ATSB
Australian Transport Safety Bureau

AUSTRALIAN TRANSPORT SAFETY BUREAU

AVIATION SAFETY INVESTIGATION
200102710

Embraer Bandeirante VH-OZG Cootamundra NSW

25 June 2001

COMMONWEALTH DEPARTMENT OF TRANSPORT AND REGIONAL SERVICES

Department of Transport and Regional Services

Australian Transport Safety Bureau

INVESTIGATION REPORT
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GLOSSARY

A	Ampere
AC	Advisory Circular
ANO	Air Navigation Order
ATS	Air Traffic Services
ATSB	Australian Transport Safety Bureau
BASI	Bureau of Air Safety Investigation
C	Celsius
CAAP	Civil Aviation Advisory Publication
CAO	Civil Aviation Order
CAR	Civil Aviation Regulation
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulation
CAVOK	Cloud and visibility OK
EST	Eastern Standard Time
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCU	Fuel control unit
GCU	Generator control unit
ICUS	In-command-under-supervision
IFR	Instrument Flight Rules
kg	Kilogram
LFL	Lower Flammability Limit
m	Metre
mm	Millimetre
MTOW	Maximum Take Off Weight
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
NTSB	National Transportation Safety Board
POH	Pilot's Operating Handbook
RPM	Revolutions per minute
RPT	Regular Public Transport
SFC	Starting flow controller
SOP	Standard Operating Procedures
UFL	Upper Flammability Limit
UTC	Coordinated Universal Time

INTRODUCTION

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Commonwealth Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

In terms of aviation, the ATSB is responsible for investigating accidents, serious incidents, incidents and safety deficiencies involving civil aircraft operations in Australia, as well as participating in overseas investigations of accidents and serious incidents involving Australian registered aircraft. The ATSB also conducts investigations and studies of the aviation system to identify underlying factors and trends that have the potential to adversely affect safety. A primary concern is the safety of commercial air transport, with particular regard to fare-paying passenger operations.

The ATSB performs its aviation functions in accordance with the provisions of the *Air Navigation Act 1920*, Part 2A. Section 19CA of the Act states that the object of an investigation is to determine the circumstances surrounding any accident, serious incident, incident or safety deficiency to prevent the occurrence of other similar events. The results of those determinations form the basis for safety recommendations and advisory notices, statistical analyses, research, safety studies and ultimately accident prevention programs. Similar to equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and conclusions reached. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. At all times the ATSB endeavours to balance the use of material that could imply adverse comment, with the need to properly explain what happened, and why, in a fair and unbiased manner.

The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) +10 hours. Times are accurate to within 30 seconds of the reported event.

EXECUTIVE SUMMARY

On 25 June 2001, an Embraer Bandeirante on a charter flight from Sydney to Griffith, sustained an in-flight engine fire during cruise. The pilot attempted to extinguish the fire, and believing it to be extinguished, commenced a rapid descent to Young. Fog at Young prevented a landing, and the pilot diverted the aircraft to Cootamundra. Smoke entered the cabin, and the pilot transmitted a MAYDAY. Only the right main landing gear extended when the landing gear was selected down, but the pilot did not get an indication of the landing gear position. Unaware that the right main landing gear had extended, he prepared to make a gear-up landing. The aircraft touched down on the right main wheel and settled onto the left engine nacelle and nose, sustaining abrasion damage as it slid along the runway. The fire in the right engine nacelle was still burning when the aircraft stopped. The occupants egressed uninjured, and bystanders extinguished the fire.

Technical investigation revealed that vibration from the worn armature shaft of the right engine starter generator initiated a fatigue crack in the fuel return line. Fuel leaked from the fractured line during the flight, and was ignited by sparks or frictional heat from the generator after the armature shaft failed.

The pilot reported that he was unable to select the fuel cut-off position with the right fuel condition lever and feather the right propeller. While carrying out the engine fire emergency checklist actions, the pilot did not complete all of the items of the manufacturer's engine fire emergency checklist and the firewall shut-off valve remained open. Fuel continued to flow to the fuel control unit and feed the fire. The investigation was unable to determine if the fire extinguisher bottle discharged effectively. The fire continued to burn and heat conducted through the firewall affected components in the wheel well. Smoke from the heat-damaged components entered the aircraft cabin though gaps between the wing root and fuselage.

Checklists carried on the aircraft did not contain appropriate smoke evacuation procedures and the pilot's attempts to evacuate smoke from the cabin were unsuccessful. Consequently, the uncontained fire in the engine nacelle, and smoke in the cabin, created a potentially life threatening situation and influenced the pilot's decision not to delay the landing while attempting to resolve the apparent failure of the landing gear to extend.

This occurrence demonstrates the need for error-free and complete checklists to be available to pilots during emergency situations. It also demonstrates the need for pilots to be familiar with the systems of the aircraft they operate, and the emergency actions to be taken in the event of abnormal or emergency situations. Regular practice of those procedures is essential if they are to be executed effectively. More thorough training and checking of (charter) pilots, as proposed in the Civil Aviation Safety Regulations Part 121B (charter) operations, if adopted, can potentially improve pilot proficiency and knowledge in emergencies, specific to the aircraft type.

As a result of this occurrence the ATSB recommended to the Civil Aviation Safety Authority, the aircraft manufacturer and the certification authorities that the temperature setting of thermal relief valves on fire bottles, and the temperature setting of fire detectors, be reviewed to avoid inadvertent discharge of fire bottles. The ATSB also recommended that crews be provided with an indication of fire bottle contents.

1. FACTUAL INFORMATION

1.1 History of the flight

The Embraer EMB-110P1 Bandeirante, VH-OZG, departed from Sydney Kingsford Smith international airport at 0855 on 25 June 2001, on a single-pilot instrument flight rules (IFR) charter flight to Griffith. The nine occupants on board the aircraft included the pilot and eight passengers.

At about 0945, while maintaining an altitude of 10,000 ft, the master caution light illuminated. At the same time, the multiple alarm panel 'GENERATOR 2' (right generator) warning light also illuminated, indicating that the generator was no longer supplying power to the main electrical bus bar. After resetting the generator and monitoring its output, the pilot was satisfied that it was operating normally.

A short time later, the master warning light illuminated again. A number of circuit breakers tripped, accompanied by multiple master alarm panel warnings. The red 'FIRE' warning light on the right engine fire extinguisher 'T' handle also illuminated, accompanied by the aural fire alarm warning. The pilot reported that after silencing the aural fire alarm, he carried out the engine fire emergency checklist actions. However, he was unable to select the fuel cut-off position with the right fuel condition lever, despite overriding the locking mechanism using his left thumb while attempting to operate the lever with his right hand. He also reported that the propeller lever did not remain in the feathered detent, but moved forward, as if spring-loaded, to an intermediate position. After unsuccessfully attempting to select fuel cut-off with the right fuel condition lever, or feather the right propeller with the propeller lever, the pilot pulled the right 'T' handle to discharge the fire bottle. The amber discharge light illuminated and a short time later the fire alarm sounded again. Passengers reported seeing lights illuminated on the multiple alarm panel and heard the sound of a continuous fire alarm in the cockpit.

At 0956, the pilot notified air traffic services (ATS) that there was a 'problem' with the aircraft, but did not specify the nature of that problem. Almost immediately the pilot transmitted a PAN radio call and advised ATS that there was a fire on board the aircraft. The nearest aerodromes for an emergency landing were not available due to fog, and the pilot decided to divert to Young, which was about 35 NM to the south east of the aircraft's position at that time. The pilot advised ATS that the fire was extinguished, and that he was diverting the aircraft to Young. Two minutes later, the pilot repeated his advice to ATS stating that a fire in the right engine had been extinguished, and requested emergency services for the aircraft's arrival at Young.

The pilot informed one of the passengers that there was an engine fire warning, and that they would be landing at Young. The passengers subsequently reported seeing flames in the right engine nacelle and white smoke streaming from under the wing. Smoke had also started to enter the cabin in the vicinity of the wing root.

The pilot subsequently reported that he had selected the master switch on the air conditioning control panel to the 'vent' position, and that he had opened the left direct vision window in an attempt to eliminate smoke from the cabin. When that did not appear to have any effect he closed the direct vision window.

The pilot of another aircraft reported to ATS that Young was clear, but there were fog patches to the north. On arrival at Young, however, the pilot of the Bandeirante was unable to land the aircraft because of fog, and advised ATS that he was proceeding to Cootamundra, 27 NM to the south southwest of Young. The crew of an overflying airliner informed ATS that Cootamundra was clear of fog. ATS confirmed that advice by telephoning an aircraft operator at Cootamundra aerodrome.

At 1017 thick smoke entered the cabin and the pilot transmitted a MAYDAY. He reported that the aircraft was 9 NM from Cootamundra, and ATS informed him that the aerodrome was clear of fog. The pilot advised that he was flying in visual conditions and that there was a serious fire on board. No further radio transmissions were heard from the aircraft.

At 1021, approximately 25 minutes after first reporting a fire, the pilot made an approach to land on runway 16 at Cootamundra. He reported that when he selected the landing gear down on late final there was no indication that the gear had extended. The pilot reported that he did not have sufficient time to extend the gear manually using the emergency procedure because he was anxious to get the aircraft on the ground as quickly as possible. Unaware that the right main landing gear had extended the pilot advised the passengers to prepare for a ‘belly’ landing. He lowered full flap, selected the propeller levers to the feathered position and the condition levers to fuel cut-off.

The aircraft landed with only the right main landing gear extended. The right main wheel touched down about 260 m beyond the runway threshold, about one metre from the right edge of the runway. During the landing roll the aircraft settled on the nose and the left engine nacelle and skidded for approximately 450 m before veering left off the bitumen. The soft grass surface swung the aircraft sharply left, and it came to a stop on the grass flight strip east of the runway, almost on a reciprocal heading. The pilot and passengers were uninjured, and vacated the aircraft through the cabin door and left overwing emergency exit. Personnel from a maintenance organisation at the aerodrome extinguished the fire in the right engine nacelle using portable fire extinguishers.

1.2 Injuries to persons

Injuries	*Crew*	*Passengers*	*Others*	*Total*
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	-	-	-	-
None	1	8	-	9

1.3 Damage to aircraft

Apart from the fire damage to the right engine and nacelle, both engines and propellers were damaged during the landing and there was abrasion damage to the lower skin panels of the left engine cowling and nose.

The left propeller blade strike marks on the runway indicated that the left propeller had stopped rotating very shortly after initial blade contact. The blades were in the feathered position and the tip of one of the three blades exhibited significant abrasion damage.

Damage to the right propeller blades was confined to the blade tips. Multiple strike marks made by the right propeller blades commenced about 180 m after touch down. The pitch of consecutive strike marks progressively increased toward the latter part of the landing.

