Australian Government
Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Investigation – AO-2007-017

Interim Factual

Fuel starvation – Jundee Airstrip, WA – 26 June 2007
VH-XUE
Empresa Brasileira de Aeronáutica S.A., EMB-120ER

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Abstract

While passing through 400 ft above ground level on final approach, the aircraft drifted left of the runway centreline. The crew decided to go around and on applying power, the aircraft rolled and yawed left, resulting in significant control difficulties for the crew. After the crew regained control of the aircraft, they realised that the left engine had stopped. The crew completed the emergency checks, transmitted a PAN call and diverted to Wiluna. It was later determined that the left fuel tank was empty and that the left engine had sustained a total power loss from fuel starvation.

The investigation is continuing.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

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1 FACTUAL INFORMATION

1.1 History of the flight

On 26 June 2007 at 0639 Western Standard Time[1], an Empresa Brasileira de Aeronáutica S.A., EMB-120ER[2] aircraft, registered VH-XUE, departed Perth, WA, on a contracted charter flight to Jundee[3] Airstrip, WA. There were two pilots, one cabin attendant, and 28 passengers on the aircraft. At 0806, on final approach for landing at Jundee, the left engine sustained a total power loss due to fuel starvation. The crew, unaware of the engine failure, elected to conduct a go-around because of difficulties maintaining alignment with the runway centreline. During the go-around, the crew were unable to retain directional control of the aircraft until the flap setting was reduced about 1 minute 20 seconds after the go-around was initiated.

The crew reported that the departure, cruise, and descent segments of the flight proceeded normally. The weather was fine, allowing a visual approach. A straight-in approach was conducted. The co-pilot was the handling pilot for the flight.

Table 1 provides the sequence of events associated with the Jundee approach and go-around. The information was obtained form the Digital Flight Data Recorder (DFDR), and is supplemented from information obtained from interviews with the crew. The DFDR analysis is still being finalised and the information contained in the table should be regarded as preliminary[4]. Because the aircraft's electrical power was operating for greater than 30 minutes after the occurrence, the cockpit voice contained no information of relevance to the occurrence.

Table 1: Interview and DFDR data

Approx local time	Altitude, Airspeed	Event
0754:31		Aircraft at top of descent (flight level 250).
0803:24	4,125 ft 198 kts	Flap 15 selected. *The crew reported that landing gear was selected down just*

1 The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST), as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC) + 8 hours.

2 The aircraft type is commonly referred to as a *Brasilia.*

3 Jundee Airstrip, 1845 ft AMSL, consisted of a 2,095 m long gravel runway 08/26 which included a 200 m sealed section at each end. The apron area was adjacent to the runway 26 threshold.

4 The actual time of each event is approximate only. However, the elapsed time between events time is based on recorded flight data. Airspeed figures refer to calibrated airspeed. Altitude figures have been converted from the recorded pressure altitude by considering the recorded altitude on landing at Wiluna, and assuming that the air pressure at Jundee and Wiluna was the same. Other parameters have been rounded to the nearest whole number. Fuel flow was recorded in pounds / hour and has been converted to kg / hour the purposes of this table. Landing gear position, thrust lever positions, fuel quantity and alerts and cautions were not recorded.

		after this time.
0805:17	2,678 ft 142 kts	Flap 25 selected.
0805:37	2,493 ft 128 kts	Flap 45 selected. When flap 45 was selected, engine torque increased from 19% to 28% for the left engine and 22% to 31% for the right engine. *The crew reported that when the co-pilot called for flap 45, the pilot in command called out that the reference speed for the approach was 111 kts. The operator's procedures required that flap 45 be used for all landings to unsealed runways (see Section 1.9.3).*
0805:44	2,416 ft 124 kts	Flaps reached 45-degree position. *The crew reported that the aircraft was configured for landing and the before landing checklist was completed at about 700 ft above ground level.*
0805:55	2,344 ft 120 kts	Aircraft descended through 500 ft above runway elevation. *The crew reported that, at 500 ft above ground level, the aircraft's enhanced ground proximity warning system (EGPWS) sounded '500 feet', in accordance with the normal operation of that system for a visual approach. The co-pilot (as pilot handling) called out 'visual – continue' in accordance with normal procedures. The pilot in command estimated that the wind at the time was 15 kts from 040 degrees. He also recalled that the left fuel gauge indicated about 200 kg and the right indicated about 250 kg.*
0806:03	2,268 ft 114 kts	Left engine torque gradually increased from 30% (0805:53) to 41% (0806:03). Right engine torque was stable at about 37 to 38% during this period. *The co-pilot recalled that shortly after the 500 ft call he noticed a subtle change in the engine sound. He noted that the engine instruments were difficult to read because of sun glare[5] (see also Section 1.4.1 Engine instrument panel). However, the engine parameters all appeared normal and relatively symmetrical. The aircraft was on profile, but as the airspeed was decreasing towards Vref, he tried to maintain the airspeed by increasing power.* *The pilot in command recalled noting that the co-pilot made a few control corrections for the crosswind and that everything appeared normal.*
0806:08	2,216 ft	Fuel flow for left engine started to decrease (from values of

5 According to the Geoscience Australia website, at 0800 WST on 26 June 2007, the sun's position was 54 degrees 55 minutes in azimuth and 13 degrees 32 minutes in elevation.

	114 kts	205-230 kg per hour to 168 kg per hour). Left engine torque started to decrease (from 42% to 33%).
0806:12	2,155 ft 112 kts	Left engine torque reached 0%, fuel flow 54 kg / hour. Roll attitude changed from 2 degrees right (0806:08) to 2 degrees left (0806:10), before moving back to 1 degree left. Heading increased to 75 degrees M (from 72 degrees M). *The co-pilot recalled that the aircraft began to drift left of the runway centreline, and to slowly roll left. He thought this may have been because the wind changed. He applied right control input to bring the aircraft back to the centreline but did not observe any response from the aircraft. He then increased the amount of control input but there still appeared to be no response from the aircraft. The pilot in command also recalled that the aircraft was drifting left of the runway centreline at this time.*
0806:13	2,141 ft 110 kts	Aircraft descended through 300 ft above runway elevation. *The crew recalled that the co-pilot advised the captain that he could not bring the aircraft back to the centreline and he suggested that they go around. As they were at not stablised at 300 ft (in accordance with the operator's stabilised approach criteria), the pilot in command called for a go-around. The crew did not recall seeing or hearing any warnings or cautions prior to commencing the go-around.*
0806:14	2,130 ft 110 kts	Go-around actions commenced. Right engine increased from 39% to 40% and fuel flow increased from 220 kg / hour to 232 kg / hour, and those values significantly increased in subsequent seconds. *The crew recalled that, as the co-pilot advanced the engine power levers at the commencement of the go-around, the aircraft yawed and rolled left 'aggressively' before the co-pilot could complete the standard call ('Going round, set power , flaps 15', see Section 1.14). The co-pilot applied right rudder and aileron but was unable to control the aircraft. He informed the pilot in command that he was unable to hold the control inputs, so the pilot in command placed his hands on the control yoke and his feet on the rudder pedals and assisted the co-pilot.*
0806:18	2,084 ft 109 kts	Right engine torque reached 125%. *During the period after starting the go-around, the crew recalled that the stick shaker activated twice, and that each time they slightly reduced the control yoke back pressure. During this period, the EGPWS warning 'too low terrain' sounded.* *Both pilots reported noticing during their efforts to regain control of the aircraft that a red master warning caption OIL PRESS (oil pressure) for engine number 1 (the left*

		engine) had illuminated and an amber master caution for FUEL had illuminated on the multiple alarm panel.
0806:20	2,073 ft 108 kts	Aircraft heading commenced veering left from 076 degrees. Left bank 10 degrees, pitch attitude 1 degree nose-up.
0806:21	2,065 ft 107 kts	Altitude temporarily stabilised at about 220 ft above runway elevation (until 0806:33). Between 0806:33 and 0806:37 there was a small increase in altitude.
0806:27	2,065 ft 103 kts	Right engine torque reached 150%. Two seconds later it decreased, reaching 130% by 0806:33 and stayed in the range of 125 to 130% until 0807:47. Left bank 16 degrees, pitch attitude 4 degrees nose-up, heading 61 degrees M.
0806:38	2,085 ft 96 kts	Flap 25 selected. Left bank 34 degrees, pitch attitude 5 degrees nose-up, heading 14 degrees M. *After deciding that control of the aircraft had been stabilised, the co-pilot called for the flaps to be retracted to the 'flaps 25' position.* *After confirming that the co-pilot had control of the aircraft, the pilot in command selected flap 25.*
0806:39	2,068 ft 97 kts	Altitude started to decrease.
0806:41	2,053 ft 100 kts	Maximum left bank recorded (39.5 degrees). Pitch attitude changed from 9 degrees to 1 degree nose-up.
0806:43	2,007 ft 99 kts	Flaps reached 25-degree position. Left bank 39 degrees, pitch attitude 2 degrees nose-up, heading 325 degrees M.
0806:49	1,898 ft 105 kts	Aircraft reached lowest altitude, equivalent to about 50 ft above runway elevation. Altitude increased in subsequent seconds. Left bank 14 degrees, pitch attitude 9 degrees nose-up, heading 285 degrees M.
8:06:59	2,009 ft 95 kts	Airspeed reached lowest reliable value (95 kts), and stayed within 95 to 97 kts range until 0807:11. Pitch attitude reached highest value (12 degrees nose-up). Left bank 7 degrees, heading 272 degrees M.
0807.35	2,089 ft 103 kts	Roll angle stablised to about wings-level. Pitch attitude 6 degrees nose-up. Heading stabilised 198 degrees M.
0809:09	2,539 ft 111 kts	Flap 15 selected.
0809.20	2,597 ft 117 kts	Flap zero selected. *The crew recalled that after raising the flaps the landing*

