Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Report – 200504768

Final

Fuel exhaustion – 18 km SW Bundaberg Airport, Qld

23 September 2005

VH-SEF

Fairchild Metro III

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Company Flight Operations Manual and Aircraft Maintenance Manual

Abstract

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.

Following the occurrence, the operator developed new procedures for fuel quantity management and the Civil Aviation Safety Authority made rule changes regarding fuel quantity measurement and verification for transport category aircraft.

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1 FACTUAL INFORMATION

1.1 History of the flight

At 1917 Eastern Standard Time[1] on 23 September 2005, a Fairchild Industries Inc.[2] SA227-AC (Metro III) aircraft, registered VH-SEF, departed Thangool, Qld, on a scheduled passenger flight to Brisbane, Qld. There were two pilots and 16 passengers on board. The copilot was the flying pilot.

The flight crew reported that as the aircraft approached overhead Gayndah (180 km north-west of Brisbane) at flight level (FL) 170, the L XFER PUMP (left fuel transfer pump) amber caution light illuminated on the annunciator panel in the cockpit. The crew consulted the quick reference checklist, which stated that the warning light indicated that, with the boost pumps operating, there was less than 70 pounds (lbs) (39 L) of fuel remaining in the left tank. They initially thought that the warning may have been false, as the fuel quantity indicator showed that there was substantial fuel in the left tank. In accordance with the checklist, they selected the alternate boost pump, but the caution light remained on. The crew continued on the basis that the warning was genuine and diverted the flight to Bundaberg (102 km north-east of Gayndah[3]), which they assessed as the nearest suitable aerodrome. When air traffic control queried the status of the flight, the crew advised that operations were normal.

The copilot continued to fly the aircraft and initiated a descent shortly after turning towards Bundaberg, initially levelling the aircraft at 4,000 ft. At approximately 18 km from Bundaberg, the left engine surged a few times and then ceased operating. The pilot in command secured the engine, while the copilot continued to fly the aircraft. The crew did not report the engine failure to air traffic control and did not declare an emergency. The copilot initiated a descent to 1,500 ft and entered the left circuit pattern for runway 32. The pilot in command took control of the aircraft during the base turn and completed an uneventful single-engine landing. The R XFER PUMP (right transfer pump) caution light did not illuminate at any stage. The crew did not record the fuel quantity indicator readings on arrival at Bundaberg.

When the aircraft was examined the following day, the cockpit fuel quantity indicator showed 250 lbs of fuel in the right tank and 400 lbs of fuel in the left tank. The aircraft tanks were drained. The left tank contained 4 lbs (2 L) of fuel and the right tank contained 49 lbs (28 L). According to the aircraft flight manual, approximately 8 L of fuel in each tank was unusable. The fuel filters contained only minor debris.

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1 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.

2 At the time of the occurrence, M7 Aerospace provided maintenance support for the aircraft type.

3 The crew did consider diverting to Gayndah, but the pilot in command had operated into there previously in a different aircraft type. His recollection was that Gayndah was not suitable for the Metro III. That assessment was later supported by the company’s check and training pilot who had landed a Metro III at Gayndah.

1.1.1 Events before the occurrence flight

On the morning of 23 September 2005, after remaining in Port Macquarie overnight, the aircraft was refuelled with 570 L (1,003 lbs) of aviation turbine fuel. According to the flight deck log[4], it departed Port Macquarie for Coffs Harbour at 0652 with 1,560 lbs (886 L) fuel on board. The aircraft then operated five sectors and was refuelled three times before it arrived in Brisbane at 1315. The flight deck log entry showed 578 lbs (328 L) as the amount of fuel on board at that time.

Before arriving in Brisbane, the crew had informed the airline's operations control of a technical fault with the left engine power lever. Consequently, after landing, the aircraft was moved to the company's maintenance provider at Brisbane Airport for rectification. Since 16 September 2005, the aircraft had been operating on Minimum Equipment List[5] (MEL) 28-1 due to a right fuel quantity indicator malfunction. The MEL conditionally allowed the aircraft to remain in service for up to 10 days with one fuel quantity indicator inoperative.

While the power lever was being repaired, maintenance personnel decided to replace the defective fuel quantity indicator with a serviceable unit that had just returned from an instrument repair facility. They reported that, as part of that task, they tested and calibrated the fuel quantity indicator in accordance with the aircraft maintenance manual[6] (see also Section 1.6, Fuel quantity indicating system calibration).

The engineers completed brief ground runs on both engines at the completion of the maintenance. No record was kept of the amount of fuel consumed during the engine runs and there was no requirement for such a record to be kept. However, because the engines were operated for no longer than a couple of minutes, the fuel used was unlikely to have exceeded 50 lbs (28 L). No fuel was drained from, or added to, the aircraft while it was in the custody of the maintenance provider. The MEL was lifted and the aircraft was returned to service at approximately 1700.

In accordance with the normal procedure, the maintenance organisation notified the airline's maintenance controller, who was based at Maroochydore Airport, that the repairs had been completed. That information was passed to the airline's operations control at Brisbane Airport. The pilot in command for the next flight (Brisbane to Thangool) requested the aircraft's fuel status and was advised by the maintenance controller that, according to the fuel quantity indicator, there was approximately 850 lbs (483 L) of fuel on board the aircraft, with 350 lbs (199 L) in the right tank and 500 lbs (284 L) in the left.

On the basis of that information, the pilot in command requested that 355 L of fuel be added to each tank (710 L or 1,250 lbs total). On arriving at the aircraft, and before any fuel was added, the pilot in command noted that the cockpit fuel quantity indicators showed 400 lbs (227 L) in the right tank and 500 lbs (285 L) in the left. He then changed the fuel order to 640 L (1,127 lbs) and, to balance the fuel between each tank, directed that 340 L (599 lbs) be placed in the right tank and 300 L (528 lbs) in the left. The flight deck log indicated that there was 2,050 lbs (1,165

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4 Part of the maintenance documentation for the aircraft that served as a record of daily operations.

5 Minimum Equipment List (MEL) means a list that provides for the operation of the aircraft with permissible unserviceabilities, subject to compliance.

6 M7 Aerospace, SA227 Series Maintenance Manual.

L) of fuel on board the aircraft at the commencement of the flight and that a 'percentage variation check' was completed (see Section 1.4, Fuel quantity measurement – operational aspects). The crew did not use the Magna sticks[7] to check or confirm the quantity of fuel on board.

The pilot in command reported that because the ground power unit was being used by another aircraft, he elected to start the right engine using the aircraft battery. On the first attempt, the engine accelerated to 25 percent RPM and the engine exhaust gas temperature (EGT) increased to 600 degrees C before the fuel flow suddenly fell to zero and the EGT and RPM decreased. The start was aborted.