1.3.1 Right engine compartment

Evidence of the in-flight fire was confined to the right engine nacelle between the rear seal and the firewall (see fig 1). The wheel well area and components behind the firewall had sustained damage from heat transferred through the firewall. The right engine upper cowl showed no signs of fire damage and although it was lightly sooted on the inside, the paint was not blistered. Fire damage to the lower cowl was evident on the outboard side. Smoke stains and an elongated hole, approximately 400 mm long, running in a longitudinal direction between the rear seal and the firewall were the only external signs of an engine compartment fire.

Components on the inboard side of the compartment showed almost no evidence of fire damage and were only lightly sooted. Soot stops depositing at temperatures over about 370 °C. Those components and the systems located on the outboard side, including fuel system components, connecting lines, and engine and propeller controls, were not sooted and exhibited evidence of having been exposed to a high temperature. The insulation on the cable looms and individual wires had either melted or burned away, exposing the wires. The outside protective layer on some of the red-coloured, silicon-fibreglass fire sleeves was blistered and flaked, or burned away.

FIGURE 1:
Damage to the inboard and outboard sides of the right engine accessory compartment

Inboard

Outboard

The starter generator, centrally located at the top of the engine compartment, sustained heat damage that melted the terminal block attached to the top of the unit, and the insulation on the feeder cables. The starter generator was not sooted.

The fire bottle revealed signs of having been subjected to high temperature. The discharge outlet, cartridge and connectors had completely melted away. The separated discharge nozzle had collapsed. The location of the hole in the lower cowl adjacent to the location of the fire bottle and the common drain manifold, suggesting that the fire was more intense in that area. The thermal relief valve was on the fire bottle side of the flexible line leading to the empty pressure indicator. It had burned away together with the attaching fitting. The flexible hose to the empty pressure indicator disconnected from the fire bottle after the attachment fitting melted away. The coloured plastic disc on the thermal relief discharge outlet was missing and streaks of black deposits extended from the outlet.

The right wheel well area sustained substantial damage from heat transferred through the firewall. There was no evidence of fire inside the wheel well. The landing gear tyre, in the retracted position, was stowed just behind the firewall. Part of the tyre outer layer had de-vulcanised after being subjected to the conducted heat and returned to its uncured state. The process of reversion takes place at temperatures above 150 °C.

Internal parts of both right landing gear doors were slightly deformed and partially melted. Most of the aluminium alloy shield protecting the fuel and the hydraulic shut-off valves, that were located at the top of the wheel well just behind the firewall, had melted away. The melted aluminium was found spattered on the components at the rear of the wheel well. Evidence of the melted aluminium was also found on the runway along the length of the landing roll. Insulation on electrical wiring behind the firewall and on the right landing gear had melted in places, partially or completely exposing the bare conductors.

There was evidence of smoke produced by the heat-damaged components in the right wheel well having entered the unpressurised aircraft cabin, via the wing root, through missing and deteriorated seals.

The rigid fuel return line between the fuel control unit (FCU) and the 'T' piece above the start flow controller (SFC) was cracked. It was subsequently examined by the ATSB, and the results of that examination are discussed in sub-section 1.16.

1.4 Other damage

Damage to property or equipment as a result of the occurrence was confined to propeller strike marks and minor gouging of the bitumen runway surface.

1.5 Personnel information

Type of licence	Commercial Pilot (Aeroplane) Licence
Medical certificate	Class 1, valid to 05 January 2002 (vision correction required)
Instrument rating	Command multi-engine (Aeroplane), valid to 30 June 2001
Flying experience (total hours)	6,850 hours
Hours on the type	253 hours
Hours flown in the last 90 days	50 hours
Hours flown in the last 30 days	33 hours
Last flight	19 June 2001

The pilot reported that he had commenced duty about 4 hours before the occurrence and had been well rested prior to commencing duty that day.

The Bandeirante was the pilots' first turbine-powered aircraft endorsement. He qualified for command on the type in August 1999 after about 5 hours of dual training that included simulated emergency procedures. Subsequent to his Bandeirante endorsement, the pilot completed conversion training for the Metroliner 2, another turbine-powered aircraft, which he also flew regularly in single-pilot operations. The engine fire in flight emergency procedure for both aircraft required the propeller of the affected engine to be feathered and shut-off valve switches selected off, before the fire bottle was discharged.

The instructor who conducted the pilot's training on the Bandeirante reported that the training followed the syllabus recommended in Civil Aviation Advisory Publication (CAAP) 5.23-1(0) Syllabus of Training - Multi-engine aeroplane type endorsement. The multi-engine turbo-prop aeroplane endorsement engineering data and performance questionnaire, as recommended by the CAAP, required candidates to detail the emergency procedures for an engine fire while airborne. The instructor reported that the engine fire in-flight emergency procedure was discussed and simulated during that training and also during the subsequent 50 hours of flying in command under supervision (ICUS) that the pilot undertook on the aircraft type.

The pilot reported that in addition to the flight training he received during initial conversion onto the Bandeirante in 1999 and the 50 hours ICUS, the only flight training he had undertaken in the Bandeirante was practice non-precision instrument approaches using a global positioning system navigation unit.

1.6 Aircraft information

1.6.1 Certification and airworthiness

The EMB 110 Bandeirante aircraft was originally certified under Federal Aviation Regulation (FAR) Part 23, applicable to aircraft less than 5,700 kg maximum take-off weight (MTOW), and therefore was not required to be equipped with engine fire extinguishing systems. The occurrence aircraft, serial number 110241, was manufactured in Brazil in December 1979. It was imported into Australia in 1988 with fire detection and suppression systems installed. Inspections by the then Department of Aviation showed that the aircraft satisfied Australian requirements. The Australian requirement for powerplant fire protection was specified in the then Air Navigation Order Part 101.4. The section relating to fire extinguishing systems specified compliance with FAR 23.1199, applicable to fire bottles. Paragraph (d) of that regulation required that the temperature of the fire bottle be maintained under intended operating conditions to prevent its pressure from rising high enough to cause premature discharge.

Certification required that the engine firewall be designed to resist a direct fire for a maximum of 15 minutes without flame penetration when the fuel shut-off valve was closed within the first five minutes of fire and remained closed for the following ten minutes.

Certain parts of Embraer Service Bulletin 110-53-011 were applicable to the aircraft. The bulletin was originally issued in December 1979, and change number 5 to the bulletin was issued in December 1985. The modifications improved sealing in the aircraft's nose area. Extension of the landing gear as part of the smoke evacuation emergency procedure applied only to pre-modified aircraft. The aircraft's documentation suggested that the aircraft had been modified in accordance with the relevant parts of the bulletin.

During the periodic maintenance inspection on 15 May 2001, the right engine cowl was removed and the engine was test run. The maintenance engineer who signed for the inspection did not notice any fuel leak, or other fuel system, or engine abnormality.

The manufacturer's maintenance procedures did not specify any inspection of the wing root to fuselage sealant, but referred to its replacement with an 'appropriate' product. The aircraft maintenance records did not show that any maintenance had been carried out in that area since the aircraft was placed on the Australian register.

1.6.1.1 Right engine starter generator

The right engine was fitted with a General Electric starter generator, serial number HT-18. Inspection of aircraft logbooks revealed that it was fitted to the engine on 1 December 2000. The starter generator was received with a release note that stated that it was overhauled and tested in accordance with the manufacturer's requirements. The release note was dated 30 April 1998.

The overhaul facility was asked to provide documentation for the overhaul of the starter generator. The facility advised the ATSB that the records were kept for two years. CASA Regulations required documentation of aircraft components to be kept until the next overhaul or until 12 months after the component had been permanently withdrawn from service[1].

The overhaul facility reported that at some time in the period between 30 April 1998 and 1 December 2000 the starter generator had been loaned to another organisation for carriage as a serviceable spare and it was returned unused.

The aircraft engineer who installed the starter generator reported that its appearance was consistent with an overhauled starter generator, as described on the release note. The maintenance records indicated that the unit had accumulated about 180 hours in service since it was fitted to the aircraft on 1 December 2000.

Examination of the damaged starter generator revealed that failure of the armature shaft had initiated from slippage between the bearing inner race and the shaft. The resulting wear dislodged the retaining clip allowing aft movement of the rear bearing. Wear on the components was consistent with operation in that condition for some time until ultimate failure of the armature shaft occurred during the occurrence flight. Both the front and rear installed bearings were not those specified in the manufacturer's illustrated parts catalogue. Slight differences between the characteristics of the specified and the installed bearings were identified. The subsequent failure of the armature shaft could not be attributed to those differences. Extensive frictional wear of the shaft fragments was consistent with continued rotation after the shaft failed. Damage and wear to the armature windings was evidence of the starter generator continuing to rotate before torsional failure of the inner shaft occurred.

The manufacturer's maintenance manual required both shaft bearings to be installed using a heat-and-press procedure to achieve the required interference fit. Retention of the bearings was dependent on shaft and bearing bore sizes and required checking that

1 Civil Aviation Order 100.5 General requirements in respect of maintenance of all Australian aircraft.

the shaft diameter was above the minimum specified. The manual precluded the use of shafts less than the minimum diameter. The overhaul facility was unable to provide documentation of the work undertaken during overhaul of the starter generator. Damage to the shaft prevented laboratory measurement in order to determine if the shaft diameter was at or above the minimum dimension.

The rear bearing showed evidence of having loosened on the armature shaft and moved partially out of the housing. Radial movement of the rear bearing resulted in wear to the shaft and retaining clip so that it lost tension and rode up out of the groove. That allowed axial movement of the rear bearing, and contact between the bearing and the impeller fan. Out of balance forces generated by the worn shaft and the loosened fan impeller would have resulted in significant levels of vibration in the accessory area of aircraft engine.

1.6.2 Aircraft and aircraft systems

1.6.2.1 Electrical system

Inspection of the aircraft circuit breaker panels revealed the following tripped circuit breakers:

- fuel pressure
- propeller synchronisation
- oil pressure (both)
- right torque
- right propeller overspeed
- right inertial separator actuator
- right inertial separator indicator
- right shut-off valve;
- landing gear control
- air conditioning valve
- right fire extinguisher
- right Px heat (electrical heating element for ice prevention)

Functional tests of both generator control units (GCU's) determined that they were capable of normal operation, and that they would have protected electrical circuits from current surges associated with the failing starter generator.

1.6.2.2 Engine and propeller controls

The condition lever cable and the propeller lever Teleflex cable were removed and examined. Both exhibited fire damage to the outer sheathing and the plastic sleeves between the inner and outer cables had been damaged by heat. Although each inner cable moved freely when tested, it could not be determined if heat damage or expansion had affected their normal operation.

The control quadrant shafts on both the FCU and SFC were found in the cut-off position and external adjustment on each unit was consistent with normal operation. The fire damaged condition of both units prevented functional testing. The P3 line of the FCU was fire damaged and became disconnected. The P3 line delivered compressor bleed air to the FCU. The P3 air pressure was used in conjunction with ambient air pressure, fuel pressures, and compressor turbine speed to regulate the amount of fuel delivered to the engine, as demanded by the selected power setting. When the P3 line became disconnected, the engine speed reduced to a preset flight idle speed between 48 and 50 per cent of the maximum engine RPM. Flight idle was sustained by fuel that continued to be delivered to the FCU. Calculations based on the estimated landing speed of the aircraft and initial strike marks made by the propeller blades on the runway surface, indicated that the right propeller was being driven at about 1,100 RPM which was consistent with about 50 per cent of normal RPM on touchdown.