		gear was selected up.
0810.34	3,407 ft 134 kts	Left engine shut-off selected. *After the landing gear was retracted, the crew turned their attention to the warnings they had noted earlier. They recalled that, in addition to the OIL PRESS and FUEL warnings, a low pressure light on the overhead fuel panel was illuminated, the white lights for both left electric boost pumps were ON, and the number 1 white engine electronic control (EEC) light was on. The fuel gauges were indicating just over 200 kg per side. The crew then completed the checklist actions for an engine failure in flight. They reported that when the left engine condition lever was placed in the feather position, there was a significant improvement in aircraft performance.*[6]
0812:07	3,603 ft 167 kts	Press-to-talk switch is activated. *The crew reported that they levelled the aircraft at 3,400 ft (the lowest safe altitude). Because Wiluna was close by, the aircraft was heading in the direction of Wiluna, and the runway at Wiluna was sealed, the crew decided to land there. The pilot in command transmitted a PAN*[7] *emergency message to air traffic control, advising an engine failure and that they were diverting to Wiluna.*
0818:00		Aircraft landed at Wiluna *The crew reported that the landing at Wiluna was uneventful.*

The aircraft's flight log indicated that there was 1,190 kg of fuel on board the aircraft prior to the departure from Perth. That amount included 680 kg residual fuel on board from the previous flight and 511 kg of fuel added immediately before the flight.

Following the occurrence, the operating company dispatched engineers to examine the aircraft. They reported that the cockpit fuel quantity gauges displayed 300 kg (left tank gauge) and 150 kg (right tank gauge).

A physical check of both tanks revealed that the left tank contained no fuel, and the right tank contained 150 kg of fuel.

6 The automatic propeller feathering system did not activate unless three conditions were met. Those were that the torque on both engines was greater than 62 percent, both power lever angles were greater than 62 degrees, and the automatic feathering system was ARMED.

7 Radio code indicating uncertainty or alert, general broadcast to widest area but not yet at level of MAYDAY.

1.2 Flight simulator replication of occurrence

At the time of the occurrence involving XUE, another local EMB-120 operator had arranged for two of its pilots to attend EMB-120 simulator training overseas[8]. That operator was approached by a Civil Aviation Safety Authority (CASA) representative to have its pilots replicate the XUE event in the simulator. That exercise was subsequently undertaken.

The pilots involved in the simulator training reported that a scenario was developed where an engine was failed on late final approach with full flap selected and the landing gear down. A missed approach was then initiated. One hundred percent torque was applied, flap 15 was selected, and the propeller not feathered. The pilots could not maintain control of the aircraft and the simulator 'crashed' after turning through about 90 degrees. Similar results were obtained using 110 and then 120 percent torque. A successful, but 'untidy' go-around, during which the stick shaker operated a number of times, was achieved when they used torque levels similar to those they had been told were used by the crew of XUE.

The pilots involved in the simulator training also reported that they attempted to continue the approach after the engine had 'failed'. They found that the aircraft's alignment with the runway could rapidly deteriorate to the stage where a landing could not be achieved. They found that with a windmilling propeller, flap 45, and landing gear down, greater than 90 percent torque was required to maintain airspeed and the approach path. Further, there was little change in engine noise when the engine failure was initiated and the first noticeable indication they received was a single alert chime followed by the illumination of the ELEC and MAIN GEN OFF BUS captions on the warning panel.

The pilots added that their responses in the simulator were against the background of knowing that an engine was going to 'fail'. They considered that detecting and responding to the actual situation would have been considerably more challenging.

The operator of XUE did not use flight simulators as part of its EMB-120 flight crew training. There was no Australian regulatory requirement for simulators to be used for flight crew training. Also, there was no EMB-120 flight simulator facility in Australia.

1.3 Flight crew

1.3.1 Pilot in command

The pilot in command obtained a commercial pilot (aeroplane) licence on 12 October 2000 and an airline transport pilot (aeroplane) licence on 21 July 2005. Prior to commencing employment with the operator, he had no previous turbine-engine aircraft experience. The pilot in command had 3,040.0 total flying hours.

On 21 August 2006, the pilot in command obtained an EMB-120 co-pilot endorsement with the operator, which involved 7.6 hours flight time. He was

8 At the time of the occurrence, there was no EMB120ER simulator in Australia. Local operators who wished to undertake simulator training had to travel to overseas facilities in the US or Europe.

cleared for line operations as a co-pilot on 20 September 2006 (after 50 hours supervised experience), and logged a total of 260.8 hours as a co-pilot. He obtained a command endorsement from the operator on 19 January 2007, which involved 6.2 hours flight time. He initially did not pass a clearance to line check after 50 hours in command under supervision. The check pilot noted no problems with his knowledge of systems of procedures, but believed he would benefit from further experience. He passed the second check after 83.8 hours with no problems noted.

After being cleared for line operations as pilot in command on 19 February 2007, the pilot in command completed 298.0 hours in that role. Prior to completing his command endorsement, his last proficiency check was the renewal of his multi-engine command instrument rating on 15 December 2006.

The operator's *Flight Standards Manual* stated that all new crew members had to complete a crew resource management (CRM) theory course 'as soon as practicable', and that all crew members 'shall receive refresher training in this subject within every two years'. The pilot in command had not completed a CRM course during his time at the operator. He had completed a Bachelor of Aviation degree in July 2003, and this degree had included a subject on human factors in 2000.

The pilot in command stated that he was well rested and in good health at the time of the occurrence. He had conducted 3.9 hours flying on the day prior to the occurrence, with his duty time finishing at 1300. He conducted no duties for the operator on the previous 10 days.

1.3.2 Co-pilot

The co-pilot obtained a commercial pilot's licence (aeroplane) on 2 January 2003. Prior to commencing with the operator, he had no previous turbine-engine aircraft experience and 25.5 hours as pilot in command of multi-engine aircraft.

On 21 April 2005, the co-pilot obtained an EMB-120 co-pilot endorsement with the operator, which involved 6.7 hours flight time. He was cleared for line operations as a co-pilot on 17 May 2005 (after 50 hours supervised experience). His total flying experience at the time of the occurrence was 1,618.3 hours, of which 1,356.1 hours was as a co-pilot on EMB-120 aircraft. The co-pilot conducted EMB-120 ground school training as part of his employment.

The co-pilot's last aircraft proficiency check was completed on 10 May 2007. He completed a 1-day CRM course on 12 October 2005.

The co-pilot stated that he was well rested and in good health at the time of the occurrence. He conducted no duties for the operator during the previous 4 days.