The ground power unit then became available, so the pilot in command elected to use it to start the left engine while the right engine cooled. The left engine started normally and a further attempt was made to start the right engine. The right engine RPM accelerated normally and adequate fuel flow was indicated. However, there was no increase in EGT, so the start was again aborted. On the third attempt, the right engine started normally. The aircraft then departed for Thangool. The crew reported that the aircraft operated normally during the flight.

No fuel was added to the aircraft at Thangool. The flight deck log indicated that the fuel consumed on the flight from Brisbane to Thangool was 780 lbs[8] (443 L) and that there was 1,270 lbs (722 L) of fuel on board the aircraft for the return flight to Brisbane. That quantity, as indicated, was sufficient for the flight. When the aircraft was examined at Bundaberg, the fuel totaliser indicated that 503 lbs (286 L) of fuel had been consumed on the flight from Thangool to Bundaberg.

1.2 Personnel information

Both flight crew held air transport pilot licences and were appropriately qualified to conduct the flight. The pilot in command had about 1,200 hours flying experience on Metro III aircraft. The copilot had about 800 hours on type.

1.3 Aircraft information

The aircraft was manufactured in 1986 by Fairchild Industries Inc. as an SA227-AC model, serial number AC-641. Metro III was the common name for the type. It was powered by two Garrett TPE331-11U fixed-shaft turboprop engines and carried a crew of two pilots and up to 19 passengers.

The aircraft was first placed on the Australian register on 6 March 2002. It had previously been operated in the US and New Zealand. At the time of the occurrence, the aircraft had accumulated 30,366.4 hours total time in service and had 32.2 hours remaining until the next scheduled maintenance. There were no outstanding maintenance issues concerning the aircraft at the time of the occurrence.

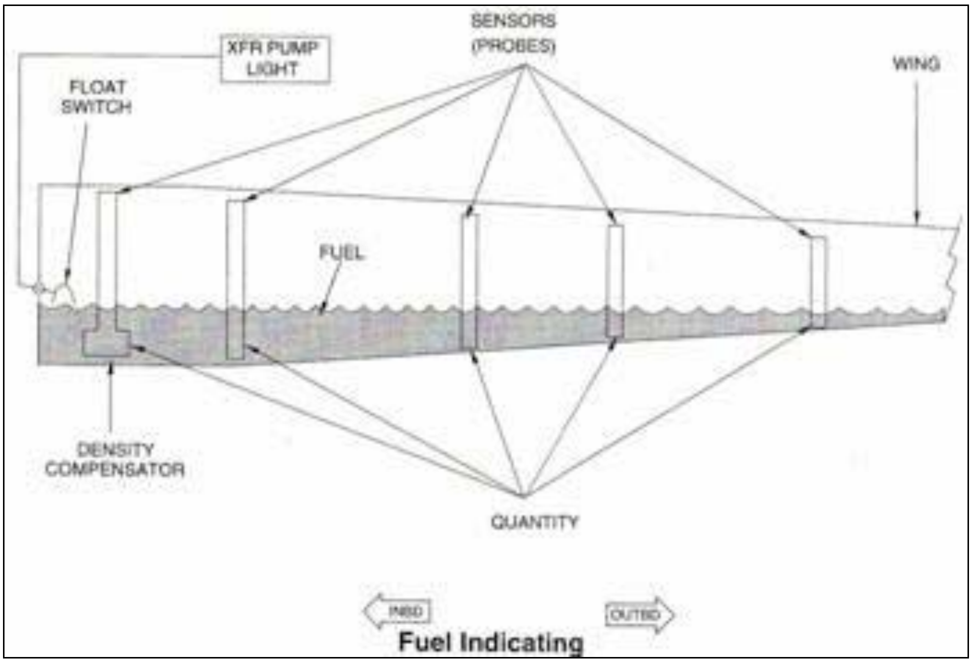
7 A mechanical, direct-reading fuel level indicator - see Section 1.3.1 for a description of Magna stick system operation.

8 780 lbs was within the normal range of fuel used for a Brisbane to Thangool flight.

1.3.1 Aircraft fuel quantity indicating system

The Metro III was equipped with a capacitance[9] type fuel quantity measurement system. The system consisted of sensors (fuel probes), indicators, float valve switches, a transfer light system, and associated electrical wiring and connectors. Each wing of the aircraft included an integral fuel tank. Five fuel probes in each tank (numbered from 1 inboard to 5 outboard) provided input to the fuel quantity indicating system (Figure 1). The capacitance of each probe depended on the depth of fuel covering the probe. Since the density of fuel, and therefore its weight, varied with temperature, the system included a density compensator that formed part of the number-1 probe.

Figure 1: Schematic showing fuel tank probe arrangement



The fuel probes were made of two concentric tubes of aluminium material and had two wires carrying impedance[10] to the internal section of the unit. Those wires passed through holes in the aluminium outer tubing material.

The capacitance value of the fuel quantity indicating system depended upon factors such as the length of wiring, proper grounding of the wire shielding, and the condition of the probes, wiring and connectors. Any anomalies in the wiring harness linking the probes and the indicator could alter the capacitance values of the circuitry from those established by the aircraft manufacturer. Further, any disturbance of fuel quantity indicating system components could alter capacitance values. The aircraft maintenance manual contained procedures for calibration of the system, including guidance on when calibrations should be conducted.

A 5-cm (approximately) diameter dual pointer indicator (Figure 2) displayed left and right tank fuel quantity in hundreds of lbs. It was located low in the centre

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9 Capacitance in an electrical system is the ratio of charge to related change in potential.

10 Resistance to alternating current (electricity).

section of the instrument panel. Because of the size of the indicator face and the markings, the quantity could be read to about the nearest 20 lbs.

Figure 2: Fuel quantity indicator

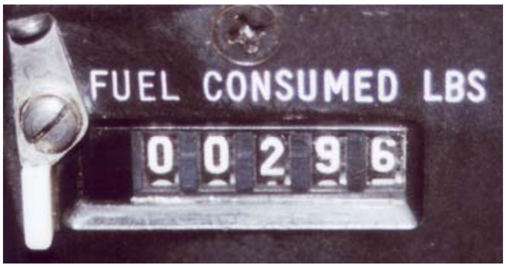
A Magna-stick was located under each wing, inboard of the engine nacelle. Magna sticks allowed checking of the fuel quantity, in 5 US gallon graduations, of each wing tank, provided the tank contained between approximately 30 and 155 US gallons (114 L to 586 L). Readings were taken by releasing a lock tab on the under surface of the wing, and allowing the indicating scale to extend below the wing (Figure 3). Because Magna sticks measured the level of fuel in the tank by means of a float attached to the top of the stick, accurate readings were obtainable only when the aircraft was on a near level surface.