1.6.2.3 Propeller synchronisation system

The propeller synchronisation system used electronic pulses from magnetic pick-ups on the propeller overspeed governors to synchronise propeller RPM. When the control box sensed a difference in propeller RPM between the left engine pick up (master) and the right engine pick-up (slave), it directed a signal to the electrical actuator on the right propeller governor speed adjustment lever to equalise the right engine speed with the left. The actuator on the right engine was found extended, corresponding to a position consistent with increasing propeller RPM.

The pilot reported that he normally used propeller synchronisation in cruise flight. The propeller synchronisation switch was found in the OFF position and the circuit breaker tripped. A caution note in the POH warned that:

> Manual feathering of the right engine by the respective propeller control lever will not be completed if propeller synchronizing is switched on.

1.6.2.4 Firewall shut-off valves

Each engine had a firewall fuel shut-off valve that provided a means of stopping fuel to the engine during an emergency, such as a fire. The shut-off valves were located on the wheel well side of the firewall in each engine compartment, and were operated by left and right shut-off switches mounted on the fire detection and extinguisher system panel in the cockpit. The switches also closed the engine's hydraulic valve. Closing either firewall shut-off valve would close both engines' bleed air valves, irrespective of which shut-off valve was activated. Closing a firewall shut-off valve isolated flammable liquids from the respective engine, and prevented entry of fumes or smoke into the cabin through the heating and cooling system.

Post-occurrence examination found both the right fuel and hydraulic valves in the open position. They were removed from the aircraft, and when tested, functioned normally. However, the right shut-off valve circuit breaker was found tripped. The pilot reported noticing that a number of circuit breakers tripped at the time of the fire warning activation. Examination of the aircraft electrical system revealed that wiring to the shut-off valves was routed through the wheel well and into the wing and fuselage, well away from the fire-affected engine accessory compartment. The shut-off valve and the shut-off switch were electrically independent and insulated from other electrical systems that may have initially been affected by the fire in the engine accessory compartment.

1.6.2.5 Air conditioning system

The aircraft had an air conditioning system to provide cabin heating and cooling. It used engine compressor bleed air, and an alternate system provided outside air to the cabin through NACA[2] air inlets in the lower nose area. Cabin air distribution was through general and individual (gasper) outlets. The general outlets were always open, and the gasper outlets could be manually opened or closed. Air was exhausted from the cabin through an opening in the tail section of the aircraft.

The air conditioning control panel, shown in figure 2, had a six-position rotary master switch that could be positioned as follows:

OFF	-	no air supplied to the cabin
GROUND	-	used for rapid pre-cooling or heating of the aircraft on the ground
VENT	-	engine bleed air shut off and external air supplied to the cabin
BOTH	-	both bleed air shut off valves open (normal position for flight)
LEFT	-	left engine bleed air valve open, right engine bleed air valve closed
RIGHT	-	right engine bleed air valve open, left engine bleed air valve closed.

FIGURE 2:
Air conditioning control panel

1.6.2.6 Landing gear

Inspection of the right main landing gear showed that the wheel and wheel well had been exposed to considerable heat. Damage to the nose and left main landing gear was confined to abrasion of the gear doors. Neither gear leg had commenced its extension cycle and remained retracted. The landing gear selector was found selected to the down position and the landing gear control circuit breaker was tripped.

The main hydraulic reservoir was empty. Inspection of the hydraulic system found a loose pump end fitting. The end fitting of the flexible hydraulic pressure line to the right engine-driven hydraulic pump displayed evidence of heating that would have allowed it to loosen and result in the loss of fluid under operating pressures.

2 National Advisory Committee for Aeronautics

The emergency reservoir sight gauge showed a full level of fluid. When tested, the emergency gear extension operated normally, extending both nose and left main gear.

1.6.2.7 Engine fire detection and extinguisher system

The aircraft had a system to detect and extinguish engine fires. The L'Hotellier fire detection system incorporated eight fire detectors of a bimetallic type arranged in series so that any breach of the circuit would trigger the fire alarm. Four detectors were located within the engine accessory compartment and the remaining four detectors were on the engine forward of the rear seal. The detectors were set to open at temperatures between 200 °C and 240 °C.

Three detectors within the engine accessory compartment were mounted on the firewall, one directly above the starter generator at the top of the compartment and the other two detectors equally spaced at an angle of about 45 degrees down each side from the uppermost detector. The fourth detector was mounted on the rear seal, adjacent to the SFC on the outboard side of the compartment.

The aircraft maintenance-planning guide required the fire detection system to be tested periodically. The aircraft logbooks indicated that a test was carried out during the last periodic inspection on 15 May 2001. The manufacturer's test required the use of a specific control box for that procedure. However, a control box was not available to test the detectors. The maintenance engineer reported that he tested each detector by subjecting it to heat, while a calibrated thermometer was placed next to it. The temperature at which the detector triggered the fire alarm was checked and found to be within the required range. The temperature at which individual detectors opened was not recorded, but the technician who performed the test confirmed that the temperatures at which the individual detectors opened were within the specified range.

Due to fire damage, the right engine fire detection system wiring could not be tested. The detector above the starter generator and the detector on the outboard side of the firewall were removed and tested. Both functioned normally.

1.6.2.8 Right engine fire bottle

The right engine fire bottle was mounted forward of the firewall at the lower outboard side of the right engine accessory compartment, and was found to be empty. Its location was adjacent to the fire breeched hole in the lower engine cowl. The specification required that the fire bottle be pressurised to between 360 and 385 lb/in2. The fire bottle pressure gauge could only be read by removing the engine cowls. The manufacturer's maintenance guidelines required that the pressure be checked during each periodic inspection. Inspection of the aircraft logbook indicated that the fire bottle pressure was checked during the last periodic inspection on 15 May 2001 and found satisfactory. That pressure reading was not recorded in the logbook, nor was it required to be.

The fire bottle was fitted with a fusible thermal valve designed to protect the bottle from bursting due to a heat-related overpressure. The manufacturer of the fire bottle advised that the fusible thermal valve was designed to melt at a temperature of between 124 °C and 126 °C. That was between 75 °C and 115 °C less than the activating temperature range for the fire detectors installed in the engine compartment.

The only indication to a pilot that the fire bottle had discharged due to over temperature was a missing disk that normally capped the outlet from the fusible thermal valve discharge nozzle (see Section 1.3.1). The discharge nozzle and disc was located on the outboard side of each engine nacelle and was not visible from the cockpit. A check that each disc was intact formed part of the pre-flight exterior inspection.

1.6.2.9 Fire detection and extinguisher operation

The engine fire detection and extinguisher system panel, mounted centrally on the eyebrow glareshield above the instrument panel, comprised the following elements for each engine.

- A 'T' handle that activated the respective fire extinguisher system when pulled. Each handle incorporated three annunciator lights: a red FIRE warning light that illuminated when any detector in the respective engine nacelle detected a temperature greater than 200 °C; a amber 'E' light that illuminated after the respective extinguisher was discharged; and an green 'OK' light that illuminated only during system test and indicated the integrity of the detonation circuit.
- An aural warning and the master caution light were incorporated into the fire warning system and activated when either fire warning light illuminated. Pressing a button on the pilot's upper left instrument panel muted the aural warning.
- A two-position firewall shut-off valve toggle switch. The switch was stepped to avoid inadvertent selection of the closed position. When selected to the closed position the switch operated electrical actuators that closed the fuel and hydraulic valves aft of the firewall of the respective engine. It also closed the bleed air shut-off valves of both engines, regardless of the position of the air conditioning system master switch. There was also a system test button for each engine system.

Figures 3 a. and b. show the configuration of the occurrence aircraft's engine fire detection and extinguisher system panel after the landing at Cootamundra.

FIGURE 3A:
Engine fire detection and extinguisher system panel

FIGURE 3B:
Engine fire detection and extinguisher system panel

1.6.2.10 Emergency in-flight engine fire procedure

The operator's checklist items for In-Flight Engine Failure or Fire were:

1. Fire Aural Warning	-	SILENCE
2. Propeller synchro.	-	OFF
3. Power lever	-	MINIMUM
4. Propeller lever	-	FEATHER
5. Fuel condition lever	-	FUEL CUT-OFF
6. Shut-off valves	-	SHUT-OFF

In the event of fire warning:

Wait 8 seconds after shut-off valve actuation and if fire warning remains ON

7. Fire extinguisher	-	DISCHARGE
8. Empty bottle light	-	ON
9. Generator	-	OFF
10. Load on remaining generator	-	BELOW 200A
11. Fuel pumps (main and auxiliary)	-	OFF
12. Crossfeed line switch	-	CROSSFEED (if necessary)

The checks were in accordance with the manufacturer's recommended procedure. The first six items were identified as memory items, and were required to be actioned in the correct sequence. Any missed item could render subsequent actions ineffective, for example, if a pilot neglected to turn off the propeller synchronisation, the right propeller could not be feathered.

Similarly, there was no physical interlock between the firewall shut-off valve switch and its associated 'T' fire handle. Therefore, it was possible to pull the fire handle with the firewall shut-off valves still open.

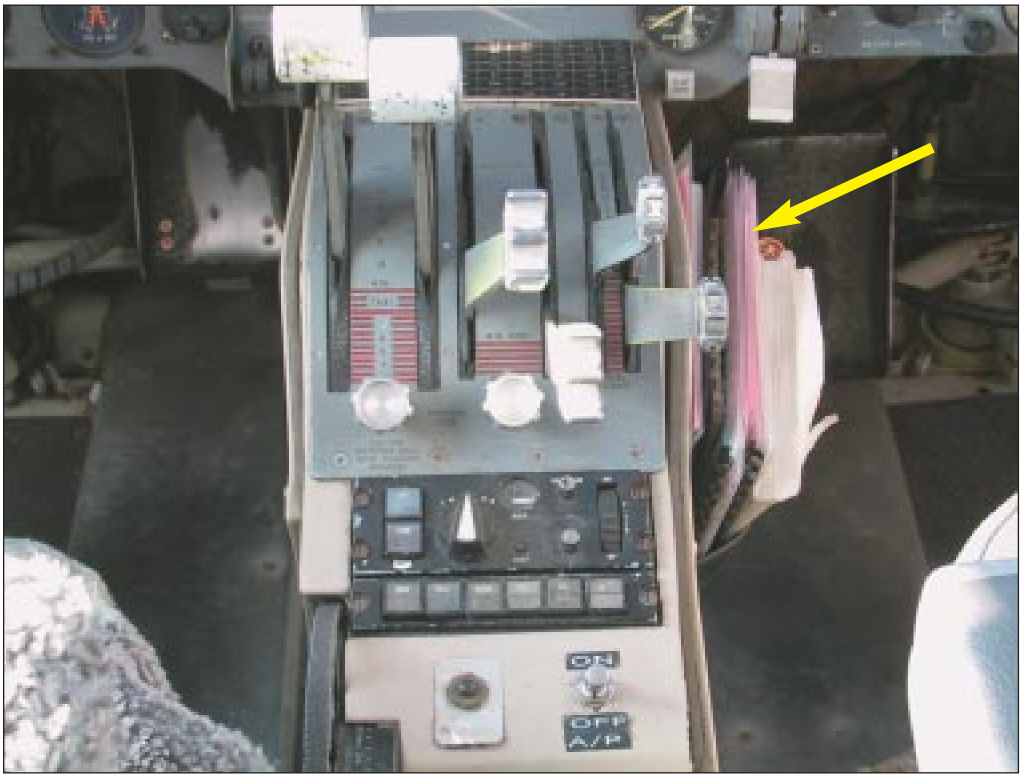
The pilot reported that when the fire warning first activated he silenced the alarm and carried out the engine fire emergency checklist actions. When later questioned, the pilot reported that he was unable to recall his actions precisely. After attempting unsuccessfully to select fuel cut-off with the condition lever and to feather the right propeller, he pulled the right fire handle. He was unable to account for the shut-off valve switch selection but reported that to the best of his recollection he had selected the closed position.