1.4 Aircraft information

The EMB-120ER[9] was a twin turboprop engine aircraft with a maximum take-off weight of 11,990 kg and was certified in the transport category for the carriage of passengers and freight. In the passenger role, it had a maximum seating capacity of

9 The letters ER denote an 'Extended Range' version of the EMB-120 aircraft.

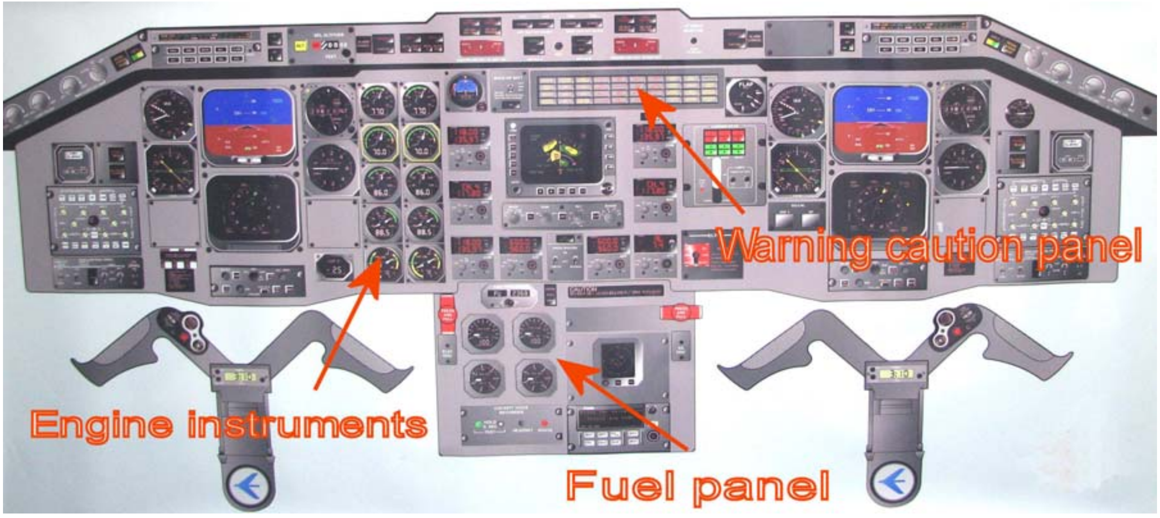
30. The crew included two pilots and one cabin attendant. It was powered by two Pratt & Whitney Canada PW118 turboprop engines.

At the time of this report, there were 22 EMB-120 aircraft on the Australian aircraft register.

1.4.1 Instrument panel

The main cockpit instrument panel is depicted in the schematic at Figure 1.

Figure 1: Schematic of EMB-120 instrument panel



Note: The schematic shows the position of engine instruments, fuel panel, and warning/caution panel and their relationship with the crew seating positions indicated by the control yokes (the pilot in command occupies the left control position)

Figure 2 shows the two columns of engine instruments - for the left and right engines. The instruments were, from top to bottom, intra-turbine temperature (T6), percentage engine torque, propeller speed (NP), low pressure and high pressure spool speed indication (NH/NL), and a combined gauge showing oil temperature and pressure. All gauges, except for oil, displayed information in analogue and digital formats. There were yellow highlighting borders around the torque gauges.

Figure 2: Engine instruments.

1.4.2 Engine power loss indications

The aircraft manufacturer provided the following information regarding engine parameter behaviour, in order, during a fuel starvation event:

- The following engine parameters will reduce:
  - torque indication
  - fuel flow indication
  - low pressure spool speed indication (NL)
  - high pressure spool speed indications (NH)
  - intraturbine temperature indication (T6)
  - propeller speed indication (NP)
  - oil pressure indication.
- When oil pressure reaches 40 psi, an OIL PRESS 1 or OIL PRESS 2 light will illuminate on the Multiple Alarm Panel (light is red) and a WARNING light will flash on the glare shield panel (cancellable through the ALARM CANCEL SWITCH). The warning is accompanied with an OIL voice message from the aural alarm system.
- The fuel starvation will lead to a fuel low pressure condition.

According to the aircraft flight manual, the sequence of events following a low fuel pressure condition would be:

- LOW PRESS and Fuel Pump ON lights flashing on the fuel panel (located in the overhead panel).
- FUEL light illuminated on the Multiple Alarm Panel (light is amber).
- CAUTION light flashing on the glare shield panel accompanied with a single chime aural alarm. (The caution light can be cancelled via the ALARM CANCEL SWITCH.)

Checks following the occurrence confirmed that the various alarm and warning systems on the aircraft were functioning normally.

The triggering of the various warning and alarm signals associated with the performance of the number-1 engine was not recorded and it was not clear from the engine performance data when the various warnings and alarms would have been displayed to the crew. Further investigation will be undertaken in an attempt to link the recorded flight data regarding the various engine parameters to the warning and caution thresholds to determine the sequence and timing of caution and warning activations that the crew should have received during the sequence. That work will be a precursor to examining the performance of the flight crew in terms of recognising and responding to the engine failure.

1.4.3 Fuel quantity indicating system

The aircraft was equipped with an electrical capacitance type fuel quantity indicating system. Each wing was fitted with six capacitive type fuel sensor units or probes. There were four fuel sensor probes in each outboard tank, and two in each inboard tank. The inboard and outboard tanks in each wing were interconnected and acted as a single reservoir. The fuel systems for each wing were identical and independent. The aircraft operating manual stated that the aircraft’s maximum fuel capacity was 2,622 kg (3,340 lt), including 22 kg (28 lt) unusable fuel. Those figures were based on an average fuel density of 0.785 kg/lt.

A fuel management panel (Figure 3) was positioned in the centre section of the cockpit instrument panel. The panel featured fuel quantity indicators, fuel flow indicators, and a fuel totaliser display for the left and right fuel systems.

Figure 3: Fuel management panel in the cockpit centre console instrument group.

The fuel quantity indicators displayed, in kg x 100, the total fuel quantity in the corresponding wing. The quantity indication was compensated for temperature and fuel density.

The fuel flow indicators displayed the fuel flow, in kg per hour, for each engine. A fuel totaliser display, positioned immediately above the fuel quantity indicators, displayed digitally the total amount of fuel used or the total amount remaining, depending on the function selected by the flight crew.

1.4.4 Fuel totaliser

The fuel totaliser digitally displayed either the fuel used or fuel remaining, via the operation of a push button function selector immediately beneath the display windows. Pressing the selector alternately selected the fuel used and fuel remaining functions. Pulling the selector caused the totaliser to automatically update the indicated quantity as a function of the fuel quantity indicating system information.

In the fuel used mode, the totaliser display was a function of data received from the engine fuel flow transmitters. The fuel flow transmitters were independent of the fuel quantity indicating system, meaning that when the totaliser was selected to the fuel remaining function, it was measuring fuel by a method independent of any information from the fuel quantity indicators. The aircraft's auxiliary power unit (APU) burned approximately 60 kg fuel per hour. APU fuel burn information was not measured and was not included in the 'fuel used' totaliser indication.

1.4.5 Dripless measuring sticks

The aircraft was also equipped with dripless measuring sticks (sometimes referred to as 'magna sticks') that enabled the manual measurement of the fuel quantity in each wing. There were three dripless measuring sticks for each outboard tank, and one for each inboard tank. The dripless stick system consisted of a magnet floating on the surface of the fuel in the tank and a calibrated stick. The sticks were unlocked via access points on the lower surface of the wing and allowed to lower until the floating magnet attracted the upper end of the stick (Figure 4). That enabled the level of the fuel to be determined. A conversion table carried on the aircraft was used to convert the reading on the stick to a fuel tank quantity in kilograms. Accurate quantity measurement using the dripless sticks required the aircraft to be laterally level.

Figure 4: Showing a dripless stick in the lowered position, indicating 2.8 on the measurement scale.

1.4.6 Fuel low level warning and EMB-120 (see also 1.11)

The EMB-120 was not equipped with a fuel low level warning system. The aircraft manufacturer advised that the EMB-120 was certified in accordance with US Federal Aviation Regulation (FAR) Part 25, which did not require the incorporation of a fuel low level warning system.

1.4.7 Fuel system maintenance history

According to the aircraft maintenance documents, on 1 September 2006, the aircraft had maintenance action that included a wire splice in the left wing that was in accordance with the manufacturer's procedures[10]. The aircraft underwent a 4C maintenance check in late 2006. That check included a check of the fuel quantity indication system (FQIS) on 15 October 2006. No defects of the system were reported as a result of that check.

On 22 October 2006, an inspection of the fuel quantity wiring harness in the area of control cable tension checks was conducted with no defects found. Between that date and this occurrence, only one fuel quantity indication system defect was recorded. That was written up as 'fuel totaliser indicating incorrectly'. The record indicated that the fault was rectified by replacing the totaliser.

There were a number of fuel system related maintenance activities recorded in the aircraft's flight logs. Those are included in Section 1.7, Table 2.

1.4.8 Examination of fuel quantity indicating system

When the aircraft was examined after the incident, the left tank was empty, while the left gauge indicated 350 kg. A check of the overall capacitance of the left fuel quantity indicating system revealed that it was out of limits on the low side. The capacitances of all probes (while still installed) were also out of limits on the low side. When the probes were removed and bench tested, all tested correctly except probe number-6 (the outboard probe) which showed similar below limits capacitance as it did while installed. After a replacement probe was fitted in the number-6 position, the system capacitance returned to the correct value.

The right fuel quantity indicating system was checked and confirmed serviceable.

A visual inspection of the left FQIS wiring harness did not reveal any abnormality. The loom was subsequently removed from the aircraft and was inspected under magnification. That inspection revealed several areas of damage on the loom, particularly on the wires in the loom relating to the number-6 probe (Figure 5). Those wires were short circuiting to the metal structure inside the wing tank and also between the AC supply, DC positive and DC negative wires causing intermittent and hard short circuits and arcing, leading to the failure of two diodes on the number-6 probe.