Figure 3: Magna stick in lowered position indicating 85 US gallons

According to the aircraft flight manual, there were inherent errors in the Magna stick system. With equal amounts of fuel in each tank, there could be up to 27 US gallons (180.9 lbs/130 L) difference between the left and right Magna stick indications. Further, there could be up to 16 US gallons (107 lbs/61 L) difference between the cockpit fuel quantity indicator and the respective Magna stick indications.

A fuel consumed totaliser received input from a fuel flow transmitter on each engine. The totaliser displayed, in the cockpit, the total amount of fuel consumed by both engines since the counter was last set to zero. Company policy was to zero the counter before each flight. Figure 4 shows the fuel totaliser display indicating that 296 pounds of fuel has been consumed since the last reset.

Figure 4: Fuel totaliser display



Company policy was that, for all flight operations purposes, fuel quantity was to be expressed in pounds weight. Because refuelling quantities were measured in litres, and Magna sticks measured fuel in US gallons, the company published standard conversion factors as follows:

– to convert US gallons to pounds, multiply by 6.7

– to convert litres to pounds, multiply by 1.76.

1.3.2 Fuel system operation with boost pumps operating

Fuel was fed by gravity flow from the respective wing tank to two collector tanks and a hopper tank located in the inboard section of each wing. The hopper tanks supplied fuel to the engines. Each hopper tank contained a main and an auxiliary electrically driven boost pump. Jet transfer pumps used boost pump pressure to transfer fuel from the collector tanks to the respective hopper tank.

Company policy was for the boost pumps to be on whenever the engines were operating[11]. The pumps were controlled by a three-position (main, off, auxiliary) switch on the cockpit centre pedestal. Company practice was for the main boost pumps to be used for northbound flights and the auxiliary pumps for southbound flights.

With the boost pumps on (and therefore the jet transfer pump system operating), the hopper tanks remained full until the wing tank fuel level reached approximately 70 lbs/40 L. The level in the hopper tank then started to decrease causing the XFER PUMP (transfer pump) amber caution light to illuminate. The fuel quantity indicator would then indicate approximately 70 lbs for the respective tank. With the jet transfer pumps operating, the unusable fuel was approximately 13 lbs/8 L per side. With the transfer pumps not operating, the unusable fuel was 88 lbs/49 L per side.

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11 According to the aircraft flight manual, the aircraft could be operated with boost pumps off under certain flight regimes.

1.4 Fuel quantity measurement – operational aspects

The Civil Aviation Order (CAO) 20.2.6, current at the time of the occurrence, detailed the requirements for establishing the fuel quantity on board an aircraft that must be completed by a pilot before flight. Section A 6.5.6 of the company operations manual detailed the company's fuel quantity measurement policy and reflected CAO 20.2.6 (Figure 5):

Figure 5: Operations Manual Section 6.5.6

6.5.6 Fuel Quantity Measurement

Flight shall not commence unless the Pilot-in-Command has ensured that the fuel quantity on board has been checked by one of the following methods:

a) Check of stick gauge (dip, drip, sight) reading against electrical gauge (potentiometer, capacitor) readings;

b) Having regard to previous readings, a check of stick or electrical gauge readings against fuel consumed indicator readings;

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

d) When a series of flight 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.

In the event the discrepancy between both readings exceeds 3% of the higher amount, then:

a) the stick gauge method must be used; and

b) the Chief Pilot must be notified for corrective action.

Section A3.1.1, Flight Deck Log, of the operations manual stated that the flight deck log ‘acts as a record for the daily aircraft operations and is an integral part of the Maintenance Release System’. Section A3.1.3 provided a step-by-step guide for recording information on the log. It included instructions for completing the fuel management section of the log (Figure 6).

Figure 6: Operations Manual Section A3.1.3.3, Entering Flight Details[12]

Step 2

FUEL MANAGEMENT							DRIP STICK	% VAR
PORT	CO.	DOC #	ADD	S/FUEL	BURN	FOB		
				1000	225	775	750	3.2
	MOBIL	12222	300	1000				

Before the first flight of the day, the "S/FUEL" column should read the fuel quantity from the previous day's operation, unless fuel is added at the start of the day, when the S/FUEL column should read the sum of the previous day's fuel quantity plus the fuel added. This must be checked by cross checking the value with the electrical gauge reading.

After each sector, the Fuel on Board (FOB) column must be completed and the "BURN" calculated.

Refuelling details must be entered into the subsequent row with the number of litres included in the "ADD" column. Following refuelling, the fuel quantity must be checked by referring to the electrical gauge reading and including this in the "S/FUEL" column.

The "DRIP STICK" and "%VAR" columns must be completed in accordance with the requirements of Section A6.5.6 "Fuel Quantity Measurement". In this example, the variation between the FOB and the Drip Stick is greater than 3% and the following actions must be taken: the stick gauge method must be used, and the Chief Pilot must be notified for corrective action.

There was no facility on the flight deck log for fuel consumed during engine ground runs to be recorded.

Part B of the operations manual contained operating procedures specific to the Metro III aircraft type. Pertinent sections regarding fuel quantity were (Figure 7):

Figure 7: Operations Manual Part B, Metro III fuel quantity

1.2.17.1. Fuel

The following procedures are to be followed to ensure that the fuel is correctly loaded.

1.2.17.1.1. Before First Flight

Prior to first flight of the day, the fuel on board should be checked using two separate methods. The fuel quantity gauge may be cross checked against one of the following:

1. After refuelling, calculate the fuel added (ie fuel docket) to the previous reading from the fuel quantity gauge (must be within 3% of the higher amount); or
2. Previous reading from the Flight Deck Log (FDL) (must be within 3% of the higher amount); or
3. Magna stick reading (must be within 16 US Gallons).

In the event that the fuel cross check is outside the allowable discrepancy maintenance action is required.

Note: Magna sticks are useful when fuel tanks are less than half full but have at least 30 gallons in them.

After the integrity of the fuel gauge has been checked, record the fuel gauge quantity in the aircraft FDL.

12 PORT means airport; CO means the refuelling company; DOC# means the refuelling docket number; ADD means quantity of fuel added; S/FUEL means starting fuel at the commencement of the flight; BURN means fuel consumed during the flight; FOB means fuel on board at the completion of the flight; DRIP STICK means Magna stick reading; and %VAR means percentage variation calculated as per Section A6.5.6 of the company operations manual.