The pilot also reported that he would have used the engine fire in-flight emergency checklist. The applicable emergency checklist procedures for an engine fire in flight, as prescribed in the manufacturer's Pilot's Operating Handbook (POH), was reproduced in a booklet style format by the operator to meet the requirements of Civil Aviation Regulation 232 – Flight Check System. The booklet included normal procedures and condensed emergency procedures checklists. It consisted of laminated sheets of A5 size cards, bound with a plastic comb-binder. Two copies of the checklist booklet were found in a loose and out of sequence condition in the pocket of the power pedestal beside the copilot's station.

Another differently formatted emergency checklist was also found in that pocket. That checklist consisted of tabulated, plastic laminated sheets that were held together in booklet form with a wire-o-binding[3]. A previous operator of the aircraft had produced that checklist and although differently formatted, it conformed to the manufacturer's in-flight fire procedure in the POH.

The location and condition of the operator's normal and emergency checklists that were found in the aircraft after the landing at Cootamundra are shown in figure 4.

FIGURE 4:
Location and condition of aircraft checklists



3 Wire-o-binding: a wire coil spine that allows a booklet to be opened flat

After the aircraft landed at Cootamundra, the right engine fire extinguisher 'T' handle shut-off was found in the discharge position. However, the right shut-off valve was found to be in the OPEN position, as shown in figures 3 a. and b.

1.6.2.11 Smoke evacuation procedure

The approved company emergency procedures (condensed) checklist did not contain the relevant smoke evacuation procedure. The emergency checklist from a previous operator did, but it contained missing and incorrect items. The checklist did not include the item requiring the pilot to pull the 'T' handles for the ram air supply, an action required for the occurrence aircraft that had NACA air inlets installed in the lower nose area. Another item on the previous operator's checklist required the pilot to extend the landing gear, an action that did not apply to the aircraft modified in accordance with Embraer Service Bulletin 110-53-011.

The prescribed emergency procedure[4], to be followed when the smoke source was not in the air conditioning system, required the pilot to select the air conditioning to BOTH, open the ram air supply, and open the cockpit direct vision windows. The procedure when the smoke source was in the air conditioning system required the pilot to select the air conditioning to VENT, open the ram air supply, and open the cockpit direct vision windows. The pilot reported that he had opened the left direct vision window to assist in clearing smoke from the cabin, but found it had no effect so closed it again.

Engine bleed air would not have been available from either engine had the fire shut-off switch on the fire detection and extinguisher system panel been closed, irrespective of the position of the six-position rotary air conditioning master switch. Therefore, if the smoke evacuation emergency procedure followed an in-flight engine shutdown because of engine fire, selection of the air conditioning to BOTH for evacuation of smoke from a source other than the air conditioning system would be ineffective. That was because both bleed air valves would close once the affected engine's firewall shut-off switch was closed.

FIGURE 5A:
Left ram air 'T' handle

4 Applicable for aircraft modified in accordance with Embraer Service Bulletin 110-53-011

FIGURE 5B:
Right ram air 'T' handle.

Figure 2 shows the configuration of the air conditioning master switch and figures 5 a. and b. show the left and right ram air supply 'T' handles of the occurrence aircraft after the landing at Cootamundra.

1.6.2.12 Emergency landing procedure

The approved company emergency procedures (condensed) checklist did not contain emergency landing checks.

The emergency procedures section of the POH included an emergency landing procedure for a gear up landing and a partial gear landing, which specified that the propeller levers were to be set to maximum RPM. The post-accident cockpit examination found both propeller levers in the feathered position.

The pilot reported that he had selected the propellers levers to the feathered position before touchdown because he understood that to be the configuration for a gear-up landing in the Bandeirante.

1.7 Meteorological information

A high-pressure system was situated over southern Australia at the time of the occurrence. The area 21 forecast, valid from 0300 until 1500 on 25 June 2001, included advice that CAVOK[5] conditions were likely, apart from some broken cloud south west of a line between Parkes and Cooma. The forecast also indicated that there would be scattered fog until 1000. The amended area 21 forecast, valid from 0800 until 2100 included advice that there would be areas of scattered fog until 1200.

The aerodrome forecast for Young, issued at 0419 on 25 June 2001, forecast a visibility of 800 metres in fog until 1000, and from 1000 until 1200, visibility 3000 metres with fog in patches. The aerodrome forecasts for Cootamundra, issued at 0419, and Temora, issued at 0446, forecast similar conditions to those expected at Young.

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5 CAVOK = ceiling and visibility OK (visibility 10 km or more with no cloud below 5,000 feet and no significant weather phenomena)

1.8 Aids to navigation

Not applicable to this occurrence.

1.9 Communications

The aircraft was equipped with two very high frequency radio communications systems appropriate for the flight being taken. All communications between ATS and the pilot were recorded by ground based automatic voice recording equipment but transmissions on the common traffic advisory frequencies at both Young and Cootamundra aerodromes were not recorded.

1.10 Aerodrome information

Cootamundra aerodrome was located immediately to the north of Cootamundra township.

The physical characteristics of Runway 16 were:

Magnetic heading	162°
Dimensions	1,427 m length and 18 m width
Surface	Bitumen
Runway strip (grass)	60 m – width
Elevation	1110 ft above mean sea level.

1.11 Flight recorders

The aircraft was not fitted with a flight data recorder or a cockpit voice recorder, nor was either required by the relevant aviation regulations.

1.12 Wreckage information

There was no wreckage trail and the aircraft remained intact. Small fragments of airframe and minor gouging along the runway were the only indications of the emergency landing.

1.13 Medical information

The pilot had monocular vision. Although he had a prosthetic left eye there was no evidence that this had any adverse affect on the pilot’s performance.

1.14 Fire

The fire in the right engine compartment was still burning after the aircraft came to a stop at Cootamundra aerodrome. Personnel from an aircraft maintenance facility located on the aerodrome extinguished the fire with portable, dry powder type extinguishers.

1.15 Survival aspects

1.15.1 Aircraft cabin

The aircraft was not equipped with supplemental breathing oxygen or any other means of smoke and fume protection for the occupants in the event of smoke or fume contamination in the cabin.

Although passengers heard and saw the cockpit warnings they were unsure of the nature of the emergency. The pilot had beckoned one passenger forward and informed him there was a fire warning indicating that there was a fire in the right engine and that he was diverting the flight to Young. The passenger told the others only that there was a problem but did not elaborate. Shortly after diverting to Young, passengers reported seeing a flame inside the right engine nacelle and white smoke trailing from behind the right wing. Light smoke appeared in the cabin. When the smoke became more dense, during the flight from Young to Cootamundra, the passengers became quite concerned. They had not been advised that there was a fire and as the smoke became more dense one passenger approached the pilot to advise him. The pilot assured the passenger that he was aware of the problem and instructed the passenger to resume his seat.

Passengers reported that the smoke appeared to enter the cabin through the floor near the over wing area against the right wall. The smoke was described as being greyish-white at first, like cigarette smoke, but as it began to intensify it became acrid and its colour became dark grey to dark brown. It was variously described as having an oil or rubber smell, or smelling of burnt plastic or fibreglass.

The passengers experienced some respiratory distress and following a suggestion by one of their number to use window curtains as an air filter, they tore down the curtains and held them against their faces. Some passengers reported that the action appeared to make breathing easier but at least one passenger reported the curtain material was too porous and ineffective. Passengers at the front of the cabin experienced less respiratory difficulty but reported that the smoke was badly affecting their eyes, causing them to 'water'.

FIGURE 6:
The smoke-filled cabin looking forward

Smoke reduced visibility in the cabin to the point that some passengers could not see other passengers that were seated two rows away. Passengers seated toward the rear of the cabin reported that they could not discern the cockpit. The pilot reported that he had not experienced any reduced visibility from the smoke. Shortly before landing at Cootamundra, passengers reported that the pilot was surrounded by strong brown smoke, which he waved away with his headset.

Some passengers attempted to stop smoke entering the cabin by jamming window curtains into openings near the floor. As the smoke thickened, a passenger unfastened the fire extinguisher stowed on the rear cabin bulkhead and prepared to use it. However, as there was no open flame in the cabin, the extinguisher was not used and it was placed in a seat back pocket.

The passengers reported that there was no panic but they were concerned that the aircraft was still airborne after a considerable time with an engine fire. One passenger had contemplated opening the emergency exit but decided against that action when the smoke in the cabin did not intensify further. When a landing was imminent, the pilot shouted a warning to brace for a belly landing and advised the passengers not to move until the aircraft stopped. He advised them that he would open the cabin door for evacuation. Deceleration forces experienced on landing were not severe and the passengers unbuckled their seat belts and evacuated. The passenger seated near the left over-wing emergency exit opened that exit without difficulty, climbed out and assisted another five passengers out through it. One of the other passengers seated near the front of the cabin attempted to open the cabin door but experienced difficulty with the latching mechanism. The pilot reported that he had intervened and opened the door allowing them to evacuate through that exit.

The passengers reported that before the departure from Sydney, the pilot gave a thorough pre-flight safety briefing that included the location and operation of the cabin door and emergency exits. Although the pilot drew their attention to the explanations on the printed briefing cards in the seat pockets, none of the passengers reported having read them at that time. All had previously travelled extensively by air and were familiar with airline safety briefings. However, before landing at Cootamundra some passengers studied the operation of the exits shown on the cards.