There was no record that the loom had ever been removed since the aircraft was manufactured in 1989.

The aircraft manufacturer advised that it was aware of only one other instance of fuel quantity indicating system malfunction in EMB-120 aircraft. That occurred in September 2001 and involved the right fuel quantity indicator reading fluctuating approximately 300 pounds. The problem was traced to a faulty cannon plug on the back of the indicator.

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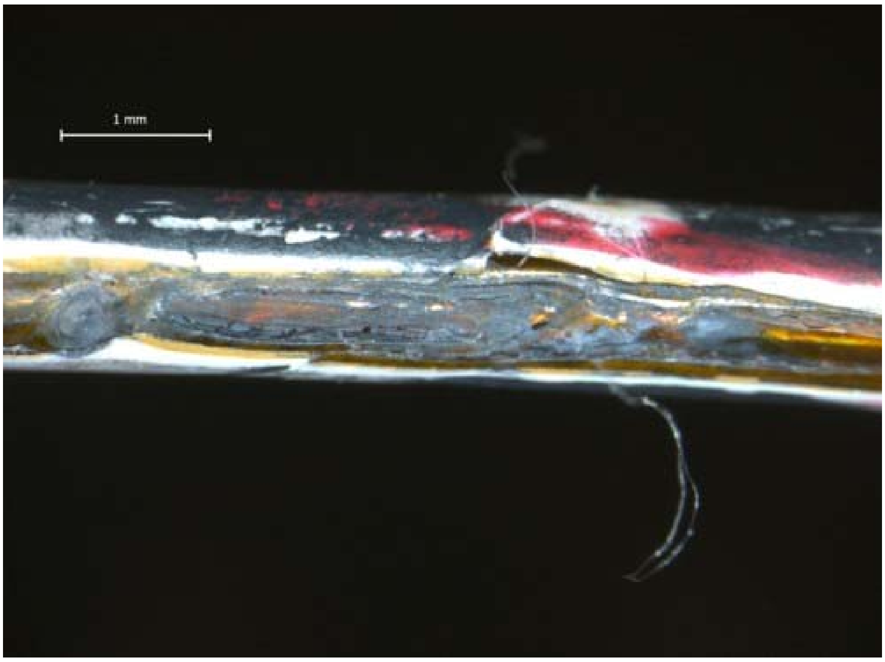
10 On 13 April 2007, the manufacturer's wiring manual was amended to include the following: 'Caution - Do not perform any kind of repair of wires or cables inside fuel tanks. An additional caution also stated, 'Do not repair the fuel cable harnesses. If you do not obey this precaution, an explosion can occur in the fuel tanks'.

Figure 5: Example of damage to wiring loom showing exposed wire and abraded insulation layers.



1.5 Fuel quantity measurement – regulatory requirements and guidance

The Civil Aviation Safety Authority (CASA) Civil Aviation Regulation (CAR) 234(1) stated:

> (1) The pilot in command of an aircraft must not commence a flight within Australian territory, or to or from Australian territory, if he or she has not taken reasonable steps to ensure that the aircraft carries sufficient fuel and oil to enable the proposed flight to be undertaken in safety.
>
> (2) An operator of an aircraft must take reasonable steps to ensure that an aircraft does not commence a flight as part of the operator's operations if the aircraft is not carrying sufficient fuel and oil to enable the proposed flight to be undertaken in safety.

Civil Aviation Order (CAO) 20.2 (*Air Service Operations – Safety Precautions Before Flight*) provided further requirements. Prior to May 2006, the CAO stated:

> 6.1 Aircraft having a maximum take-off weight in excess of 5700 kg (12,500 lb) shall not commence a flight unless the pilot in command has ensured that the fuel quantity on board has been checked by two separate methods.
>
> 6.2 The cross-check procedures required by paragraph 6.1 must be specified by the operator, together with the allowable discrepancy which must not exceed 3 per cent of the higher amount.
>
> Note: Acceptable cross-check methods are:
>
> 1. Check of stick gauge (dip, drip, sight) readings against electrical gauge (potentiometer, capacitor) readings.

2. Having regard to previous readings, a check of stick or electrical gauge readings against fuel consumed indicator readings.

3. After refuelling and having regard to previous readings, a check of stick or electrical gauge readings against the refuelling tank measurements.

4. When a series of flights is undertaken by the same crew and refuelling is not carried out at intermediate stops, cross-checks, other than the first of the day, may be made by checking the gauge readings against the computed fuel on board.

As part of a regulatory change process, CASA stated that these requirements appeared to be unique to Australia. CASA proposed changing the requirements to be consistent with the outcome-based rules of the US Federal Aviation Administration and the European Aviation Safety Authority. Accordingly, CAO 20.2 was amended by replacing paragraphs 6.1 and 6.2 with the following (8 May 2006):

6.1 The operator of an aircraft having a maximum take-off weight of more that 5 700 kg and engaged in commercial operations must ensure that the operations manual contains instructions and procedures for the pilot in command of the aircraft to verify the quantity of fuel on board the aircraft before flight.

Note See Airworthiness Bulletin 28-002 for advice on instructions and procedures that may be adopted to verify the quantity of fuel on board an aircraft before flight.

In addition, Airworthiness Bulletin (AWB) 28-002, dated 15 May 2006, stated the following:

Unless assured that the aircrafts tanks are completely full, or a totally reliable and accurately graduated dipstick, sight gauge, drip gauge or tank tab reading can be done, the pilot should endeavour to use the best available fuel quantity cross-check prior to starting. The cross-check should consist of establishing the fuel on board by at least two different methods, such as:

1. Check of visual readings (tab, dip, drip, sight gauges against electrical gauge readings); or

2. Having regard to previous readings, a check of electrical gauge or visual readings against fuel consumed indicator readings; or

3. After refuelling, and having regard to previous readings, a check of electrical gauge or visual readings against the refuelling installation readings; or

4. Where a series of flights is undertaken by the same pilot and refuelling is not carried out at intermediate stops, cross-checks may be made by checking the quantity gauge readings against computed fuel on board and/or fuel consumed indicator readings, provided the particular aircrafts fuel gauge system is known to be reliable.

Civil Aviation Advisory Publication (CAAP) 234-1(1) was revised in November 2006 to provide similar guidance as that contained in AWB 28-002[11]. More specifically, the CAAP stated:

> 13.1 Unless assured that the aircraft tanks are completely full, or a totally reliable and accurately graduated dipstick, sight gauge, drip gauge or tank tab reading can be done, the pilot should endeavour to use the best available fuel quantity crosscheck prior to starting. The cross-check should consist of establishing the fuel on board by at least two different methods such as
>
> a) Check of visual readings (tab, dip, drip, sight gauges) against fuel consumed indicator readings: or
>
> b) Having regard to previous readings, a check of electrical gauge or visual readings against fuel consumed indicator readings: or
>
> c) After refuelling, and having regard to previous readings, a check of electrical gauge or visual readings against the refuelling installation readings: or
>
> d) Where a Series of flights is undertaken by the same pilot and refuelling is not carried out at intermediate stops, cross-checks may be made by checking the quantity gauge readings against computed furl on board and/or fuel consumed indicator readings, provided the particular system is known to be reliable.

1.6 Operator’s fuel quantity measurement processes

1.6.1 Operator’s procedures

The operator published fuel quantity checking procedures in its *Flight Operations Manual* and its *Brasilia Flight Operations Manual*. The content of the two manuals was consistent, with the Brasilia manual content being more detailed.

The *Flight Operations Manual* stated:

> Aircraft with a MTOW exceeding 5700 Kg shall not commence a flight unless the PIC has ensured that the fuel quantity on board has been confirmed by use of two separate cross check methods. The maximum discrepancy between the two methods shall be the quantity defined in the aircraft type operations manual…

The Brasilia manual stated:

> Prior to flight, a check of the total fuel on board must be carried out by two separate methods. The difference between these two checks shall be less than 60 kg.
>
> Acceptable methods of cross checking fuel for the [Operator’s] Brasilia are:
>
> - Check of magna stick readings against electrical gauge readings; or
> - Having regard to previous readings, a check of electrical gauge or magna stick readings against fuel consumed indicator readings; or

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11 In late 2007, AWB 28-002 was withdrawn as a listed CASA publication.

> - After refuelling, and having regard to previous readings, a check of electrical gauge or magna stick readings against the refuelling installation readings; or
> - Where a series of flights is undertaken by the same pilot and refuelling is not carried out at intermediate stops, cross-checks may be made by checking the quantity gauge readings against computed fuel on board and/or fuel consumed indicator readings, provided the particular aircrafts fuel gauge system is known to be reliable.
>
> The APU [auxiliary power unit] burn allowance of 58 kg per hour may be considered when making the fuel cross check.
>
> When using the magna sticks, significant variations may occur if the aircraft is not level. A check of level may be made on the EADI. A pitch of ± 2° is allowable. The recommended practice when using the magna sticks is the [sic] take the reading then immediately return the stick to the locked position.

