-energised.

1.16.4 The electrical system

A test was carried out, on the ground, to determine the consequences of leaving the start sequence uninterrupted after a failed start, using internal power which was being supplied by an on-line generator and the aircraft's battery. The start sequence was left uninterrupted for nine minutes, during which time the operating generator remained on-line with an output limited to approximately 275 amps. It was considered prudent to discontinue the test at this point due to the likelihood of damage to components from overheating. The main bus-bar voltage and battery voltage decayed over the nine minute period to approximately 15 volts, with the most rapid decay occurring over the last two minutes. There was a small increase in the monitored battery temperature.

1.16.5 Engine air intake anti-ice system

With the engines running and the air intake anti-ice systems switched on, the temperature achieved by the electrically heated anti-ice mats was measured and found to be acceptable and similar for both engines.

1.16.6 Avionics

The P1 artificial horizon and communication/navigation systems 1 and 2 were bench tested and found to be serviceable. The artificial horizon OFF flag became visible at approximately 10-11 volts DC, although the instrument was still functioning. With the OFF flag visible and electrical power at approximately 10 volts being applied, the instrument was vigorously exercised in both pitch and roll attitudes. The response was sluggish but the instrument did not topple. The No 1 communication transmitter/receiver was found to be within specification down to 13.75 volts DC supply.

1.16.7 The subsequent air test

Upon completion of the airframe repair, two overhauled engines were installed, one of which incorporated the original right-hand starter/generator, and a full ground run and C of A air test were carried out. After a few faults (not relevant to this investigation) had been rectified, the tests were successfully completed. After these tests, the aircraft was returned to scheduled service, where it was reported to be operating satisfactorily.

1.17 Additional information

1.17.1 Minimum crew

The regulations concerning the composition of crew of aircraft are laid down in the Air Navigation Order, 1980, (ANO), Part IV, Article 17. Relevant extracts are given at Appendix 2.

The Flight Manual for the Bandeirante aircraft contains the following minimum crew limitations:

Minimum Flight Crew

'For flights conducted wholly outside controlled airspace: one pilot. For flights conducted partially or wholly within controller airspace: one pilot and one other crew member who shall hold a Private Pilot's Licence, or a Commercial Pilot's Licence or a Senior Commercial Pilot's Licence or an Airline Transport Pilot's Licence or a Flight Navigator's Licence, together with a Flight Radio Telegraphy or Telephony Operator's Licence; however, if a serviceable auto-pilot with altitude and heading hold modes is available at the commencement of the flight, this second crew member need not be carried.'

1.17.2 *Weather landing minima*

The United Kingdom Air Pilot, Rules of the Air and Air Traffic Services, RAC 4–5–1, details the minimum landing conditions for a Surveillance Radar Approach to runway 17 at Aberdeen Airport. The termination range from touch-down is 2 nautical miles, and the Obstacle Clearance Limit (OCL) is 620 feet above the runway threshold. These limits were noted by the commander and correctly recorded in his airborne flight log.

1.17.3 *Engine failures on Bandeirante aircraft*

Examination of UK Occurrence Reports for the Bandeirante since 1978 shows that there have been six occurrences of in-flight engine failures without any form of prior warning. Subsequent investigation showed that:

Two of these occurrences had been caused by mechanical failures within the fuel system.

One was found to have 'slight' water contamination in the fuel tank, but all the filters were found to be satisfactory, as was the engine ground run.

One had no fault found except for a small amount of sooty contaminant in the FCU which may conceivably have restricted an orifice; however, this should only have caused the engine power to reduce to the idle condition.

In the two remaining occurrences no fault was found; one was successfully restarted in flight and the other on the ground; both installations continued in service with no further problems.

Examination of US Occurrence Reports since 1980 shows that there have been nine occasions of in-flight engine failures. Six of these occurrences were due to mechanical failures within the fuel system, two were catastrophic failures and one was caused by lack of fuel in the tank. There were no reports of unexplained in-flight engine failures.

1.17.4 Engine inlet icing

The engine manufacturer, Pratt & Whitney Aircraft of Canada, (P & W C), was asked for its experience and opinion on intake icing generally and with reference to this case specifically.