1.2.17.1.2. Refuelling

The Pilot-in-Command is responsible to ensure that the correct amount of fuel is on board, the fuel system water detection check is completed and the fuel caps are secure. The Pilot-in-Command may delegate the fuelling responsibility to the First Officer during pre-flight planning or turn-arounds.

1.2.17.1.3. Subsequent flights

For subsequent sectors, calculate the fuel consumption using the totaliser and crosscheck with the fuel contents gauges. Record the fuel remaining on board and the fuel consumption in the aircraft FDL.

Refuel the aircraft if the remaining quantity on board is inadequate for the next flight. Fuel reading on the contents gauges in above plus fuel added from the docket must agree with fuel contents gauges after refuel, to within 3% tolerance of the higher figure.

At any time doubt exists as to the fuel quantity on board the aircraft, an additional fuel quantity check using the magna-stick must be carried out.

1.2.17.1.4. After Last Flight

At the end of the last flight of the day, add the sector fuel consumption and record the total fuel used in the FDL.

Calculate and record the average block hour fuel rate (lb/hr) for the day in the FDL.

1.4.1 Information from company pilots

The investigation interviewed the company chief pilot, the check and training pilot, and ten company Metro III line pilots (including the pilots on the incident flight).

Most line pilots described the method used to determine the quantity of fuel on board the aircraft as follows:

- add the quantity of fuel on board, as indicated by the fuel quantity indicator, to the quantity of fuel added during a refuel to determine what the indicator should read
- note the actual indicator reading
- the two quantities should be within 3 percent of the higher figure.

A few pilots referred to sometimes taking a Magna stick reading before the first flight of the day.

Pilots were questioned regarding the use of the Magna stick system in determining fuel quantity. A predominant view was that the errors and limitations of the Magna stick system meant that any 3 percent check using Magna stick readings was of little use and had little credibility. Their reasons included:

- Magna sticks could be used only within a limited range of tank contents
- they frequently did not settle smoothly to the correct position
- they were only useful if the aircraft was on a level surface [13]
- comparing the fuel quantity indication with the Magna stick reading would mean that the 3 percent variation would always be exceeded.

Flight operations management personnel indicated that, about 18 months before the incident, there had been discussion among company pilots regarding the use of

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13 The tarmac aprons of two of the locations the airline operated into were reported to slope sufficiently to cause the Magna sticks to be unusable.

Magna sticks because of difficulties in achieving a percentage variation of less than 3 percent. The then check and training captain held a strong view that the Magna sticks did not provide the level of accuracy necessary to do a proper 3 percent variation check. Management considered that pilots might have taken heed of that view and moved to not using the Magna sticks, even though there had been no change to company procedures or formal advice to pilots. No pilot reported using the Magna stick system as a means of conducting a gross error check on the fuel quantity indication system.

No copilots could recall being asked by a pilot in command to check the flight deck log fuel quantity calculations, such as conversions from litres to pounds, and the 3 percent variation check. Some were occasionally asked to read the Magna sticks.

To many pilots, the 3 percent variation check was an administrative exercise that was necessary to meet the legal requirements for operating the aircraft. They viewed the check as being of little practical value because of the limitations in the quantity indication systems.

1.4.2 Examination of flight deck logs

Between 13 and 23 September 2005, VH-SEF was operated on 71 flights and crewed by seven different pilots-in-command and seven different copilots. Examination of the fuel management sections of the flight deck logs for those flights revealed the following:

- When the aircraft was refuelled on 13 September following maintenance (which involved emptying the tanks), the amount of fuel added was 1,760 lbs. That compared with 2,050 lbs that was entered in the fuel on board (FOB) section of the flight deck log for the first flight after maintenance.
- The percentage variation (%VAR) entered against the Brisbane-Thangool flight on 23 September 2005 was 0.1 percent.
- There were 10 instances where the start fuel (S/FUEL) differed by more than 100 lbs from the FOB from the previous flight plus fuel added, and six instances where that difference was greater than 200 lbs.
- An entry in the %VAR column appeared against 21 flights. All of the recorded variations were less than 3 percent, except one, which was 9.7 percent. There was no record on the log of a Magna stick check being done or of any maintenance action being taken in response to that discrepancy.
- Calculations showed that, where the %VAR had not been entered in the log, the variation exceeded 3 percent on many occasions. The greatest variation was 23 percent. In that instance, the S/FUEL was entered as 1,450 lbs whereas the previous FOB (947 lbs) plus added fuel (ADD) (845 lbs) totalled 1,792 lbs.
- For log entries made after aircraft refuelling, the S/FUEL figure was rounded (e.g. 1,530 lbs, 1,600 lbs, 1,660 lbs).
- Generally, the recorded BURN fuel was an exact figure (e.g. 677 lbs, 469 lbs, 684 lbs).
- When the aircraft had not been refuelled, the FOB was an exact figure (e.g. 1,567 lbs, 1,393 lbs, 916 lbs). Those entries corresponded to having been obtained by subtracting the BURN fuel from the S/FUEL.

- There was no entry in the DRIP STICK column for any of the 71 flights.
- In the period covering the 71 flights, 38,884 lbs of fuel was added to the aircraft. The total fuel burn recorded in the flight deck logs for those flights was 38,662 lbs, a difference of 0.6 percent.

1.4.3 Company oversight of fuel usage

Section A3.7 of the company operations manual included the following information regarding fuel usage records (Figure 8):

Figure 8: Operations Manual, Section A3.7

3.7 FUEL USAGE RECORDS

Provision has been made for fuel and oil consumption to be recorded on the Company FDL. Fuel taken on board at each location should be recorded in the space provided. This provides the Company with a check for accounting purposes and the pilot with the means of computing fuel consumed.

The Maintenance Controller is responsible for collecting the fuel usage records from the FDLs.

The records are to be forwarded to the Chief Pilot by the Maintenance Controller at the end of each month in order to collate and monitor the fuel usage records for the purpose of safety and economy, and to ensure correct engine operating parameters are met.

The company advised that maintenance control correlated the fuel usage records from the flight deck logs. That process was primarily a check on average fuel burn per sector/aircraft and was more related to cost than it was to tracking fuel on board and logged fuel quantities. It did not include reference to previous fuel on board figures. There were no instructions as to how the ‘collate and monitor’ function was to be conducted. The chief pilot did not check the logs. There was no system of feedback to flight crews about errors or discrepancies in flight deck logs.

1.5 Fuel transfer pump caution light emergency procedures

Section 3A, Abnormal Procedures, of the US Federal Aviation Administration (FAA) Approved Airplane Flight Manual for the aircraft detailed procedures to cover situations of a less serious nature, including illumination of the fuel transfer pump caution light (Figure 9).