1.15.2 Rescue and fire fighting services response

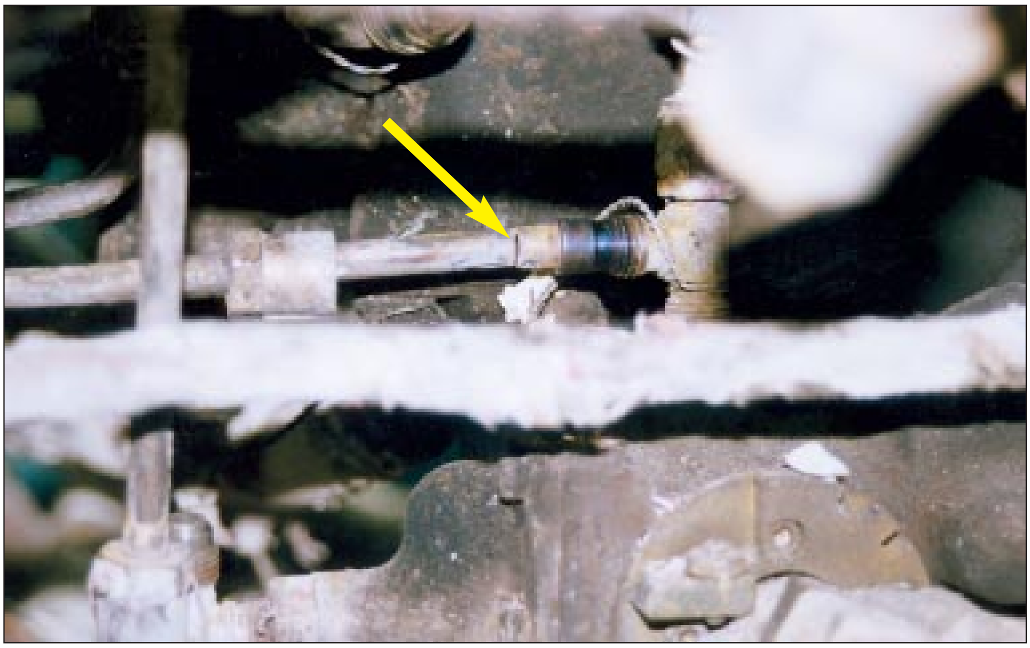
Following initial notification from ATS of the intended emergency landing of the aircraft at Young, the regional police headquarters at Wagga Wagga alerted local emergency services. The New South Wales ambulance service immediately dispatched ambulances from Young and Cootamundra to Young aerodrome. The ambulance service was then advised the aircraft was diverting to Cootamundra, and redirected the Cootamundra ambulance to Cootamundra aerodrome. On arrival at the aerodrome, the ambulance crew experienced a short delay while they tried to identify the correct key to unlock the emergency access gate. They witnessed the emergency landing while they were trying to open the gate and proceeded to the aircraft.

Fire fighting services at Young and Cootamundra relied on volunteers from the local communities. When alerted by police, volunteers assembled and personnel and equipment were dispatched to provide all necessary rescue and fire fighting support in the event of an aircraft mishap. There was initial confusion at the communications centre when notification of the emergency landing at Young was followed a short time later with a similar request for Cootamundra. The Cootamundra Fire Brigade was alerted and although not at the scene until 10 to 15 minutes after the aircraft landed, the turnout was within the agreed response time.

1.16 Tests and research

A fatigue crack was found in the rigid fuel return line between the fuel control unit (FCU) and the 'T' piece above the starting flow controller (SFC). Fractures had started on the outer surface of the line at two separate locations, next to the 'T' piece as shown in figure 7.

FIGURE 7:
The cracked rigid fuel return line



Laboratory examination of the cracked, rigid fuel return line determined that the crack resulted from progressive fatigue cracking and that the cracking had initiated and propagated from vibration loads. No pre-existing condition was found and there was no evidence that the fuel line had been loose or poorly installed.

A search of the Civil Aviation Safety Authority (CASA) Major Defect Reporting database found 90 reports relating to problems of the FCU, SFC, flexible and rigid fuel lines and controls on the PT6 engines, during the last 20 years. Five reports dealt with the fractured rigid fuel return line. The reasons for the cracking of the line or descriptions of the failure were not always given. One report stated that cracks to four fuel return lines were experienced on the same engine within a 50-hour interval. Those failures were attributed to an internal engine vibration.

Research conducted into the ignition of the fuel in the engine accessory compartment showed that the fuel must mix with the air in a ratio appropriate for combustion. If the fuel-air mixture remains below the lower flammability limit (LFL), it will be too lean for ignition to occur, while above the upper flammability limit (UFL) the mixture will be too rich to ignite.

The temperature range of combustible mixture was calculated to be between 40 °C and 80 °C at the aircraft's cruising altitude of 10,000 ft AMSL. It was estimated that the radiated heat from the engine accessories and starter generator could have easily raised the temperature within the compartment to the level required for ignition.

The amount of fuel needed for the mixture to reach the LFL could not be determined, and would have depended on airflow through the compartment. The engine compartment was relatively well sealed, and the air entering was predominantly ram air for cooling the starter generator. Cooling air within the compartment was evacuated by two venturis, one on each side of the compartment. The aircraft manufacturer was unable to provide the ATSB with information on the flow pattern through the compartment, but the most likely route was from the fan housing at the rear of the starter generator to the venturi outlets. Cooling airflow on the outboard side of the compartment passed near the FCU and SFC.

1.17 Organisational information

1.17.1 Civil Aviation Safety Authority (CASA)

Civil Aviation Regulation 217 required operators of aircraft with a MTOW exceeding 5,700 kg, or operators of regular public transport (RPT) services, to provide a training and checking organisation so as to ensure that crews maintained their competency. A requirement of that organisation was to include provision, within a calendar year, for two checks of a nature sufficient to test the competency of each member of the operator's crews. For pilots engaged in RPT operations, a satisfactory flight proficiency test in each type of aeroplane was required to have been undertaken in the preceding 15 months[6]. The syllabus for that check included application of emergency procedures set out in the Operations Manual, either orally or by demonstration, and included action in the event of in-flight engine fires.

None of the aircraft types operated by the company had maximum take-off weights exceeding 5,700 kg and the company did not operate any RPT services. The operator was therefore not required to provide a training and checking organisation and that pilot proficiency on each aircraft type was not regularly checked, nor was it required to be.

Civil Aviation Order 20.11 – 'Emergency and Lifesaving Equipment and Requirements for Passenger Control in Emergencies' required crews to undertake and pass an annual proficiency test of knowledge and use of passenger emergency equipment. The pilot was approved by CASA to conduct CAO 20.11 checks for company pilots, and had his proficiency in those procedures checked by CASA personnel.

CASA has indicated that under the proposed Civil Aviation Safety Regulation (CASR) Part 121B – Air Transport Operations (Small Aeroplanes), it intends to introduce proficiency checking for all pilots engaged in air transportation. CASR 121B will regulate existing charter operations, and require operators to establish formal training and checking of pilots, similar to the existing CAR 217 requirements.

1.17.2 Operator

Civil Aviation Orders Section 82.1 Appendix 1, required that charter operators maintain a training file for each crew member containing endorsement training courses completed or attempted, including results of each phase of training, the number of times each exercise was undertaken and the results of each test or check. The pilot reported that the operator did not provide the Bandeirante endorsement. It

6 Civil Aviation Orders Subsection 8 of section 82.3 and subsection 11 of section 40.1.5

was a private arrangement between the pilot and a contract instructor that did not require the operator to maintain any records of that endorsement training. The instructor who conducted the pilot's endorsement training in the Bandeirante reported that he did not make any written record of that training but gave verbal critiques during the training or in the debrief.

Regulations governing airwork and charter operations did not require pilots to demonstrate their proficiency in normal, abnormal and emergency procedures on each aeroplane type. Once endorsed on an aircraft type, charter pilots had only to satisfactorily complete an 'Aeroplane Flight Review' biennially or, in the case of instrument rated pilots, an instrument flight test every year.

Multi-engine aircraft instrument rating renewals required satisfactory completion of a flight test, including simulated one-engine inoperative flight. The instrument rating test did not specify an engine fire in-flight emergency procedure to be simulated during the test.

There was no requirement for candidates undertaking an instrument rating renewal to demonstrate their proficiency in a specific aircraft type. The pilot of the Bandeirante undertook his annual command instrument rating renewals in either Cessna 310 or Piper Navajo aircraft. Neither of those aircraft was equipped with fire detection or suppression systems.

The instructor who conducted the pilot's conversion training on the Bandeirante reported that during simulated emergency exercises it was the usual practice to carry out the initial or Phase 1 checks from memory and then refer to the appropriate aircraft emergency checklist for the following or Phase 2 checks.

Part B1.2 of the company Operations Manual for the EMB 110 BANDEIRANTE stated:

> The Emergency Procedures Checklist (condensed) is carried on board the aircraft adjacent to each pilot position and is coloured red. This checklist is to be used for any Emergency condition. The checklist is intended to be carried out in a read-and-do manner and as such need not be committed to memory. The only exceptions to this are the memory items (PHASE 1) which are enclosed in a box.
>
> PHASE 1 check items are to be committed to memory. The PHASE 1 items are the only items which may be carried out without physical use of the checklist. Once the PHASE 1 items have been actioned they must be checked against the appropriate checklist to finalise the Emergency procedure.

Depending on the aircraft role and respective regulatory requirements, the Bandeirante could be operated in either a single-pilot or multi-crew configuration. Regulations permitted single-pilot operation of the Bandeirante on non-scheduled (charter) flights with up to 15 passengers[7]. The company operated the Bandeirante as a single-pilot operation in the charter and airwork categories.

The pilot reported that for single-pilot operation, the normal checklists were not used as action lists but to check that those actions performed from memory had been actioned. The actioning of checklist items was integrated into the operation of the aircraft so that with frequency of use those actions were accomplished without undue

[7] Civil Aviation Orders Section 20.16.3 subsection 6

distraction. Unlike multi-crew operation, where the pilot-not-flying would read the appropriate checklist item and the pilot flying would action the item and respond, the single pilot had to action most items from memory.

Procedures not designated as either EMERGENCY or NORMAL were considered ABNORMAL. ABNORMAL procedures were considered not of sufficient urgency as to require an immediate response or checklist. Crews were directed to consult the relevant section of the POH for details about their rectification. No POH was found in the aircraft.

1.18 Additional information

1.18.1 Crew resource management in single-pilot operations

In 1996, the then Bureau of Air Safety Investigation published a report on fatal aircraft accidents in Australia that identified poor judgement as the most commonly assigned human factor in accidents[8]. Poor in-flight decision-making and poor pre-flight preparation were also identified as significant human factors in many of those accidents.

Single-pilot general aviation operations involve high, and sometimes complex, workplace demands on pilots, particularly if those operations involve high performance aircraft, for example, turbo-propeller aircraft operating under instrument flight rules. Pilots must therefore adopt a systematic approach to the operation of an aircraft, particularly during those phases of flight that involve abnormal or emergency operations. Pilots must also understand that they themselves form an integral part of the aircraft system, and that like other complex systems, failure of a system component may jeopardise the entire system safety.