The operator reported that, prior to May 2006, its procedures included 3 per cent as the maximum allowable discrepancy. When the amended CAO was issued, the operator changed the allowable discrepancy for the EMB-120 to 60 kg[12]. The rationale for that change was that, while 60 kg was less than 3 per cent at maximum and higher fuel quantities, it was close to 3 per cent at the quantities that were used in most day to day operations. The change was reported to CASA and incorporated into the operator's manual.

The operator provided a Flight Log form for recording various operational data for each day's operations for each aircraft. The 'fuel load' section of the form contained columns for recording fuel quantity information for each flight. The log had four columns that were for:

- Total fuel quantity at departure
- Burn (or fuel used during a flight)
- Residual (or fuel remaining at the end of a flight)
- Added (or fuel added prior to the next flight).

In relation to completing the form, the *Flight Operations Manual* stated:

> The figure placed in the 'Fuel Total' column of the Flight Log Form shall be the fuel total as read from the fuel gauges (corrected if necessary), not the calculated fuel total.
>
> Crews shall consistently check the fuel burns against the residual fuel figure for accuracy on every sector.
>
> Fuel on board gauge readings are to be checked prior to departure by adding the fuel quantity uplifted, as per the release note, to the fuel quantity remaining at the end of the previous flight which has been recorded on the Flight Log.

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12 The operators fleet included three other aircraft types in addition to the EMB-120.

1.6.2 Fuel quantity cross-check practices

Six company EMB-120 pilots, including the fleet manager and a training and checking pilot, were interviewed to understand what practices were used by the operator's pilots for fuel quantity management. Those practices were as follows:

- The 'total fuel quantity at departure' was read from the totaliser set to the 'fuel remaining' mode. The totaliser was preferred to the fuel gauges because it provided a digital readout that was easier to read than a gauge pointer. The figure was obtained after any refuelling had been completed.
- Two different practices were described for obtaining the 'burn' figure. Most pilots reported that they obtained the figure by calculating the difference between the 'total fuel quantity at departure' and the 'residual' figure at the end of a flight. However, two pilots, including the fleet manager, stated that they obtained the figure from the totaliser set to the 'fuel used' mode.
- The 'residual' figure was read from the totaliser set to the 'fuel remaining' mode. The figure was obtained after the engines had been shutdown and the totaliser had been updated.
- The 'added' figure was obtained by converting the refuelling docket quantity (litres) to kilograms. The operator's manuals prescribed the figure '0.8' to be used as the specific gravity of aviation turbine fuel for that purpose.
- For the first flight of the day, the 'residual' figure was copied from the final residual from the previous flight log. This figure was compared with the fuel quantity gauge and/or totaliser display. There was no procedure to follow in the event of a discrepancy between those readings.
- The 'total fuel quantity at departure' figure was cross-checked against a figure calculated by adding the 'residual' and the 'added' figures. If there was a discrepancy of 60 kg or more between the totaliser total fuel and the calculated total fuel figures, then the discrepancy had to be resolved to the satisfaction of the crew. If the discrepancy could not be resolved, then magna sticks were used to confirm the quantity in the tanks. The reason for any discrepancy of 60 kg or more was noted in the 'comments / observations' section of the flight log.
- The most common reason for a discrepancy between the totaliser total fuel and the calculated total fuel figure was APU fuel burn prior to departure. APU fuel burn was not normally recorded. However, if APU burn explained a discrepancy of 60 kg or more between the totaliser total fuel and calculated total fuel, then the APU fuel burn would be noted in the 'comments / observations' section.
- It was reported that some pilots regularly reset the totaliser during flight. The reason for doing a reset was to ensure that the fuel remaining display matched the fuel gauge display. It was reported that, by the end of a flight, the difference between the two figures was often about 20 to 30 kg if the totaliser was not reset.
- Magna sticks were rarely required to be used to resolve discrepancies, with several pilots reporting that they had been shown how to use them during line training but had not needed to use them in normal operations. It was also reported that, if they were used, this would not always be documented on the flight logs.

- EMB-120 were rarely refuelled to full capacity during normal operations for operational reasons. However, the aircraft were occasionally refuelled to full capacity for training flights.
- Flight logs were audited by a pilot delegated by the fleet manager to do the task on a sample basis. Each flog log was checked for its accuracy, but there was no analysis of trend figures over more than one flight log. Any problems identified on the flight logs were notified to the relevant pilots. When problems were notified, they usually related to weight and balance or flight hours rather than problems with fuel figures.

The investigation team reviewed a sample of the operator’s flight logs. The sample included all flight logs for XUE from the last recorded maintenance activity where the fuel quantity indicating system was calibrated (7 October 2006) until the day before the occurrence (25 June 2007). Flight logs for the operator’s other five EMB-120 aircraft for the period 1 April 2007 until 25 June 2007 were also examined. Observations regarding fuel recording practices based on that review included:

- Of the 22 different pilots in command who completed the flight logs, only three appeared to use the totaliser fuel used function to calculate the ‘burn’ figure. Those pilots included the fleet manager, the pilot in command of XUE on the occurrence flight (who changed to the practice after 4 April 2007) and another pilot in command (who changed to the practice after 18 June 2007). The pilot in command of the occurrence flight reported that he had changed to using the totaliser after receiving advice from the fleet manager. The fleet captain always appeared to use the totaliser fuel used function to calculate the ‘burn’ figure (from logs ranging from 26/11/06 through to the occurrence).
- Fuel burns occurring during maintenance activities were regularly recorded on the flight logs.
- The use of magna sticks was noted on two occasions. Both involved the same pilot in command and were to confirm discrepancies in the totaliser total fuel figure and the calculated total fuel figure following maintenance activities.
- During the period 1 April to 25 June 2007, there were 68 occasions across all six aircraft when the difference between the recorded ‘total fuel quantity at departure’ figure was 60 kg or more different to the applicable calculated figure. On 51 occasions the reason provided was ‘APU burn’. No reason was provided on 15 occasions. Flight logs for XUE during the period 8 October 2006 to 31 March 2007 indicated a similar pattern.
- During the period 1 April to 25 June 2007, there were 29 occasions across all six aircraft when the final residual at the end of a day’s operations was different to the first residual figure on the flight log for the first flight the following day. On nine occasions the difference was 60 kg or more. No reasons were provided on the flight log to explain those differences. On most of the occasions, the change in the residual figure brought the calculated total fuel figure to within 60 kg of the totaliser total fuel figure for the first flight of the following day. Flight logs for XUE during the period 8 October 2006 to 31 March 2007 indicated a similar pattern.

1.7 Analysis of fuel quantity data

The examinations of the flight logs for XUE and other aircraft identified that the fuel 'added' figures generally exceeded the fuel 'burn' figures. That 'excess' was due to two main factors:

- The use of a specific gravity of 0.8 to convert fuel added in litres to kilograms. A lower specific gravity would reduce the margin.
- The 'burn' figures did not include the APU fuel burn that occurred before the total fuel at departure figure was obtained from the totaliser.

Because of those two factors, it was not possible to identify with reasonable precision when problems with the accuracy of the fuel quantity gauges on XUE began. However, further analysis of the figures showed that there were differences in the pattern of data for XUE compared with the other aircraft, and that those differences appeared to commence in the period March - April 2007. More specifically:

- The excess for XUE appeared to be lower in the period April to June 2007 relative to previous months. The excess per month during the period November 2006 to March 2007 ranged from 711 kg (89.6 flight hours) to 1,243 kg (123.4 flight hours). The excess figures for April, May and June (up to 25 June) 2007 were -38 kg (84.8 hours), 496 kg (127.7 hours) and -52 kg (73.2 hours).
- The excess figures for the period 1 April to 25 June 2007 were significantly lower for XUE relative to the other aircraft. Those differences are shown in Table 2. XUE figures for January to March are also included. The January to March period was chosen to provide a similar period of flight time to the 1 April to 25 June period.
- Much of the difference in the excess between XUE and the other aircraft was probably due to XUE having a higher fuel burn rate during this period (see Table 2). Fuel burn rate was calculated by only examining those flights where the recorded 'burn' figure was based on the totaliser fuel used function.