Figure 9: Approved Airplane Flight Manual Section 3A, Abnormal Procedures

> In the event that a XFER PUMP annunciator illuminates with a boost pump ON, the other boost pump in that tank should be turned on.
>
> **CAUTION**
>
> WITH TRANSFER PUMPS OPERATIVE AND LESS THAN 70 POUNDS OF FUEL IN THE AFFECTED TANK, THE TRANSFER PUMP CAUTION LIGHT SERVES AS A LOW FUEL WARNING. A LANDING SHOULD BE MADE AS SOON AS PRACTICABLE.

1.6 Fuel quantity indicating system calibration

The M7 Aerospace SA227 Series Maintenance Manual, Chapter 28-40-10, Fuel Indicating – Maintenance Practices, included sections on system description and operation, fault isolation, and maintenance practices. It detailed procedures for calibrating and testing the fuel quantity indicating system and stated in part:

> **Section 1. Removal/Installation – Fuel Indicating.**
>
> NOTE: Replacement of indicator requires Indicator Calibration performance.
>
> **Section 2. Adjustment/Test – Fuel Indicating**
>
> NOTE: If indicator or any other part of fuel quantity gauging system is repaired or replaced, some or all of these tests may be required. Refer to each test to determine applicability.
>
> **Section 2.B. Self Test Procedure**
>
> …involved selecting the aircraft battery switches ON and pressing the fuel quantity indicator test switch. Both indicator needles should register 1250 lbs. When power was switched OFF, the indicator needles should register below zero.
>
> **Section 2.C. Capacitance Measurement - Cockpit Circuit**
>
> This measurement is performed “dry” to establish a baseline if repairs are performed or components replaced in fuel wet areas of the aircraft. Measurements are performed with 5.0 US gallons of fuel in each tank to provide calibration data for indicator. Measure capacitance of left and right tank and compensator probe circuits and record in aircraft log.

The method described in Section 2.C. was commonly referred to as the ‘dry calibration method’. It involved draining the aircraft of all fuel and measuring the capacitance of the left and right circuits. That process was repeated after 5 US gallons of fuel was added to each tank. The manual included the option of measuring capacitance with the tanks full. The manual included a Capacitance Measurement Record Form, which recorded the capacitance at the dry, wet, and tanks full values. The form also listed a range for acceptable capacitance values at each of those tank contents. The manual stated that the form was to be included as part of the aircraft maintenance log.

Section 2.D. Insulation Measurement (Cockpit)

NOTE: This measurement is performed to assure installed circuits are correctly wired and possess suitable electricity properties. Incorrect grounding, open circuits, defective probes, etc can be detected by this test. Insulation Measurement (Wing) will identify specific defective components.

Section 2.E. Indicator Calibration

NOTE: This procedure requires use of capacitance values measured in 2.C., Capacitance Measurement. If there is any doubt as to origin of values shown in aircraft log, discard those values and re-establish new calibration data. This is the preferred Fuel Quantity Indicator calibration method. Indicators may also be calibrated IAW 2.I., Indicator Calibration, Alternate Method.

Section 2.F. Capacitance Measurement (Wing) allowed 'evaluation of individual components of the system. Defective probes, wiring, etc may be identified either directly or by elimination.' It included a 'fuel capacitance tank probe and system capacitance chart' that was to become part of the aircraft log book.

Section 2.H. Indicator Test (Cockpit or bench)

NOTE: This procedure allows evaluation of the fuel quantity indicator without installation in the airplane. May be performed in the cockpit using airplane power or on bench using a 28 volt filtered power supply

The procedure described in Section 2.H. involved using a test unit to simulate capacitance values for empty and full fuel tanks, and adjusting the indicator needle positions to the empty and full positions.

Section 2.I. Indicator Calibration - Alternate Method required the use of capacitance values determined under Section 2.C. Capacitance Measurement-Cockpit Circuit (and which should be placed in the aircraft maintenance log). It allowed calibration of the Fuel Quantity Indicator without defuelling the aircraft and was commonly referred to as the 'wet calibration method'.

1.7 Aircraft fuel quantity indicating system maintenance history

The aircraft's maintenance records indicated that it underwent repairs in the US on 23 April 1987 following a wheels-up landing. Those records did not include a detailed description of the damage to the aircraft or the extent of the repair work. However, it is possible that the repairs included work on the aircraft's fuel quantity indicating system wiring below the cabin floor.

Checking the calibration of the fuel quantity indication system was included as part of the aircraft manufacturer's Second Intermediate Segment inspection schedule. That inspection was due each 9,000 hrs and called for verification of the fuel quantity system calibration using suitable fuel quantity system test equipment. The aircraft records showed that the most recent calibration check was conducted on 29 November 2001, while the aircraft was being operated on the New Zealand register. The most recently recorded fuel system capacitance data was included on a capacitance chart dated 29 June 2000. That chart included a note stating that all fuel probes, except the compensator probe, were changed at the time. The aircraft total time in service recorded against that maintenance was 26,304.4 hours.

The aircraft records also included reference to an erroneous fuel quantity indication that occurred on 30 November 2001. On that occasion, when the fuel quantity indicator press to test button was engaged, the right fuel quantity indicator indicated 1,700 lbs and did not return to the normal reading. Further examination revealed that the indicator displayed 950 lbs with the right fuel tank empty. The problem was traced to a fault in the shielding of the wire to the number-5 fuel probe in the right wing tank.

The next record of maintenance on the aircraft's fuel system was dated 13 August 2005, when the aircraft entered maintenance to repair fuel leaks. On 14 August, the left and right tanks were drained to facilitate the leak repairs. The quantity of fuel drained from the tanks was not measured. Between 14 August and 8 September, repair work required extensive disruption to fuel tank fittings, internal components, and wiring in both the left and right tanks.

On 26 August, the fuel quantity indicator was removed from VH-SEF and installed in another company Metro. The indicator removed from that aircraft was sent for repair.

On 9 September, a replacement indicator was installed in VH-SEF. The maintenance log recorded the indicator replacement but contained no information about calibration of the fuel quantity indicating system; nor did it include a completed Capacitance Measurement Record Form as required by the maintenance manual. The engineer who undertook the task reported that he could not recall the specific details of the calibration. However, he had conducted more than 40 fuel quantity system calibrations in Metro aircraft. The method he employed involved calibrating the fuel quantity indicator in accordance with Section 2.C. of the maintenance manual, including with the tanks full. He could not recall whether a Capacitance Measurement Record Form had been completed.

On 9 September, the aircraft was fuelled with 1,001 L and a leak test conducted. Further leaks were observed, so the aircraft was defuelled and further repairs were undertaken between 9 and 13 September. Those repairs involved disruption to fuel tank components and system wiring. There was no record of any further fuel system calibrations.