A single-pilot operation therefore requires a pilot to effectively manage all available resources, information, and equipment to achieve safe flight operations, and relies on that pilot adopting disciplined and orderly decision-making processes. Those processes will be reinforced and developed through structured initial and recurrent training programs.

1.18.2 Cockpit checklists

A review of the US National Transportation Safety Board (NTSB) accident data for the period 1983 to 1993, by the U.S. Federal Aviation Administration (FAA) Office of Integrated Safety Analysis, revealed that accidents had occurred where checklists were not used or followed[9]. Some of those accidents involved checklists that were inadequate for the aircraft involved, or failed to include critical steps for safe operation.

The FAA review of the NTSB data included an analysis of checklist error incident data. Significant areas of checklist errors were identified, and included:

- crew failed to use the checklist(s)
- crew overlooked item(s) on the checklist
- crew failed to verify settings visually

8 Bureau of Air Safety Investigation, *Human Factors in Fatal Aircraft Accidents*, 1996

9 U.S. Department of Transportation, Federal Aviation Administration, *Human Performance Considerations in the Use and Design of Aircraft Checklists*, 1995

- checklist flow was interrupted by outside sources
- operator's or manufacturer's checklist contained error(s) or was incomplete.

The review noted that the final three items were:

> the same items that have been identified by the NTSB as causal or contributing to several major accidents.

The review also examined human factors considerations and how they affected checklist performance. It noted that those factors with the potential to affect crew performance and therefore lead to checklist error included fatigue, crew reliance on working or short-term memory, crew interruption or distraction, and complacency or failure to visually verify aircraft configuration.

The FAA review included information that working memory was limited, and that unaided, it could contain about seven (plus or minus two) unrelated items. Unless actively rehearsed or aided by some external 'memory jogger', the information contained in working memory would generally be lost with 10 to 20 seconds.

Interference from noise, incoming verbal messages, interruptions or distractions was the main reason that information was lost from working memory. Additionally, stress-related emotions, such as panic, anxiety, confusion, or frustration, could negatively affect the ability to retain information in working memory.

The FAA advised that because of the working memory's short duration and limited capacity, pilots should develop their own memory 'joggers'.

Checklists act as an aid to memory, and are intended to ensure that critical items relating to the safe operation of an aircraft are correctly actioned or configured. Checklists are therefore necessary defences[10] for the assurance of flight safety. They provide a logical and sequential framework to cope with the complex environment that is associated with operating an aircraft, particularly during emergency conditions.

1.18.3 Checklist design considerations

An aircraft manufacturer normally publishes relevant checklists for normal, abnormal, and emergency operations in the various flight and operations manuals relating to the operation of that aircraft. Although published in a manual, checklists are designed for ease of reference and independent use so that the user does not need to refer to the manual. They are used to provide pilots with an easily accessible means to ensure that a particular series of actions are accomplished in a logical and sequential manner, and to verify that the aircraft is in the correct configuration appropriate to a particular phase of flight.

In 1990, the National Aeronautics and Space Administration (NASA) published NASA Contractor Report 177549[11] that analysed the normal checklist, its functions, format, design, length, usage, and the limitations of the humans who must interact with it. The report also referred to non-normal and emergency checklists, and included information that they were intended to assist pilots during emergencies and/or

10 Reason, J. *Managing the Risks of Organisational Accidents,* 1997, ISB 1 84014 1050

11 Asaf Degani, Earl L. Wiener, *Human Factors of Checklists: The Normal Checklist,* University of Miami, Florida

malfunctions of aircraft systems. To cope with such situations, those checklists served to:

- act as a memory guide
- ensure that all critical actions were taken
- reduced variability between pilots
- enhanced coordination during high workload and stressful conditions.

The report contained information that checklists formed part of the standard operating procedures (SOPs) of an aircraft. While expanded explanations of those checklists were contained in the various flight and operations manuals relating to the operation of that aircraft, it was not intended that those manuals be referred to in-flight.

In 1992, NASA published NASA Contractor Report 177605[12] on the design of flight-deck documentation. The report included information on, among other things, font, type size, style, and spacing. It also included advice that line length was an important consideration in the design of checklists. A common problem with checklist layouts was the existence of a large gap between the entry (the 'challenge') and the corresponding information relating to that entry (the 'response'). There was a greater chance that the reader would make a mistake through perceptual misalignment of the correct response to a particular challenge item when the gap between those items was increased.

In January 1995 the FAA published information on the design and presentation of checklists[13]. It also included advice on legibility of print, readability and contrast, and noted that operators must format checklists with:

> …reasonable care and concern for the crews ability to perform the checklist with maximum accuracy. This can only be done if it is presented in a practical and useable format.

The FAA noted that how operators presented abnormal and emergency checklists was particularly important. Deficiencies in the design of those checklists was critical because of the time limitation, workload and stress associated in dealing with such situations, and those checklists:

> …must be in a format that allows quick retrieval and rapid identification of the correct procedure. A mistake in an emergency procedure has the potential to create an irreversible situation.

In September 2001, CASA published draft Advisory Circular AC 91-100(0) titled Flight Check Systems. The circular contained information on checklists, and advised that a checklist was:

> …a means of overcoming the limitations of the crew's memory.

The circular also advised that an emergency checklist was:

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12 Asaf Degani, *On the Typography of Flight-Deck Documentation*, San Jose State University Foundation, San Jose, California, 1992, prepared for U.S. National Aeronautics and Space Administration

13 U.S. Department of Transportation, Federal Aviation Administration, *Use and Design of Flightcrew Checklists and Manuals,* 1991 and *Human Performance Considerations in the Use and Design of Aircraft Checklists,* 1995

> …a checklist procedure prepared in advance to enable flight crews to handle a specified type of in-flight emergency.

The circular contained information on single-pilot checklists, and noted that the pilot of a single-pilot aircraft:

> …may quite literally have his or her hands full during flight, and in a critical situation it may be difficult to quickly find the relevant section if the checklist is poorly presented or poorly stowed. In particular, ready access to a well-indexed checklist will enable the pilot to make early reference to it in an emergency situation. In a single-pilot aircraft the manner of presentation and stowage of the checklist will largely determine whether or not it is actively used in flight. Handy stowage, prominent flip or slide arrangement or electronic presentation will encourage use of the formal checklist rather than memorised checks.

1.18.4 Checklist formatting

United States FAA reports[14] published in April 1991and in January 1995 and the U.S. NASA Contractor Report 177605[15], studied human factors of cockpit documentation and produced guidelines for the design and presentation of checklists. In addition to the typography and presentation items previously mentioned the studies made recommendations in layout, colour, contrast, and durability. A comparison of advantages and disadvantages of the different types of checklists was made between mechanical, electronic, and paper types. No preference was accorded to the types of checklists. Disadvantages of the laminated, paper type checklists (most common) was that they were easily misplaced, were hand-held, difficult to read if type size or fonts were not adequate, and difficult to locate appropriate checks without tabs. Additionally, surface glare hindered readability in certain lighting conditions, and there was no automatic means of noting progress if the pilot was interrupted or distracted.

Those studies recommended the use of anti-glare plastic sleeves or laminate, good quality card or paper, and sharp print. Black characters over white or yellow background were recommended. Yellow was a military standard for abnormal or emergency procedures. Black lettering over a red background was not recommended.

Those checklists that were easy to use were well indexed and tabbed. An example of a good checklist booklet was given in the FAA report. Its features included:

- colour-coding
- laminated tabs
- well-indexed
- ‘Abnormal’ and ‘Emergency’ sections
- heavy, hard-finished paper pages
- very legible 10-point type or larger.

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14 U.S. Department of Transportation, Federal Aviation Administration, Use and Design of Flightcrew Checklists and Manuals, 1991 and Human Performance Considerations in the Use and Design of Aircraft Checklists, 1995

15 Asaf Degani, On the Typography of Flight-Deck Documentation, San Jose State University Foundation, San Jose, California, 1992, prepared for U.S. National Aeronautics and Space Administration

Moreover, the report stated:

> …the aircraft for which it was designed had a convenient storage slot for it, its compactness would make it easy to adapt other aircraft to accommodate it.

1.18.5 Checklist use

In April 1991 an FAA report[16] was published that studied the design and use of good cockpit checklists. That followed an accident investigation where the US National Transportation Safety Board (NTSB) concluded that 'the flight crew did not perform the checklist procedures in the manner prescribed in the company's Airplane Pilot's Handbook.' They noted that the training and checking practices then in use did not promote effective use of checklists. A study of accidents and incidents investigated by the NTSB and from Aviation Safety Reporting System (confidential) reports found that crews' failure to use checklists, missing checklist items, or improper use of checklists, featured in a significant number of occurrences.

The report concluded that crews were not well trained in the use of those aids and recommended that checklist training be incorporated into company training including:

- proper use of checklists
- crew coordination in the use of checklists
- the necessity for compliance with checklists.

1.19 New investigation techniques

Not applicable to this occurrence.

16 U.S. Department of Transportation Federal Aviation Administration, *The Use and Design of Flightcrew Checklists and Manuals, 1991*

2. ANALYSIS

2.1 Introduction

The failure of the right starter generator during flight precipitated a sequence of events that resulted in a fire in the right engine accessory compartment. Although the failure of the right starter generator could not have been foreseen, its failure alone should not have resulted in an accident. Despite fog preventing an emergency landing at nearby aerodromes, the delay caused by flying to a more distant aerodrome, should not have affected the outcome if the correct in-flight emergency procedures had been followed. Following the engine fire, smoke entered the cabin. The pilot did not action critical items of the manufacturer's emergency procedures, resulting in the fire not being extinguished or smoke being removed from the cabin. Those critical items were necessary safety defences to prevent or minimise the chance of those events escalating and jeopardising the safety of flight. Lack of proficiency in handling emergency procedures and a lack of adherence to emergency checklist procedures meant the pilot was not able to respond appropriately to the developing emergency. Additionally, missing items and procedures in the emergency checklists did not provide necessary safety defences.

The design of the aircraft's fire extinguishing system was such that it was possible for the fire bottle to discharge through the thermal relief valve uncommanded, and before the pilot received a fire warning. Additionally, there was no indication to the pilot that the fire bottle had discharged. Furthermore, that resulted in the retardant being discharged overboard, rendering the system ineffective. That was identified as a safety deficiency, and the subsequent recommendations appear in section 4.

The analysis examines the interrelation of the events that resulted in a potentially life-threatening accident.

2.2 Aircraft serviceability

The post-flight examination of the aircraft revealed that failure of the right starter generator resulted from aft movement of the rear bearing of the armature shaft. That resulted in contact with the fan impellor, and led to significant vibration. Movement caused by slippage between the bearing and the shaft was consistent with an inadequate interference fit. The reason for the slippage could not be determined because of the damage to the failed components and lack of documentation relating to its last overhaul. Although slight differences were identified between the specified and installed bearings, their characteristics were found to be comparable. The differences were not considered significant to the subsequent failure of the armature shaft and the investigation did not establish if the substitution of those parts was approved.