The manufacturer stated that all PT6A turboprop engines, including the PT6A–34, are protected from engine air inlet icing by an inertial separator system which was developed by themselves and approved by the Department of Transport, Canada. In addition, each individual PT6A engine installation, including the Embraer EMB 110–P1, was examined and approved by them for conformity relating to air inlet configuration.

Over the past several years P & W C have documented a number of cases where ice was suspected to have caused compressor damage and they have some considerable experience, through their customers' activities, of the operational effects of inlet ice build up. Generally they have found that there is a power loss and increased turbine temperature which is often followed by compressor stall. Generally following such an event the power returns automatically to near normal as any possible blockage clears. Subsequent ground inspection usually reveals a few bent first stage compressor blades. They have not recorded any incidents of engine failures due to suspected icing.

P & W C suspect that operation in sustained heavy precipitation below freezing and without the inertial separator system deployed can cause ice build-up under the inlet screen. It is the ice release impacting the wide chord first stage compressor blades that causes the stall and, typically, curled tip type damage. PT6A engines are not fitted with inlet guide vanes in front of the first compressor stage.

They stated that the kind of weather the aircraft was in prior to the engine failure was just the type of weather where the anti-ice system was needed although they do not believe that the lack of anti-icing contributed to the engine failure.

It is the P & W C considered opinion that the failure of the left engine could in no way be attributed to intake icing in view of the following:

At no time during the flight did the inlet air temperature reduce below the freezing point.

The engine failed apparently without warning, which is not possible if ice were involved.

There was no compressor blade damage, which would be quite unusual if ice were involved.

The right engine continued to operate normally under the same climatic conditions, which is considered strange if ice were involved.

1.17.5 *In-flight generator failure*

On 1 November 1982, 5 days before the accident, this aircraft suffered an in-flight failure of the right-hand generator while flying in cloud. The generator was successfully re-set and the flight continued normally. A comprehensive engineering check was carried out and no fault could be found. Examination of the maintenance records for this aircraft and others of the same type showed that generator and associated system failures were not an uncommon occurrence, although none resulted in a situation arising that was hazardous to the safe operation of the aircraft. They were therefore assessed as not warranting a Mandatory Occurrence Report (MOR).

1.17.6 *Battery condition*

During the investigation into the previous in-flight generator failure referred to in paragraph 1.17.5, an engine start on the battery only was carried out. The start was performed normally with all indications that the battery was in good condition. There were no reports or indications in the maintenance records that the battery was in a poor condition prior to the accident.

2. Analysis

2.1 General

The sources of evidence available to the investigation were largely limited to the aircraft itself, the commander's recollection of the flight, and the recording and transcription of the associated RTF communications. In spite of extensive examination and testing of the aircraft and its equipment, it has not been possible to establish positively either the cause of the engine failure and its failure to re-start, or the reason why the right-hand generator dropped off line and failed to re-set.

2.2 The engine failure

Once a gas turbine engine is running there are basically only three factors which can cause it to run down, and these are discussed below.

2.2.1 *Mechanical failure*

This possibility can be discounted because no mechanical defect was found either during the on site or subsequent investigations, and the engine was later run on a test bed installation and found to be fully serviceable.

2.2.2 *Failure, interruption, or contamination of the fuel supply*

Evidence from the on site examination shows that there was a sufficient quantity of fuel available, and that it was of the correct type and was uncontaminated. The fuel delivery system was subsequently found to be functioning correctly, the fuel tanks and main filter were clean, and the fuel flow checks were satisfactory. Similarly, the possibility of an air-lock in the fuel system was discounted in view of the fact that the engine had been running satisfactorily for about 13 minutes since take-off, following a turn-around during which the fuel system was not disturbed.

No traces of water could be found in the fuel remaining. Therefore, although the possibility of water contamination cannot be ruled out, there is no positive evidence that it did occur.