On 13 September, the aircraft was refuelled with 1,000 L. No leaks were evident and the aircraft was returned to service. On 16 September 2005, during an engine ground run, maintenance personnel noticed that the right tank fuel quantity indication was intermittently registering zero and then returning to indicate the tank content. A replacement indicator was ordered and Minimum Equipment List (MEL) 28-1 applied for operation with one fuel quantity indicator inoperative. The aircraft operated from 16 to 23 September 2005 with the MEL applied.

On 23 September, the day of the occurrence, the fuel quantity indicator that had been sent for repair on 26 August was returned. The associated job card stated that no fault was found with the unit and that it had been passed as serviceable. That indicator was then fitted to VH-SEF.

The aircraft maintenance log entry stated that the fuel quantity indicator had been replaced and set up in accordance with Section 28-40-10 Revision 125 and 'found to be serviceable'. The log did not indicate which procedures(s) in Section 28-40-10 had been followed. However, the maintenance engineers involved in replacing the indicator reported that, because there had been a history of fuel indication problems in the company's Metro aircraft, they thought that the problem lay with the gauge and not with the other components in the fuel quantity indicating system. They reported that they performed the procedure in the Section 28-40-10, 2.H. Indicator Test (Cockpit or Bench) of the maintenance manual. That involved checking the quantity indication against capacitance values specified in the maintenance manual at Table 202, of Section H. The procedure was conducted in the cockpit using aircraft power. The capacitance values were set on the test equipment that was connected to the rear of the fuel quantity indicator. They then conducted the test at Section 28-40-10, 2.B. Self Test Procedure of the maintenance manual and verified that both indicator needles registered 1,250 lbs. One of the engineers involved reported that, upon reconnecting the indicator to the aircraft fuel quantity indicating system, the fuel quantity indicated was approximately the same as before the indicator was fitted. The other engineer could not recall what the fuel quantity indication was before the indicator was replaced.

The aircraft was then returned to service for the flight to Thangool.

1.8 Examination and testing of fuel quantity indicating system

When the aircraft was returned to the maintenance organisation following the incident, the fuel tanks were drained and the fuel quantity indicator readings checked. With the tanks empty, the left indicator read 500 lbs (248 L) and the right indicator 450 lbs (256 L). Calibration of the fuel quantity indicator was confirmed using the test unit that had been used when the replacement indicator was installed on 23 September 2005. The gauge was then recalibrated using another test unit. Only slight adjustment was required and indications of 500 and 450 lbs respectively remained. A cockpit capacitance measurement was conducted in accordance with Chapter 28-40-10, Section 2.C. Capacitance Measurement – Cockpit Circuit of the maintenance manual (see Section 1.6). That showed the actual capacitance values to be outside the allowable range.

Examination of the aircraft fuel quantity measurement system components, including the wiring harness and fuel tank probes, was undertaken. That included tests conducted in accordance with the maintenance manual to check the condition of the fuel quantity indicating system wiring circuits and the fuel probes. Slight movement of the wiring revealed evidence of intermittent faults that caused significant variations to the capacitance values.

The fuel quantity indicating system was found to contain a range of faults, all of which affected the capacitance of the system:

- different sized wires had been spliced (e.g. 2 mm spliced to 1 mm) (Figure 10)
- shielding of the wiring had not been properly grounded in several sections of the harness (Figure 11)
- wire insulation was chafed in some areas and had broken down in others
- the wiring loom was contaminated with glue and chemicals
- several plug connector pins had poor electrical continuity.

Figure 10: Splicing of different sized wires

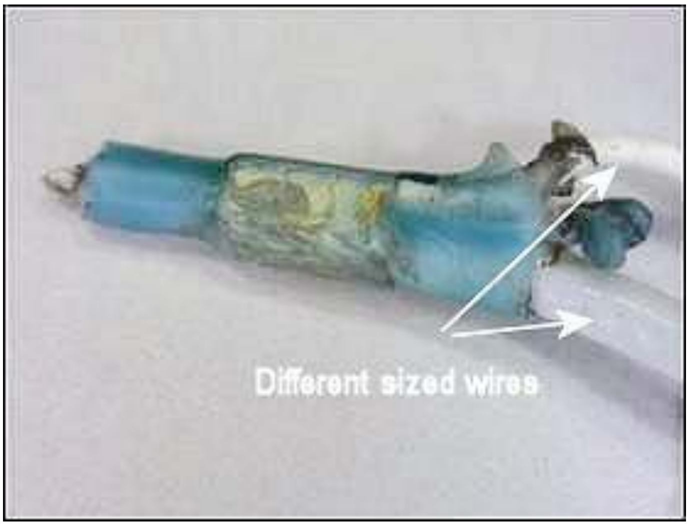
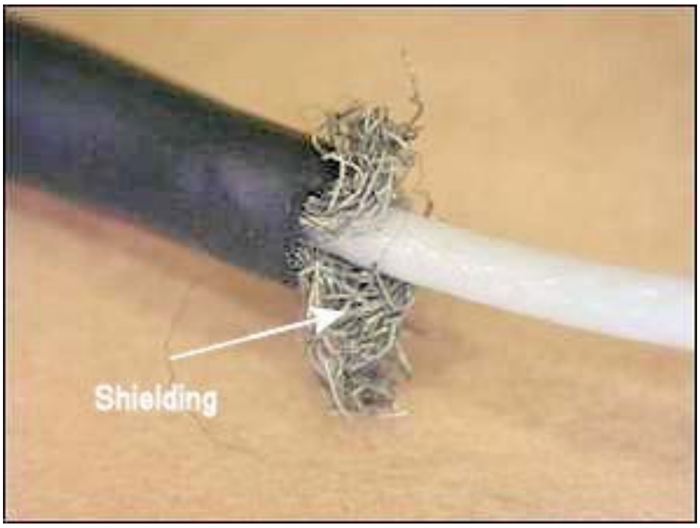


Figure 11: Wire shielding (or braiding) not grounded



An additional wiring harness had been installed between the indicator and the original connector for the instrument. The harness, which may have been installed for ease of maintenance, increased the total capacitance of the circuit beyond the manufacturers recommended values and resulted in the fuel quantity indicator showing 50 lbs per tank when the tanks were empty.

Chafing was observed on the high impedance wire of probe number 2 in the right wing fuel tank. The capacitive element of that probe had chafed into the wire insulation but had not penetrated to the conductor. Chafing was also present on probe number 3 in the left wing fuel tank. The insulation on the high impedance wire of that probe had been chafed through the insulation and into several strands of the conductor (Figure 12). The aluminium tube, which contained the inner components of the probe, displayed signs of arcing of the conductor to the tube near a pass through hole (Figure 13).