The deterioration of the sealant between the wing root and fuselage permitted smoke to enter the cabin following the fire. Had the sealant been maintained in good condition, it is unlikely that the contamination of the cabin with smoke and fumes would have reached the level of intensity that resulted in respiratory distress to the aircraft occupants.

2.3 Engine compartment fire

Vibration from the failing starter generator most likely led to the development of a fatigue crack in the fuel return line between the fuel control unit (FCU) and the starting flow controller (SFC). It would have been extremely difficult to detect the crack in the line during normal operation and maintenance of the aircraft. The fuel line was partially obscured by the SFC and other components in the engine accessory compartment and would have been impossible to inspect without removing the lower cowl. Although it was established that the crack was initiated and propagated under vibratory loads, it could not be determined if the crack was present at the time of any maintenance inspections.

Initially the small amount of fuel would have evaporated without posing any significant fire risk. As the crack developed during the flight, the quantity of fuel that escaped resulted in the presence of a combustible mixture. Sparks or frictional heat generated by the failed starter generator and transferred by the cooling airflow to the vicinity of the FCU provided the most likely ignition source for the escaped fuel (see section 1.16 of this report). The fire detectors were of a bimetallic type, and required a temperature in excess of 200 °C to operate. They may not, however, have detected the initial ignition of fuel-air mixture, because the initial fire may not have released the amount of heat required to operate the fire detectors. Once the fire became established, it would have continued burning adjacent to the source of the fuel leak in the area of the SFC. One fire detector was located on the rear seal, just above the SFC. That detector should have detected the fire and activated the fire warning. However, the reported multiple alarm panel warning lights that illuminated, loss of some right engine instrumentation, tripped circuit breakers and possible heat affected Teleflex cables suggested that the fire might have been burning for a period of time before the pilot received the fire warning. The possibility that the fire warning activation was due to an electrical short circuit as a result of fire damage to the cable loom within the engine accessory compartment could not be discounted. It was unable to be determined if and for how long the fire may have burnt before the fire warning activated.

The protection afforded by the firewall, as required by certification, was met despite the fire persisting longer than the design time limit. Although the fire in the engine accessory compartment did not breach the firewall, heat generated by the fire was transferred through the firewall into the wheel well resulting in heat damage to wiring and other components.

The pilot could not recall which circuit breakers had tripped. The tripped circuit breakers were most likely those associated with circuits whose electrical wiring was damaged by the fire in the accessory compartment. Those circuits were the right engine instrument indications (right torque, right Beta, fuel pressure, and oil pressure) and the right inertial separator actuator and propeller synchronisation.

The other circuit breakers could have tripped later in the flight as heat damage to the wiring in the right wheel well resulted in short-circuits. There was no evidence of any relationship between the fire damaged wiring in the engine accessory compartment and the tripped right shut-off valve circuit breaker. That circuit breaker probably tripped some time after heat was conducted through the firewall and damaged wiring insulation in the wheel well. It is likely that the shut-off valves and the shut-off switch would have been capable of normal operation for a period of time after the fire warning activation.

2.4 Fire bottle discharge

The fusible thermal valve on the fire bottles was designed to melt at a temperature of between 75 °C and 115 °C, less than the temperature setting of the fire detectors in the engine accessory compartment. Had the temperature within the accessory compartment risen above 126 °C and the thermal valve operated as designed, the contents of the fire bottle would have been discharged overboard. The pilot would not have been aware that the fire bottle was empty. Illumination of the amber 'Empty' light would only occur after the fire handle was pulled and detonation of the squib on the fire bottle opened the circuit.

Heat or fire damage to the wiring would have caused a short circuit that tripped the right fire extinguisher circuit breaker, deactivating the system. The investigation was unable to determine if the content of the fire bottle was discharged by pilot action, or if the retardant had been discharged overboard due to thermal overpressure as a result of the in-flight fire.

Damage to the fire bottle manifold, precluded examination of the components to determine if the contents of the fire bottle had discharged through the squib, or inadvertently through the fusible thermal valve. However, the disparity between temperature settings of the fire detectors and the thermal rating of the fire bottle was regarded as a safety deficiency, and recommendations relating to the settings and the cockpit indications have been made in Section 4.

2.5 Engine fire procedures

There were inconsistencies between the operation and selection of controls and switches associated with the engine fire checks reported by the pilot, and those selections found during the examination after the aircraft had landed at Cootamundra. The pilot reported that, to the best of his memory, he had selected the right firewall switch to the shut-off position. However, both the right shut-off switch and the right firewall shut-off valves were found in the open position. Had the firewall shut-off valve been closed during the Phase 1 checks, it would have stopped the flow of fuel and hydraulic fluid into the engine compartment. Without fuel to aid combustion, it was unlikely that the fire in the engine accessory compartment would have remained alight for the following 25 minutes of flight, and continued to burn after the aircraft had landed.

Physical interlocking of the firewall shut-off valve and the fire bottle discharge into the fire handle action, as found on more recently designed aircraft, would have removed the need for a pilot to remember to execute the actions, in the correct order. The absence of a physical interlock meant that the pilot had to remember the correct actions, then perform those actions in the correct sequence. That relied on the correct recall of the vital actions during a period of increased workload and stress. An in-flight fire, for example, increased the risk of error. The best defence against missing vital actions in a series of step-by-step processes is regular practice and rehearsal of the procedures.

The pilot reported that when he attempted to feather the right propeller, the propeller control lever would not remain in the feathered position, and returned to the low RPM position. The pilot also reported that he was unable to select the fuel condition lever to the cut-off position. The post-flight examination of the aircraft revealed that the right propeller lever was in the feathered detent position, and that the right fuel condition lever in the cut-off position. Examination of the propeller and fuel condition lever

Teleflex control cables revealed that although both had sustained some heat damage, the cables operated without restriction. It could not be determined if the heat affected Teleflex cables had prevented normal operation of the propeller and fuel condition levers when as reported by the pilot he conducted the engine fire emergency actions.

The pilot stated that propeller synchronisation was normally used in flight, and that he recalled switching the propeller synchronisation system off before attempting to feather the right propeller. When activated, the propeller synchronisation prevented feathering of the right propeller. The post-flight examination of the aircraft revealed that propeller synchronisation switch was in the off position, and that the propeller synchronisation circuit breaker was tripped. The circuit breaker probably tripped when heat damage to wiring of the propeller synchronisation slave system occurred after the fire commenced. It could not be determined if the propeller synchronisation was on when the pilot attempted to feather the right propeller.

The differences between the pilot's recollection of the position and operation of the cockpit controls and switches during flight, and the position of those controls and switches found during the post-flight examination of the aircraft could not be reconciled.

2.6 Smoke evacuation procedures

The smoke evacuation procedures contained in the manufacturer's POH listed two alternative smoke evacuation procedures, depending on the source of the smoke. The smoke evacuation procedure for a smoke source in the air conditioning system required the pilot to select the air conditioning system rotary master switch to VENT. The procedure for a smoke source not in the air conditioning system required the pilot to select the air conditioning system rotary master switch to BOTH. Both procedures specified that the ram air supply 'T' handles were to be pulled to allow ram air into the main distribution duct from the NACA air inlets located in the lower nose area.

If either of the firewall shut-off switches were selected to the closed position, both engine bleed air valves would close, irrespective of the position of the air conditioning master switch. The POH did not provide guidance about the selection position of the air conditioning master switch if either firewall shut-off switch was closed.

In this occurrence, the correct procedure for smoke evacuation would have required the air conditioning master switch to be selected to the VENT position, if the right engine firewall shut-off switch had been closed in accordance with the engine fire emergency checklist procedure. That was due to no engine bleed air being supplied to the air conditioning system distribution duct after the firewall shut-off switch was closed, because it also closed both engine bleed air valves. Under those circumstances, with no bleed air to supply air to the cabin, both ram air 'T' handles needed to be pulled to the open position to supply air to the distribution duct. The procedure also required both direct vision windows to be opened to assist in the smoke evacuation.

Post-flight examination of the aircraft revealed that the air conditioner master switch was in the VENT position, and that both ram air 'T' handles were closed. That configuration would have resulted in little or no airflow circulation throughout the cabin, because no airflow was possible through the cabin air distribution duct in that configuration.

The investigation was unable to determine if opening the direct vision window in flight, as reported by the pilot, would have assisted venting smoke and fumes from the cabin. The procedure was designed to eliminate smoke from within the cabin. Closing the window may have decreased the inflow of smoke and fumes through the unsealed joints between cabin and the wing root area. Although extending the landing gear, as directed by the previous operator's checklist, may have extracted the smoke and fumes from the wheel well and avoided smoke contamination of the cabin, flight with one engine inoperative would have precluded that action.

2.7 Emergency landing and procedures

Heat damage to the right wheel and tyre and the induction of smoke into the cabin until just prior to landing suggested that the right main landing gear leg extended about the time the pilot reported that he selected the gear down. Although not conclusive, a low hydraulic fluid quantity and pressure, and differences in sensitivity of the individual landing gear actuators, could account for extension of the right main gear leg only. The landing gear control circuit breaker would have tripped after the gear was selected down. Damage to wiring in the right wheel well would have prevented a down and locked (green) light illumination.

The pilot did not attempt to extend the landing gear using the emergency gear extension procedure when he did not get a positive indication that the gear was down and locked. The Bandeirante was approved for single-pilot operation and emergency extension of the landing gear by the pilot was physically possible. However, the urgency to land the aircraft as soon as possible, increased cockpit workload beyond the pilot's capacity to manually extend the landing gear. Had the engine fire and smoke removal procedures been followed, emergency extension of the landing gear may not have been required. Alternatively, if it were necessary, the urgency to land would not have been as great and pilot workload would have permitted adequate time to complete the emergency extension procedure.

The pilot selected the propeller levers to the feathered position, prior to touchdown. That was contrary to the manufacturer's POH procedure for a gear-up landing. Although that action had no effect on the outcome of the emergency landing, it demonstrated a lack of detailed knowledge of emergency procedures for the aircraft type.

2.8 Checklists

There were two different emergency checklists on board the aircraft. One of those checklists was the operator's CASA-approved emergency checklist, and the other was that of the previous operator of the aircraft.

The operator's emergency checklist did not contain a smoke evacuation procedure. Instead, it directed the pilot to refer to the manufacturer's POH for that procedure. That was contrary to the findings of the report commissioned by NASA into the human factors of checklists, which recommended that checklists be stand-alone documents. The necessity for a pilot to refer to another document, such as the POH, during an in-flight emergency had the potential to divert attention from time-critical actions that required ready access to information and instructions relevant to that emergency. No POH was found in the aircraft after the occurrence.

The previous operator's emergency checklist contained two procedures for smoke evacuation. One for smoke in the air conditioning system and the other for smoke not in the air conditioning system. Neither procedure, however, contained an instruction that both ram air 'T' handles were to be pulled to the open position.