Table 2: Comparisons of fuel data

	XUE (Jan-Mar)	XUE (Apr to Jun)	Average for other 5 aircraft[13] (Apr to Jun)
Flight hours	314.0	285.7	226.4
Fuel added (kg)	158,672	148,131	118,782
Excess (kg)	2,754	406	3,565
Flight hours where used totaliser fuel used function to record burn	30.7	36.8	53.1
Fuel burn rate (where used totaliser fuel used function) (kg/hour)	503	510	493
Sum of differences between final	90	-420[14]	188

13 Based on the flight logs provided, one of the aircraft did not operate during the period 1 April to 11 May 2007.

residual and next log first residual (kg)			

In summary, the differences in excess between XUE and the other aircraft were not necessarily useful in identifying when problems with gauge indications may have commenced. However, useful information was identified in the differences between the final residual figures recorded on a flight log and the initial residual recorded on the subsequent flight log. As noted above, during the period 1 April to 25 June 2007, there were 29 occasions across all six aircraft when such differences were recorded. The pattern of these changes was different for XUE relative to the other aircraft. More specifically:

- For XUE, all of the seven changes were negative (that is, the figure recorded on the subsequent log was higher). On two occasions comments were made on the flight log noting the change, but no reasons or follow-up action were recorded.
- For the other aircraft, the 22 changes were positive (that is, the figure recorded on the subsequent log was lower).
- During the period 8 October 2006 to 31 March 2007, there were 14 changes for XUE. Half of these were positive and half were negative, although the negative changes were all relatively small (all 10 or 20 kg except one change of 30 kg).

Table 3 lists notable events identified in the flight logs for XUE during the period 8 October 2006 to 25 June 2007. They include situations where there was a significant (40 kg or more) increase in the residual fuel recorded on a flight log relative to the previous log's final residual, situations where the aircraft may have been refuelled to full capacity, and notable maintenance-related activities.

Table 3: Notable events in XUE flight logs

Date	Event
19/10/06	'Engineering defuel' of 570 kg. Reason not specified. Occurred in middle of day between two flights.
03/11/06	'Refuel from hangar stock' of 894 kg. Maintenance ground runs of 16 kg burn then conducted.
06/11/06	Possible refuel to full capacity. Recorded total quantity 2590 kg, calculated total quantity (excluding APU burn) 2683 kg. Revenue flight. Comment 'APU burn 50 kg' to explain more than 60 kg margin difference.
06/12/06	280 kg removed from left wing, then 280 kg added to left wing. Reasons not stated. Occurred at end of day.
19/12/06	Possible refuel to full capacity. Recorded total quantity 2600 kg, calculated total quantity (excluding APU burn) 2675 kg. Revenue flight. Comment 'APU burn 40 kg' to explain more than 60 kg margin.
06/03/07	Possible refuel to full capacity. Recorded total quantity 2510 kg, calculated total quantity (excluding APU burn) 2621 kg. Revenue flight. Comment 'APU burn' to explain more than 60 kg margin.
12/03/07	Engine ground runs of 608 kg. Reason for such a large amount not stated.

14 The figure of -420 kg included the -110 kg difference on 24 April 2007 between the residual following ground engine runs and the residual used for calculating the next total quantity at departure noted (see Table 2).

10/04/07	Initial residual 70 kg higher than previous log's final residual. No reason provided.
24/04/07	Residual 110 kg higher than residual following engine ground runs. Previous log's residual of 530 kg was entered at top of the log. Following engine runs by maintenance personnel with 60 kg fuel burn, the recorded residual was 470 kg. Comment by maintenance personnel on log was 'fuel remaining – 580 kg prior to refuel'. The subsequent total fuel quantity at departure was consistent with a residual of 580 kg.
28/04/07	Likely refuel to full capacity. Recorded total quantity 2700 kg, calculated total quantity (excluding APU burn) 2720 kg.Training flight. Log completed by contractor check pilot who may not have been fully familiar with the operator's recording practices. Fuel added was recorded as 2000 kg, whereas fuel docket stated 2528.6 L (or 2023 kg if use 0.8). Therefore calculated fuel was actually 2743 kg. All recorded figures were written to nearest 50 or 00, and therefore '2700' was approximate.
29/04/07	Possible refuel to full capacity. Recorded total quantity 2600 kg, calculated total quantity (excluding APU burn) 2600 kg. Training flight. Log completed by contractor check pilot who may not have been fully familiar with the operator's recording practices. Fuel added was recorded as 1100 kg, whereas fuel docket stated 1390.2 L (or 1112 kg if use 0.8). Therefore calculated fuel was actually 2612 kg. Previous day's residual of '1500' was probably to nearest 50 kg, as may have been '2600'. Subsequent figures that day were to nearest 10 kg.
04/05/07	Initial residual 40 kg higher than previous log's final residual. No reason provided.
04/06/07	Initial residual 50 kg higher than previous log's final residual. No reason provided.
11/06/07	Initial residual 50 kg higher than previous log's final residual. Comment on log '60 kg difference from previous day'.
18/06/07	Initial residual 70 kg higher than previous log's final residual. No reason provided.

1.8 Other fuel starvation related occurrences involving EMB-120 aircraft

The ATSB air safety occurrence database included one previous event involving fuel starvation in an EMB-120 aircraft on 14 January 2005 (see description below). That event was classified by the ATSB as a Category 5[15] occurrence. Consequently, there was no investigation by the ATSB and information held on the occurrence was limited to that provided by the operator. However, following the XUE occurrence, the operator involved in the 14 January 2005 occurrence provided further information on the 14 January 2005 event to the ATSB.

That operator advised that, during the 14 January 2005 event, the right engine ceased operating shortly after the crew observed the 'low fuel pressure' warning illuminated. At the time, the right fuel gauge was fluctuating between 300 and 500 kg, while the left was steady at 500 kg. After a single engine approach and landing,

15 Resource constraints limit the number of investigations that the ATSB can initiate and conduct each year. As such, difficult decisions are often required in determining which occurrences are investigated. Where a decision is made not to investigate, details of the occurrence are included in the ATSB's data base for trend monitoring and/or future reference.

the right gauge read 250 kg, and the left 500 kg. Prior to departure, both the left and right gauges indicated 1500 kg. A subsequent check revealed that the right tank contained no fuel. A faulty number 6 fuel probe was found to have caused the incorrect gauge reading.

Before the flight, the crew noticed a discrepancy between the gauge reading of 900 kg and the recorded fuel remaining figure from the previous flight (400 kg). However, because the aircraft had just returned from maintenance, they assumed that fuel had been added by engineering staff, but had not been recorded. The crew's fuel quantity check, based on the residual fuel being 900 kg, fell within the 3% margin.

Immediately following the occurrence, the operator amended its procedures to require that the dripless sticks be used to confirm the fuel quantity before the first flight of the day. A further direction prohibited an aircraft being dispatched in the event of a discrepancy between the residual fuel recorded in the flight log and the gauge indication.

CASA investigated the 14 January 2005 occurrence. However, it did not advise other EMB-120 operators of the circumstances of the occurrence, or of the revised fuel quantity measurement procedures that had been introduced as a result.

In November 2005, details regarding the 14 January 2005 occurrence were discussed at an EMB-120 operators' conference. The operator of XUE did not attend that session of the conference and did not know about the January 2005 event until after the XUE occurrence in July 2007. Other Australian EMB-120 operators at the conference, as a result of learning of the 14 January occurrence, amended their procedures to require daily dripstick measurements of fuel quantity.

The aircraft manufacturer advised that it had not been notified of the 14 January 2005 occurrence and that, as of early February 2008, it was attempting to ascertain why that situation existed. The manufacturer had in place a system for issuing *Operator Advisory* notices concerning safety and other information regarding an aircraft type to all operators of that type, and indicated that events such as that of 14 January 2005 would generate the issuing of an *Operator Advisory*.

On 22 February 2008, the aircraft manufacturer advised the ATSB that another in-flight engine power loss due to fuel exhaustion involving an EMB-120 aircraft occurred in Europe on 20 February 2008. Preliminary information indicated that shortly after commencing descent from flight level 190, the crew observed a right engine fuel pressure low warning. They then noticed that the engine torque was zero. There was 400 kg fuel indicated by both fuel quantity indicators at the time. The crew secured the engine and completed an uneventful landing at the destination airport. A check revealed that the right wing tank contained no fuel. Before the flight, the crew had found a discrepancy between the refuelling panel quantity indicator and the cockpit indicator for the right tank. The matter was reported to have been rectified and agreement achieved between the refuelling panel and cockpit indicators, and the right tank shut-down fuel quantity from the previous flight. There was no information as to whether a dripstick reading had been taken to confirm the fuel quantity.

The manufacturer was gathering further information on the occurrence, including recorded flight data.

The aircraft manufacturer also advised that it knew of only one other instance of fuel starvation in EMB-120. That had been caused by incorrect positioning of selectors on the refuelling panel and was not related to the fuel quantity indicating system.

1.9 Fuel low level warning systems

Although fuel low level warning systems are not specifically required for Part 25 aircraft, many aircraft in this category have them installed. However, the design of some systems has been questioned in safety investigation reports.