Figure 12: Chafing of right number 2 probe high impedance wire

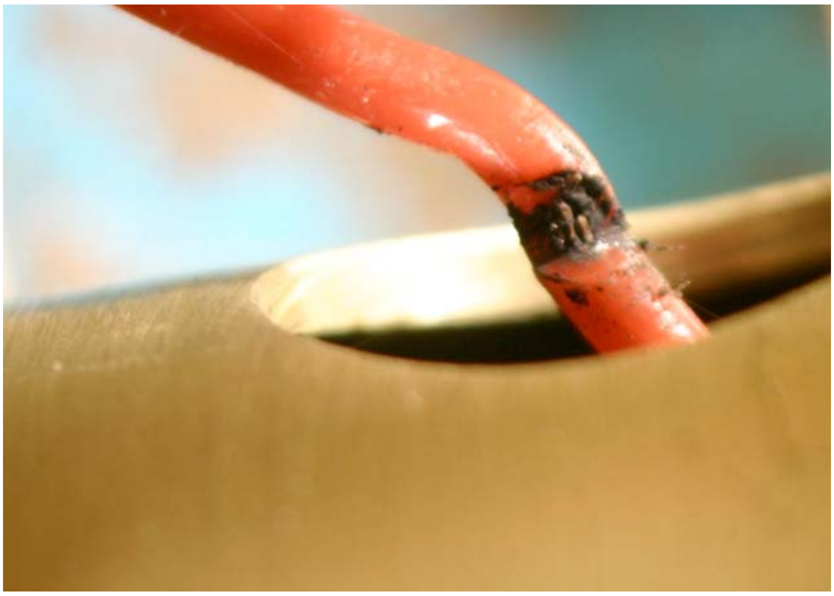
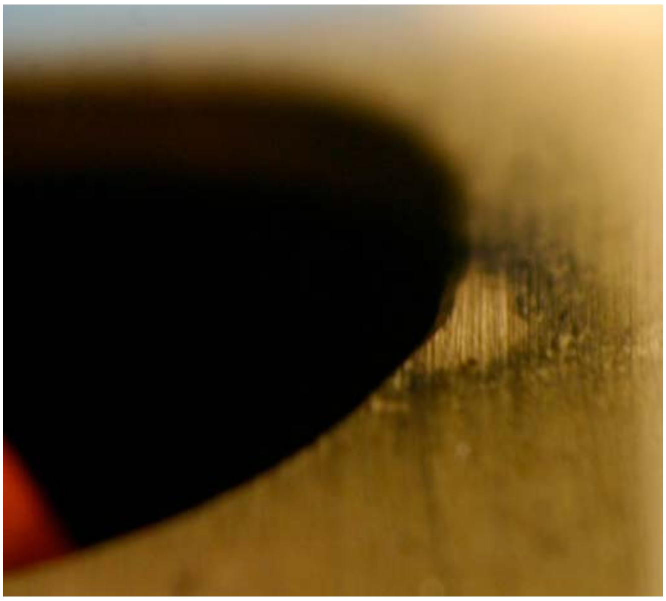


Figure 13: Evidence of arcing at edge of pass-through hole



Following repairs, the fuel quantity system was recalibrated in accordance with Section 2C, Capacitance measurement – Cockpit Circuit of the aircraft maintenance manual (the ‘dry calibration method). Fuel was then added to the tanks and the quantity indicating system registered within limits with respect to the amount of fuel added and the Magna stick indications. No further quantity indication problems were reported.

The reason the right fuel transfer pump (R XFER PUMP) caution light did not illuminate when the fuel quantity in the right tank fell below 70 lbs, as the aircraft approached Bundaberg, was not determined.

1.9 Damage to fuel probe from another Metro aircraft

On 24 May 2006, the ATSB was advised that chafing had been found on the high impedance wire in a fuel tank probe from another Metro 23 aircraft. That aircraft had a total time in service of 13,471.7 hours. ATSB examination of the probe revealed damage to the high impedance wire similar to that evident in Figure 13.

1.10 Aircraft fuel state 13 to 23 September

A detailed picture of the aircraft fuel state between 13 and 23 September 2005 was obtained by comparing the flight deck log information with the aircraft refuelling data. Using the ADD and BURN fuel data from the flight deck logs, and working back from the fuel remaining on board when the aircraft landed at Bundaberg, the START fuel for each of the 71 flights was calculated. The calculations were based on the fuel used and the fuel added information from the flight deck logs, matched against refuelling company records. Figure 14 compares the derived START fuel and the corresponding flight deck log START fuel entries for those flights.

The data indicated that the derived START fuel was less than the logged START fuel for all 71 flights.

Figure 14: Logged (blue) vs derived (red) START fuel for 71 flights, 13 to 23 September 2005

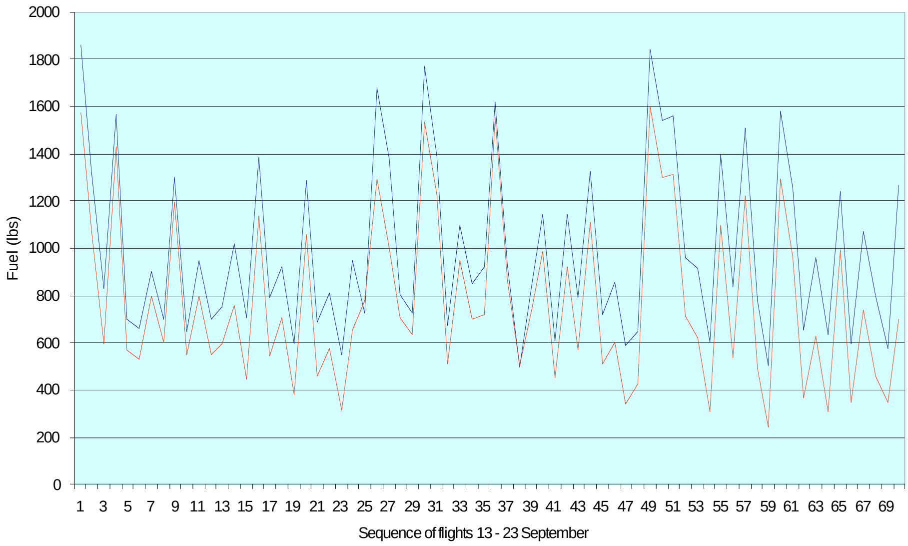


Figure 15 compares the logged fuel on board (FOB) at the completion of a flight with the derived FOB, again working backwards from the actual fuel on board at Bundaberg.