The U.S. FAA Office of Integrated Safety Analysis review of accident data from 1983 to 1993 included information on accidents where checklists were inadequate or failed to include critical steps. The operator's emergency checklist was inadequate, because it contained no smoke evacuation emergency procedure. The previous operator's emergency checklist, which was also carried on board the aircraft at the time of the occurrence, was also inadequate, because it did not include a requirement to pull both ram air supply 'T' handles.

It could not be determined which, if any, emergency checklist was used by the pilot during his attempt to evacuate smoke from the aircraft.

Checklists are designed to maximise procedures for optimum pilot performance, especially in critical phases of flight or in emergencies. They form a valuable source of information, and are an essential tool to assure effective crew resource management during single-pilot operations. Well-disciplined use of checklists and regular practice of emergency procedures are the most practical form of defence against slips or lapses that may result in missed vital emergency actions.

Previous studies of checklist design and presentation contain much useful guidance and information for the production of flight deck documents. There was no evidence that the operator used that guidance or information when preparing the emergency checklist for the aircraft.

The design and presentation of the operator's emergency checklist had:

- poor quality binding that was broken
- loose and out-of-sequence pages
- sections that were not indexed or tabbed
- pages that were laminated with high-gloss reflective plastic
- referred to another document that was not available (POH)
- missing procedures, that included the smoke evacuation procedure.

Those factors meant that the emergency checklist would have been difficult to use in single-pilot operation especially when attempting to handle more than one emergency.

By comparison, the previous operator's emergency checklist was properly bound and tabbed for easy reference. Its presence in the cockpit suggested that it was more likely to have been used in preference to the operator's checklist.

The operator's engine failure or fire checklist contained six items that were to be accomplished by memory. The FAA review found that the working memory could contain about seven (plus or minus two) unrelated items. It was therefore possible that the pilot overlooked closing the firewall shut-off valve during his conduct of the shutdown procedure, particularly as that item was the final item of the memory items. The pilot's reported inability to select the fuel condition lever to cut-off and the propeller lever to feather may also have distracted him during the accomplishment of those six memory items.

The smoke evacuation procedures in the manufacturer's POH did not adequately accommodate all likely circumstances, particularly, if smoke was not coming from the air conditioning system following an in-flight engine fire and shutdown. Both the pilot and the instructor who trained him on the aircraft stated they used an emergency checklist during practice of simulated engine fire in flight emergency procedures. It could not be determined which emergency checklist had been referred to during those training sequences, that is, the operator's checklist or that of the previous operator of the aircraft. Additionally, neither pilot seemed aware that the emergency checklist procedures provided in both checklists were either deficient or contained missing items.

Missed items during the engine fire and smoke evacuation emergency sequences suggested that the pilot was probably not fully familiar with the emergency procedures memory items or the use of emergency checklists for the aircraft.

The proper execution of the manufacturer's engine fire emergency procedure would have isolated fuel from the right engine. Without fuel to feed the fire, and irrespective of the ineffective discharge of the fire bottle, the subsequent sequence of events would probably not have become so serious. With the fire extinguished, the necessity to land at Young would not have been so critical. When fog prevented the pilot from landing the aircraft at Young, the additional flight time to Cootamundra allowed the fire and smoke to intensify and their affects become noticeable and potentially life threatening.

The increasing urgency to land the aircraft as soon as possible was a consequence of the pilot's inability to contain the fire and to evacuate smoke from the cabin. This occurrence demonstrates the essential need for error-free and complete checklists to be available to pilots during emergency situations. It also demonstrates the need for pilots to be familiar with the systems of the aircraft they operate, and the emergency actions to be taken in the event of abnormal or emergency situations. Regular practice of those procedures is essential if they are to be executed effectively. The proposed arrangements in the Civil Aviation Safety Regulations Part 121B (charter) operations has the potential for pilots to improve pilot proficiency and knowledge in emergencies, specific to the aeroplane type.

Making full use of all available resources at times of high pilot workload and during emergencies can improve pilot performance. Crew resource management training introduced those concepts to multi-crew operations but was not required training for single-pilot operations. The use of passengers who are capable of assisting with unskilled tasks, during an emergency, maybe a worthwhile consideration in single-pilot operations.

3. CONCLUSIONS

3.1 Findings

3.1.1 Aircraft

1. The aft bearing of the right starter generator slipped, resulting in vibration and progressive failure of the starter generator.
2. As a result of vibration, a fatigue crack developed in the fuel return line between the fuel control unit and the stop flow controller.
3. Sparks or frictional heat generated by the failed starter generator ignited the combustible fuel/air mixture in the right engine accessory compartment.
4. The fire may not have been immediately detected by the fire detection system.
5. The firewall shut-off valve remained open and fuel continued to feed the fire.
6. The thermal relief valve on the fire bottle was set to discharge between 75 °C and 115 °C less than the minimum temperature sensed by the fire detectors.
7. After pulling the fire handle, the pilot received the amber empty light but had no indication as to whether the retardant had been discharged through the manifold into the engine compartment or outboard through the thermal relief discharge line.
8. Smoke from the fire entered the cabin.
9. The aircraft had a valid maintenance release.
10. There were two different emergency checklists carried on board the aircraft at the time of the occurrence.
11. The operator's approved emergency checklist on board the aircraft did not contain a procedure for smoke evacuation.
12. The smoke evacuation checklist of the previous operator, also aboard, was not appropriate for the configuration of the aircraft.
13. The documentation for overhaul of the right starter generator was not kept as required by regulation.

3.1.2 Air Traffic Services

1. Airservices Australia communicated the pilot's request for emergency services to the relevant agencies.
2. Based on information from the crew of an overflying aircraft and telephone confirmation from an observer at Cootamundra aerodrome, ATS advised the pilot that conditions would permit a visual approach.

3.1.3 Pilot

1. The pilot was properly licensed and qualified for the flight.
2. There was no evidence that incapacitation or physiological factors affected the pilot's performance.

3. The pilot advised ATS that there was a problem but did not immediately convey the nature of the emergency.
4. The pilot's actions and statements indicated that his knowledge and understanding of the aircraft systems was less than adequate.
5. It could not be determined which, if any, checklists were used by the pilot to shut down the right engine after the fire warning, or to evacuate smoke from the aircraft cabin.
6. The pilot did not complete all of the required items of the manufacturer's engine fire and smoke evacuation emergency checklist.
7. The pilot selected the propeller levers to the feather position prior to landing, which was contrary to manufacturer's POH procedure for a gear-up landing.

3.1.4 Damage

1. Fire damage was confined to the right engine nacelle and components, including the fire bottle manifold.
2. Propeller, engine and lower skin damage resulted from the subsequent emergency landing.

3.1.5 Fire

1. The fuel-fed fire was not extinguished and continued burning until after the aircraft had stopped at Cootamundra.

3.1.6 Operator

1. It could not be determined if the pilot's training on the aircraft was in accordance with the syllabus recommended in CAAP 5.23-1(0) due to a lack of training records.
2. The operator's training and checking had not ensured that the pilot's knowledge of aircraft systems and emergency procedures was of adequate standard to handle single-pilot emergencies.

3.1.7 Survivability

1. The aircraft was not equipped with an occupant oxygen system, nor was it required to be for that type of operation.

3.1.8 Emergency response

1. The emergency services responded in accordance with the CASA approved aerodrome emergency procedures.

3.1.9 Weather

1. Fog prevented the pilot landing at aerodromes nearest to the point where the emergency originated and resulted in additional flight time.

3.2 Significant factors

1. Vibration from the worn armature shaft of the right starter generator resulted in a fractured fuel return line.
2. The armature shaft of the right engine starter generator failed in-flight.
3. Sparks or frictional heat generated by the failed starter generator ignited the combustible fuel/air mixture in the right engine accessory compartment.
4. Items on the engine fire emergency checklist were not completed, and the fire was not suppressed.
5. The operator's CASA approved emergency checklist did not contain smoke evacuation procedures.
6. The pilot did not attempt to extend the landing gear using the emergency gear extension when he did not to get a positive indication that the gear was down and locked.
7. The aircraft landed on the right main landing gear and slid to a stop on the right main gear, left engine nacelle and nose.

4. SAFETY ACTION

4.1 Recommendations

4.1.1 Civil Aviation Safety Authority

Recommendation R20020054

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority review the location of fire bottles on aircraft to reduce the possibility of a premature discharge of fire retardant where the temperature in the area that contains the fire bottle rises above the setting of the fusible valve.

4.1.2 Federal Aviation Administration of the USA

Recommendation R20020055

The Australian Transport Safety Bureau recommends that the Federal Aviation Administration of the USA:

a) Review location of fire bottles on aircraft to reduce the possibility of a premature discharge of fire retardant where the temperature in the area that contains the fire bottle rises above the setting of the fusible valve.

b) Review the adequacy of the current requirements for fire-extinguishing systems to include a requirement that the pilot be provided with an in flight indication of an uncommanded discharge of fire retardant.

4.1.3 Departmento de Aviaco Civil – of Brazil

Recommendation R20020056

The Australian Transport Safety Bureau recommends that the Departamento de Aviaco Civil – of Brazil review location of fire bottles on aircraft to reduce the possibility of a premature discharge of fire retardant where the temperature in the area that contains the fire bottle rises above the setting of the fusible valve.

4.1.4 Empresa Brasileira De Aeronautica (Embraer)

Recommendation R20020057

The Australian Transport Safety Bureau recommends that Empresa Brasileira De Aeronautica consider development of a modification for the fire suppression system of its aircraft so that a pilot is provided with an in flight indication of an uncommanded discharge of fire retardant.

4.2 Safety action

As a result of this investigation the following safety actions were initiated:

4.2.1 Civil Aviation Safety Authority

The Authority agreed with the Bureau's draft recommendation that installation of a fire bottle in the same compartment that might experience fire, can, in the event of a fire in that compartment, render the fire extinguisher system ineffective.

The Authority will undertake an investigation into the fire extinguisher system fitted to that type of aircraft and its location.

The Authority will also review the certification process and whether that aircraft met the requirements of Civil Aviation Order 101.4. Following that review, the Authority will advise the Bureau of the outcome in a full response to the Recommendation.

The Bureau will monitor the progress of the review.

4.2.2 Aerodrome operator

As a result of the delay experienced by the ambulance crew in gaining access to the movement area of the aerodrome, the Cootamundra Shire Council installed crash links to the securing chain of the access gate. Crash links enable emergency vehicles responding to an accident to break the chain and avoid unnecessary delay created by having to locate a key and unlock the padlocked chain.

4.3 Other safety action

As a result of this and other investigations the Australian Transport Safety Bureau is investigating a safety deficiency in relation to crew compliance with checklist actions and issues related with adherence to prescribed procedures.

Any safety output issued, as a result of the analysis, will be published on the Bureau's website: **www.atsb.gov.au**