For example, in an investigation into a British Aerospace J-3101 accident (21 May 2000)[16], the US National Transportation Safety Board (NTSB) noted that the aircraft was equipped with low fuel quantity lights for each tank on the instrument panel. However, the position and characteristics of the lights meant that they could be easily overlooked, even when illuminated.

An Irish Air Accident Investigation Unit (AAIU) report into an ATR-42 incident (8 August 2003)[17] found that, although that aircraft had fuel low level warning, the warning was not independent of the fuel gauges. The final investigation report (August 2005) included the following recommendation:

> The European Air Safety Agency (EASA) should review the certification criteria for public transport aircraft low fuel contents warning systems, with a view to requiring such systems to be independent of the main contents gauging systems.

The Italian safety investigation agency, Agenzia Nazionale per la Sicurezza del Volo (ANSV), issued a similar recommendation to EASA following the accident involving an ATR-72 offshore of Palermo Airport (6 August 2005).[18]

Following an incident involving an Airbus 340 aircraft (8 February 2005)[19], the UK Air Accident Investigation Branch (AAIB) issued four recommendations relating to low fuel level warning systems. These were:

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16 NTSB Accident No. DCA00MA052, Executive Airlines, British Aerospace 3101, N16EJ, Bear Creek Township Pennsylvania, 21 May 2000. The right engine stopped due to fuel starvation and there was intermittent stoppage of the left engine due to fuel starvation. Due to communication problems, the crew probably thought more fuel have been added to the tanks prior to the last flight than was actually added. The 19 people on board were fatally injured.

17 AAIU Formal Report No: 2005-014, Serious Incident to ATR 42, EI-CBK, near Dublin, 8 August 2003. During a regular passenger flight, the right engine stopped due to fuel starvation. The crew declared an emergency and diverted the flight for an uneventful single engine landing. The fuel gauge been providing erroneous indications for several weeks prior to the incident.

18 The final report for this accident has not been released. The ATR-72 aircraft ditched after both engines ceased operating due to fuel exhaustion. At the time, the fuel quantity indicator (FQI) was indicating 1,800 kg even though the fuel tanks were empty. That situation arose because the FQI had been replaced with one applicable to ATR-42 model aircraft. Of the 39 people on board, 16 were fatally injured.

19 AAIB Report on the incident to Airbus A340-642, registration G-VATL en-route from Hong Kong to London Heathrow on 8 February 2005. The number one engine lost power and ran down due to fuel starvation. A few minutes later, the number four engine started to lose power. Fuel had not been transferring from the centre, trim and outer wing tanks to the inner wing tanks due to a

AAIB Safety Recommendation 2005-108: It is recommended that the European Aviation Safety Agency introduces into CS-25 the requirement for a low fuel warning system for each engine feed fuel tank. This low fuel warning system should be independent of the fuel control and quantity indication system(s).

AAIB Safety Recommendation 2005-109: It is recommended that the European Aviation Safety Agency should review all aircraft currently certified to EASA CS-25 and JAR-25 to ensure that if an engine fuel feed low fuel warning system is installed, it is independent of the fuel control and quantity indication system(s).

AAIB Safety Recommendation 2005-110: It is recommended that the USA's Federal Aviation Administration should introduce into FAR-25 a requirement for a low fuel warning system for each engine feed fuel tank. This low fuel warning system should be independent to the fuel control and quantity indication system(s).

AAIB Safety Recommendation 2005-111: The Federal Aviation Administration should review all aircraft currently certified to FAR-25 to ensure that if an engine fuel feed low fuel warning system is installed, it is independent of the fuel control and quantity indication system(s).

EASA responded to the AAIB, stating that it agreed with the recommendations and was developing plans to amend the relevant legislation by 2009. The AAIB accepted EASA's responses.

In response to AAIB recommendation 2005-110, the FAA stated[20]:

As noted within the Discussion section of the AAIB Safety Recommendation (File Ref:EW/C2005/02/03): "It could be argued that the need to indicate fuel system failures to the crew on complex aircraft is covered by EASA CS-25 1309 para c." The AAIB goes on to state that: "Indeed, when the fuel control system is operating normally on the A340-600 this is true, but this incident demonstrated a need for more specific requirements for certain warnings such as low fuel level in an engine feeder tank".

Compliance with 25.1309 (c) is just as relevant during any anticipated failure condition as it is when the system is operating normally. Traditional designs may not have effectively met the intent of 25.1309 (c)[21] for certain "unsafe system operating conditions", including "low fuel level in an engine feeder tank". As evidenced by the Notice of Proposed Rulemaking (NPRM) (NO. 87-3) published in the Federal Register on May 12, 1987 (52 FR 17890), titled "Low Fuel Quantity Alerting System Requirements for Transport Category Airplanes" the FAA once agreed with the AAIB that this "demonstrated a need for more specific requirements".

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computer problem. Although transfer was partially achieved, the expected indications of fuel transfer in progress were not displayed so the commander decided to divert to Amsterdam where the aircraft landed safely on three engines.

20 AAIB, Progress Report 2007: Responses to Air Accidents Investigation Branch (AAIB) Safety Recommendations, pp.8-9.

21 US Federal Aviation Regulation 25.1309 (Equipment, systems, and installations), paragraph (c) stated: Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and

> While adding a more specific rule may focus special attention and unique provisions onto a particular "unsafe system operating condition" , it will not relieve an applicant of the obligation of complying with 25.1309 (c) for that condition. After considering the comments from NPRM 87-3 and reviewing all the relevant service history, the FAA has concluded that there is no need for any new regulatory provisions in this case. The addition of a more specific requirement will be redundant to those regulatory objectives already covered by 25.1309 (c). Furthermore, promulgation of a more specific requirement could inadvertently impede future design innovation and would not be an efficient use of our limited rulemaking resources.
>
> The FAA now intends to develop clearer 25.1309 (c) compliance guidance in the form of an interpretive policy on this issue. Successful completion of that action would effectively address FAA Safety Recommendation 06.006.

The AAIB classified this response, and the FAA response to recommendation 2005-111, as ‘Rejected’.

1.10 Procedures for operations on unpaved surfaces

1.10.1 Aircraft manufacturer

The aircraft manufacturer published procedures for operations on unpaved surfaces in Supplement 14 to the *EMB120 Brasilia Airplane Flight Manual*. The supplement stated that:

- Non-normal landing can be made with either flap 25 or flap 45, as applicable, and
- Normal landing must be made with flaps 45.

1.10.2 Aircraft operator

The operator’s *Brasilia Flight Operations Manual, Section 2, Normal Procedures*, paragraph 2.11.3, included the following information regarding flap selection:

> Flap 25 shall be the landing flap selection for all instrument approaches unless the runway length or surface requires Flap 45.

Paragraph 1.9.2, *Unpaved Runway Operational Requirements*, in Section 1 of the operations manual stated that flap 45 must be used for landings on unpaved surfaces, but that flap 25 or 45 could be used as required in the case of a non-normal landing on an unpaved surface.

1.10.3 Flap selection

The operator’s *Brasilia Flight Operations Manual, Section 2*, paragraph 2.11.3, *Flap Selection,* was as follows:

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associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.

For runway approaches to aerodromes requiring Flap 45, the selection of Flap 45 shall not be made until the aircraft has been established visual. For circling approaches to aerodromes requiring Flap 45, the selection of Flap 45 shall not be made until the aircraft is positioned on final approach to the runway. In both cases, aircraft must be stabilised in the final approach configuration by 300' AGL.

The operator advised that the majority of landings conducted away from the operator's home base were to unpaved runways, and therefore required flap 45 in accordance with the manufacturer's procedures. Landings on sealed runways were almost always done in the flap 25 configuration.

It was apparent from discussions with the operator's senior EMB-120 pilots that, prior to the XUE occurrence, there had been no company procedure for briefing a committal height on final approach. However, all pilots were generally made aware during training that once flap 45 had been selected, or when the aircraft reached 300 ft above runway elevation, the approach should be continued to landing in the event of an engine failure. Training had also included the requirement to use no more than flap 25 for single engine approaches.

1.11 Procedures for go-around

The operator's *Brasilia Flight Operations Manual, Section 2, Normal procedures,* defined the procedures for a go-around from final approach with both engines operating. *Section 2, Abnormal and Emergency Procedures,* paragraph 3.3.4 defined the procedures for a single engine go-around/missed approach. The initial actions were identical for both procedures and were as follows:

FLYING PILOT	MONITORING PILOT
Call, ***"GOING AROUND, SET POWER, FLAP 15"***	
Press the Flight Director Go-Around button and pitch up to follow the command bar. At the same time Advance Power Levers to within 10% of the pre-determined target torque	Set the pre-determined target torque, select Flaps to 15 and call, "***POWER SET*"**. and call ***"FLAPS 15"*** when 15 flap is indicated
When a positive rate of climb is established call, ***"GEAR UP"***	Select Gear Up and when fully retracted call ***"GEAR UP"***

Those procedures reflected the aircraft manufacturer's recommended procedures.