2.2.3 *Air starvation due to intake icing*

In view of the fact that the aircraft had recently climbed through comparatively warm air to a level that was at or just below the freezing level, it must be considered unlikely that a build-up of ice could have occurred in the intake sufficient to cause a sudden, unheralded, engine run-down. This view is in line with that expressed by the engine manufacturer, and given further support by the fact that the other engine remained unaffected throughout the flight. Nevertheless, it must be mentioned that several further instances are known to have occurred on Bandeirante aircraft of unexplained engine run-downs in similar conditions. However, it is considered that the chances of the run-down occurring as a result of intake icing are remote.

2.3 **The unsuccessful re-starting attempt**

The tests which have been carried out to determine the cause of the engine failure similarly failed to disclose the reason for its failure to re-start. The test runs had also showed the ignition and re-light system to be fully serviceable. It must therefore be postulated that the commander's attempt to start the engine using the RE-START WITH STARTER drill was unsuccessful either for the same reason as the initial failure or because the commander may have carried out the drill incorrectly. The engine starting and generator control switches for each engine are similar in size and shape, and positioned close together on the roof panel, thus introducing the possibility that, in a high stress situation, the wrong switch could have been operated. However, evidence to the contrary is provided by the commander's statement, made shortly after the accident, that when he operated the engine start switch he noticed a dimming of the cockpit lights. This would certainly indicate the presence of an additional electrical load, and probably the initiation of the start cycle. Assuming that the commander did indeed operate the engine start switch, in view of the evidence that the engine/propeller combination was found to be fully serviceable after the accident, it remains impossible to account for the fact that he did not notice a rise in gas compressor speed and in consequence did not re-introduce the fuel. However, in the circumstances, it is understandable that he made no further attempt to re-start the engine at that time, since he was well placed as regards height and proximity to Aberdeen.

2.4 **The electrical failure**

Detailed examination and exhaustive testing of the starter/generators did not reveal any reason for the right-hand starter/generator dropping off line. The aircraft subsequently returned to service, with the original right-hand electrical equipment fitted, and no unserviceabilities or failures were reported. However, a possibly significant factor is that just prior to the generator dropping off line, the aircraft had climbed through appreciable moisture; also that, five days prior to the accident, the right-hand generator had dropped off line whilst the aircraft was flying in cloud. It would seem possible, therefore, that moisture had affected the electrical system on the accident flight; however, detailed ground examination could find no evidence that this had been the case.

The examination of the left-hand starter/generator had showed signs of severe overheating which could have occurred in either the starter or generation modes. Of the two possibilities, it is considered that the overheating is most unlikely to have occurred whilst in the generation mode, for the following reasons. Firstly, because the only way an electrical load of the size required to produce such an overheating effect could occur at the left-hand starter/generator in the generation mode, would be during a start of the right engine on internal power; however, since the right engine is normally started first, this is a very infrequent occurrence. Secondly, because, during a normal starting cycle, the starting current is only required for a period of about 20 seconds. Accordingly, a more likely explanation for the overheating would seem to be that, at some time, the starter on the left-hand engine had been left engaged for a period of time considerably in excess of the maximum of 60 seconds allowed in the Flight

Manual. Since there is no entry in the aircraft's maintenance documents or technical logs indicating that this occurred at any time prior to the accident, it seems more than probable that it took place on the accident flight. Nevertheless, when ground tests were carried out to assess the effect of leaving the left-hand starter/generator in the START mode, simulating the failure of an engine to start, the right-hand generator remained on line, contrary to what occurred on the accident flight, although in the tests there was a marked deterioration in bus-bar and battery voltage. It must also be remarked that, in flight, the current required to accelerate and maintain the gas compressor at the normal starting Ng would normally be less than in the case of a ground start.

The commander reported the deterioration in the performance of his flight instruments and navigation equipment about 12 minutes after the failure of the left engine and the attempts to re-start. The subsequent tests indicated that if, after the second failure to re-start, the commander had omitted to move the starting switch to INTERRUPTION, the main bus-bar and battery voltage would certainly have decayed to an extent sufficient to affect the operation of the aircraft's flight instruments and navigation equipment in a manner similar to that which took place on the accident flight. The commander cannot remember whether or not he operated the switch; if he had not done so, the green ignition 'reminder' light should have remained on. However, this light was on the roof panel above his head and, bearing in mind the other failure lights which would by then have been illuminated, could easily have been missed. In all, this remains the most likely supposition as to what occurred.

At the time of the accident, the warning concerning the necessity to operate the starting switch to INTERRUPTION after a failure to achieve an engine start was not included in the Emergency drills under the 'airborne re-start' section, although it was mentioned in the Normal drills under 'engine starting'. The CAA has since advised all UK operators of this deficiency.

2.5 Subsequent action

The actions to be taken in the event of a double generator failure are clearly listed in the Aircraft Flight Manual, and repeated, in less detail, in the flight check lists. Essentially, the stated drill is that the emergency bus-bar switch should be selected to EMERGENCY as soon as it is apparent that neither generator can be re-set. The consequence of failing to do so is not emphasised in the check lists, which merely include the note that:- 'battery in good condition will supply power for up to 30 mins'. Although check lists cannot be expected to include all the detail properly given in the Flight Manual, it is recommended that the CAA remind all Bandeirante operators of the necessity, following a double generator failure, to select the bus-bar switch to the EMERGENCY position without undue delay; and that check lists be amended accordingly. However, provided the pilot's workload at the time is not excessive, the five minute delay assumed by the airworthiness authority between the loss of the second generator and the operation of the emergency bus-bar switch to EMERGENCY should provide a sufficient margin of time in which the necessary action can be taken.

There is good reason to believe that, on the accident flight, after the failure of the second generator, the commander did not immediately select the bus-bar switch to EMERGENCY, and, in fact, that there was a considerable delay before this selection was made. This evidence comprises the RTF transmission that the commander made to his company using the No 2 VHF radio, the operation of the flaps to the TAKE–OFF position at some time during the SRA approach, and the final reading found on the fuel totalizer. All these facilities are powered from the main bus-bar, and could not have operated at all had the bus-bar switch been selected to the EMERGENCY position. The most significant evidence is provided by the final reading on the fuel totalizer, which suggests that the selection was made during the descent, at approximately 1300 hrs, that is to say some 20 minutes after the second generator failed. By this time the battery capacity was largely spent.

During the course of the investigation it was noted that there had been, originally, one significant difference between the FAA's and CAA's initial requirements for certification of the Bandeirante. Because the basic system which powers the aircraft's flight instruments is totally electric, the FAA had required an independent source of power, separate from the aircraft's main electrical system, to supply the pilot's attitude instrument. Subsequently, lack of adverse service experience resulted in a relaxation of this requirement. Although consideration has been given to the inclusion in the report of a recommendation that such an independent emergency supply be required on all Bandeirante aircraft engaged in public transport operations, it is concluded that, on the balance of the available evidence, a recommendation on these lines cannot be justified.

2.6 Operational considerations

The accident sequence, from the time that the left engine failed at about 1233 hrs, until the precautionary landing at about 1355 hrs, lasted for some 82 minutes. Throughout this time the commander was flying the aircraft manually, for the most part in cloud and in conditions of moderate to severe turbulence; he had to attempt to carry out emergency drills, and also to manage a rapidly deteriorating electrical system. Thus, the cockpit workload and resulting stress must have been considerable and it is not surprising that his recollection of the precise sequence of events is incomplete.

At the time that he reported the failure of the left engine to Scottish Airways, and declined to declare an emergency situation, the decision to continue to Aberdeen, some 85 nautical miles, was entirely reasonable. The single engine stabilising height was well above FL 70, and the destination weather, although poor, was within company limits. It was also logical to continue to the company's main engineering base. However, after the failure of the second generator, the commander's handling of the situation must be called into question. The loss of the second generator in an aircraft whose avionics and attitude reference instruments are totally electric would be serious in any circumstances; when added to the earlier loss of an engine and the poor weather conditions, it is clear that an emergency existed. Yet at no time did the commander transmit a MAYDAY call, nor, whilst he still had good two-way radio communication with Aberdeen radar, did he even inform the controller of the nature of his problem. It was fortunate that the Airways supervisor appreciated the seriousness of the situation and alerted the search and rescue services. Equally it should be noted that, in the latter stages of the flight, the commander showed considerable skill.