2 SAFETY ACTIONS

2.1 Aircraft operator

On 1 July 2007, the operator amended its fuel quantity management procedures to require:

- A dripless stick reading to be carried out each day and for the results to be recorded on the flight log
- Auxiliary power unit (APU) fuel burn to be recorded on the flight log
- the aircraft to be placed unserviceable and engineering assistance requested if dripless stick readings differed from the fuel gauge readings by more than 3 percent
- All flight logs to be checked on a daily basis
- The conversion factor for Jet A1 fuel to be changed from 0.8 kg per litre to 0.785 kg per litre.

2.2 Civil Aviation Safety Authority

On 3 July 2007, the Civil Aviation Safety Authority (CASA) issued a series of directions to the operator which addressed fuel quantity measurement procedures and flight crew training.

In late 2007, CASA withdrew Airworthiness Bulletin 28-002.

2.3 ATSB Safety Action

Background information

In addition to the occurrence involving VH-XUE, the ATSB is aware of two other occurrences involving Australia registered aircraft since January 2005 involving engine power loss due to fuel starvation in turbo-prop aircraft with a maximum take-off weight (MTOW) above 5,700 kg. In each case, the practices used by the flight crew to establish fuel quantity did not detect erroneous fuel quantity indications. The operators involved subsequently amended their procedures to include dripstick checks as a mandatory part the procedures for establishing the quantity of fuel on board the aircraft.

It is possible that there are other examples among turbo-prop operators of aircraft with a MTOW greater than 5,700 kg where the procedures used to determine the quantity of fuel on board the aircraft do not include independent comparative checks of fuel quantity.

On 14 September 2007, the ATSB issued AO-2007-017-Safety Advisory Notice-013:

The ATSB suggests that all turboprop operators take note of the following safety issue and review their processes accordingly:

> The processes used by some turboprop operators for checking the fuel quantity on board prior to flight have not used two methods of sufficient independence. In particular, the practice of using a comparison of a gauge indication after refuelling with the gauge indication prior to refuelling plus the fuel added is not adequate to detect gradually developing errors in gauge indications.

On 25 February 2008, the ATSB advised CASA and all Australian operators of EMB-120 aircraft of the report regarding the EMB-120 engine power loss occurrence that occurred in Europe on 20 February 2008. The ATSB will provide further information on the occurrence to those parties as it is received.

In the meantime, the ATSB re-emphasises AO-2007-017-Safety Advisory Notice-013 (above) issued on 14 September 2007.

3 APPENDIX A : FUEL STARVATION RELATED OCCURRENCES INVOLVING AUSTRALIAN REGISTERED AIRCRAFT OTHER THAN EMB-120 AIRCRAFT SINCE JANUARY 2005

Fairchild Metro III, 23 September 2005 (BO/200504768)

At 1910 Eastern Standard Time on 23 September 2005, a Fairchild Industries Inc. Model SA227-AC (Metro III) aircraft, registered VH-SEF, departed Thangool on a scheduled flight to Brisbane, Qld. There were two pilots and 16 passengers on board. Approaching overhead Gayndah, the L XFER PUMP (left fuel transfer pump) amber caution light illuminated, indicating low fuel quantity. The fuel quantity indicator showed substantial fuel in the tanks. The crew completed the checklist actions but the light remained on so they diverted the flight to Bundaberg. About 18 km from Bundaberg, the left engine stopped. The crew subsequently completed a single-engine landing at Bundaberg.

Four pounds (2 L) of fuel was subsequently drained from the left tank, indicating that the left engine stopped because of fuel exhaustion. There was 49 lbs (28 L) fuel in the right tank, sufficient for about 10 minutes flight.

Faults were found in a number of components of the fuel quantity indicating system. The maintenance manual procedures for calibration of the fuel quantity indicating system had not been followed correctly on two occasions in the previous 10 days. The result was that the fuel quantity indicating system was over-reading. The crew relied on the fuel quantity indicator to determine the quantity of fuel on the aircraft before the flight. That practice was common to most of the operator’s crews. The fuel quantity management procedures and practices within the company did not ensure validation of the aircraft’s fuel quantity indicator reading. There was also no system in place to track the aircraft’s fuel status during and after maintenance. The aircraft type was fitted with dripsticks.

Boeing Co B747-338, 5 February 2007 (BO/200700368)

On 5 February 2007, the crew of a Boeing Co 747-338, registered VH-EBY, shutdown the number 3 engine in flight, due to a fuel related problem, approximately 256 km from the destination airport.

Approaching the top of descent the crew noticed that the number 3 main fuel tank quantity indicator was reading zero and that both fuel-boost pump low pressure lights had illuminated. The crew then shut down the number 3 engine, declared a PAN and the flight continued for an uneventful landing at Melbourne.

The subsequent investigation by engineering personnel found that the number 3 main fuel tank was empty. An ‘over read’ malfunction in the number 3 fuel quantity indicator system (FQIS) had caused the crew to believe there was a greater quantity of fuel remaining in that tank than was actually present. The planned quantity of fuel for arrival at Melbourne for the number 3 tank was 2500 kg. The investigation determined that the malfunction was caused by either an electrical malfunction, water contamination or a combination of both.

The FQIS system fault was rectified and the aircraft returned to service.

Investigation by the operator's safety group found that the refuelling procedures current at the time were not able to accurately verify the base line quantity of fuel on board, or to alert the flight crew or line engineers to the consequences of an erroneous FQIS indication. The investigation also reviewed the refuelling procedures for all other of the company fleet types to ensure serviceability of those installations. As a consequence a series of recommendations were made requiring amendments to the published refuelling procedures and including revision of the risk management process, intended to prevent a possible recurrence of the incident events.

At the time of publication of this report, the investigation was continuing.

Cessna Aircraft Company C404 Titan, 18 October 2007 (AO-2007-049)

On 18 October 2007, the pilot of a Cessna Aircraft Company C404 Titan aircraft was conducting a charter flight from Adelaide Airport, SA to Parafield Airport, Beverley airstrip, and return to Adelaide. The pilot had commenced descent into Adelaide on the final sector of the flight when the right engine lost power. There were no apparent anomalies and the fuel quantity gauges were showing adequate fuel in each tank. After securing the right engine, the pilot continued to Adelaide Airport and landed without further incident.

Aircraft maintenance engineers who inspected the aircraft reported that 3 L of fuel was drained from the right tank and 90 L was drained from the left tank. The fuel quantity gauge was indicating 150 lbs (95 L) in the right tank. An engineer found that one of the electrical circuits in the right fuel quantity indicating system had a high resistance. After wiring in the circuit was repaired, the fuel quantity gauge correctly indicated zero fuel in the right tank. Calibration of the fuel quantity indicating system was carried out and during that process, the left and right signal conditioners were found to be unreliable and were replaced or repaired.

The operator amended its fuel documentation and fuel planning procedures to include a secondary means of verification of fuel on board to cross-check the electric fuel indication system.

At the time of publication of this report, the investigation was continuing.

Fairchild Metro III, 20 December 2007

The pilot in command submitted the following report to the ATSB:

After my arrival it was discovered that the aircraft had been refuelled twice and by fuel records alone 3500lbs of fuel should have been on board. The fuel flow totalizer indicated that 200lbs of fuel had been used. It was assumed that this amount was used during engine ground running for maintenance purposes. As a result the fuel on board should have been 3300lbs.

The serviceable left tank fuel gage indicated 1100lbs of fuel [the right fuel gage was unserviceable as per the aircraft MEL], well short of the expected value of 1650lbs. Both tank fuel quantities were checked utilizing the Magna-stick which indicated that at least a total of 2100lbs of fuel was in the fuel tanks. (The magna-sticks are only accurate between 130 and 1050lbs of fuel/tank) Endurance was planned on 2100lbs of fuel, performance was planned on the fuel record value of 3300lbs and the flight conducted without incident.

After landing, the magna-sticks revealed that 1100lbs of fuel remained in the tanks. Based on the fuel used for the flight of 1300lbs and the fuel remaining, we had departed Brisbane with 2400lbs of fuel some 900lbs of fuel less than the flight record sheet suggested.

I contacted … to enquire if any maintenance had been performed on the fuel tanks … and was told that both tanks had been drained into... to enable fault finding on the unserviceable right fuel gage.

As the fuel remaining figure of 1000lbs on flight record sheet 59278 [from the previous flight] had been drained this explains the discrepancy of 900lbs of fuel.

It appears that we have no system in place to track the aircrafts fuel status during and after maintenance.