The reconstruction of the aircraft's track shows that, after the overshoot from the SRA approach to Aberdeen, when the aircraft's radio had failed and the gyroscopic instruments had become unreliable, the aircraft orbited for some 13 minutes, in a random fashion, an area centred about 15 miles north of Aberdeen. The commander eventually decided to attempt a let-down to the east over the sea, and then to fly back towards the coast in order to be able to navigate visually to Aberdeen Airport. In the circumstances this was the only sensible course remaining. That the let-down, through cloud with no attitude instruments, was successful reflects considerable credit on the commander. However, it was unfortunate that, after visual contact with the coast had been achieved, he was unable to establish his position. Bearing in mind that he did not know the aircraft's fuel state because all fuel gauges and engine instruments were inoperative, and that fuel cross-feeding was not possible, his decision to make a precautionary landing was undoubtedly a prudent one. It seems probable that the presence of wind-shear at low level contributed to the heavy landing, and the saturated state of the ground to the subsequent collapse of the nose landing gear following a bounce.

Also worthy of mention was the commendable conduct of the Aberdeen approach controller in attempting to assist the commander in his descent until long after two-way communication was lost, and to vector the search and rescue aircraft towards the emergency area.

2.7 Single pilot operation

The UK certification requirements for the Bandeirante allow single pilot operation, within controlled airspace, provided that there is a serviceable automatic pilot at the commencement of the flight. Although these requirements were met on the accident flight, there is considerable circumstantial evidence to suggest that the pilot's workload became such that emergency drills were carried out incorrectly.

Although the loss of the second generator comes into the double failure category and was therefore probably considered as extremely unlikely when assessing flight crew workload, it is such cases which are prone to lead to accidents and which therefore merit the particular attention of flight safety authorities. The autopilot, although a boon to pilots in many circumstances, was of no assistance once the single failure (of engine plus associated generator) developed into a true emergency.

It is therefore clear that the presence of a second pilot to read and monitor the drills from the check-list would have reduced the possibility of potentially serious errors being made by a pilot under pressure. The second pilot's presence would also cover the case of crew incapacitation. Accordingly, it is recommended that the CAA reviews the current regulations concerning crew complement in aircraft in this category engaged on public transport flights.

3. Conclusions

(a) *Findings*

(i) The commander was properly licensed and well experienced for the flight.

(ii) The aircraft had been properly maintained and a valid Certificate of Airworthiness and Certificate of Maintenance were in force.

(iii) It was not possible to determine the cause of the failure of the left-hand engine or why it would not subsequently re-start.

(iv) It was not possible to determine the cause of the failure of the right-hand generator; however, there is considerable evidence to suggest that it was over-loaded.

(v) Due to pressure of work after the failure of the second generator, the commander delayed selecting the emergency bus-bar switch to EMERGENCY for about 20 minutes, contrary to the double generator failure procedure.

(vi) A probable over-load to the aircraft's electrical system and the delay before the commander selected the emergency bus-bar switch to EMERGENCY caused the battery voltage to deteriorate to an extent that the RTF equipment failed and all flight and navigational instruments became unreliable.

(vii) In the difficult circumstances prevailing, the commander's decision to make a precautionary landing was justifiable.

(viii) The heavy landing that ensued was probably caused by the presence of wind shear at low level.

(ix) The search and rescue agencies were alerted promptly and with initiative, and responded accordingly.

(b) *Cause*

The accident was caused by the complete loss of the aircraft's electrical power in adverse weather conditions. A contributory factor was the commander's mismanagement of the electrical system under conditions of high workload.

4. Safety Recommendations

It is recommended that:

4.1 All Bandeirante operators be reminded of the necessity to operate the starting switch to the INTERRUPTION position following a failure to achieve an airborne re-start, and that the check lists should be amended accordingly.

4.2 All Bandeirante operators be reminded of the necessity, following the loss of both generators, for the battery bus-bar switch to be selected to the EMERGENCY position without undue delay, and that check lists should be amended accordingly.

4.3 The current regulations concerning crew complement in aircraft engaged on public transport flights be reviewed.

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