The data indicated that the fuel quantity at shut down was less than 200 lbs on four occasions before the occurrence flight and less than 250 lbs on nine other occasions.

Figure 15: Logged (blue) vs derived (red) fuel on board (FOB) for 71 flights, 13 to 23 September 2005

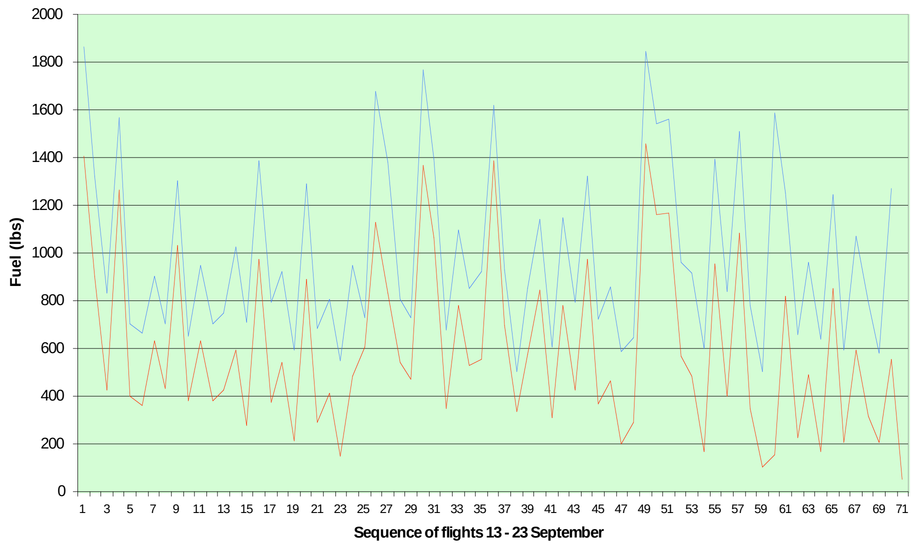
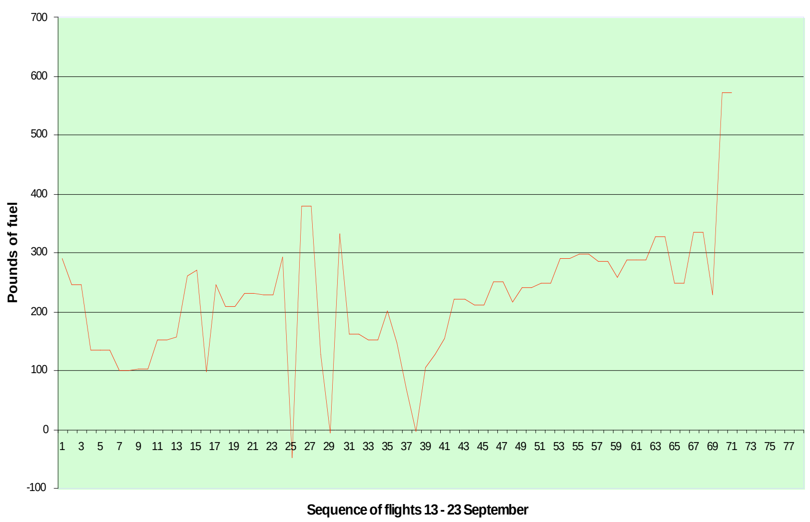


Figure 16 displays the amount by which the logged START fuel exceeded the derived START fuel for the 71 flights. The chart shows that the quantity varied significantly and apparently randomly. A sudden and significant increase in the exceedance is apparent for flights 70 and 71 (Brisbane to Thangool and Thangool to Bundaberg on 23 September), after the fuel quantity indicator had been changed.

Figure 16: Amount that logged START fuel (red line) exceeded derived START fuel for 71 flights, 13 to 23 September 2005



1.11 Other Metro fuel quantity indicating system information

During the investigation, fuel quantity measurement procedures of other Metro operators were obtained for comparison with those of the operators of SEF. Those procedures included:

- A requirement for the fuel quantity indicating system to be calibrated every 12 months. If that requirement had not been met, then an additional 10 minutes fuel at the holding rate had to be carried on each flight.
- Advice to flight crew that electrical fuel quantity indicators could be read to the nearest 25 lbs, and Magna sticks to within 2 to 5 US gallons.
- Whenever the 3 percent variation was exceeded, the aircraft was to be referred for maintenance action.

1.12 Minimum Equipment List

The operator's approved MEL for the SA227-AC aircraft, number 28-01.1, included the following operational requirements for an unserviceable fuel quantity indicator:

> PLACARD
>
> Placard on or adjacent to the affected fuel quantity indicator.
>
> OPERATIONS (O) PROCEDURES
>
> a. Ensure that either the Fuel Crossflow Annunciator Switch or Crossflow Valve Position Light is installed and operative.
>
> b. Determine that the fuel quantity on board meets the regulatory requirements for the flight by either filling the affected tank full or using the Magnastick readings, or adding a known quantity of fuel to a valid Magnastick determined quantity.
>
> c. Check both Fuel Flowmeters are operative.

There was no evidence that the tank(s) were filled to full, or that known quantities were added to valid Magna stick determined quantities to determine the fuel on board during the period 16 to 23 September when the MEL was applicable.

1.13 Maintenance control manual

In 2003, the airline had recognised the need for a new maintenance control manual and flight deck log. A draft manual was prepared by the operator's maintenance organisation at Maroochydore Airport and submitted to CASA for approval in November 2004. The manual included a redesigned maintenance release, aircraft flight deck log, aircraft maintenance log, and defect deferral log forms. The defect deferral log included a section for recording fuel used during maintenance. It required start and shut-down fuel to be entered, and included a signature box. CASA approved the manual on 30 November 2004.

In May 2005, CASA conducted a compliance surveillance audit on the airline. The audit found that the maintenance release, aircraft flight log, aircraft maintenance log, and deferral defect log forms as contained in the maintenance control manual approved in November 2004 were not in use. The company was asked to rectify the matter by CASA.

In August 2005, the airline moved its base of operations from Maroochydore, Qld to Brisbane Airport and aircraft maintenance was contracted to a maintenance provider at that airport. Maintenance control arrangements remained unchanged and continued to be performed by the maintenance controller located at Maroochydore.

On 7 September 2005, the operator advised CASA that its response to the maintenance control manual issues had been delayed due to the airline's move to Brisbane.

The airline advised that the November 2004 draft maintenance control manual was prepared by the maintenance organisation at Maroochydore without consultation with airline operations staff. Operations staff were not aware of the new manual's existence until June 2005 when they assessed it and found it to be unsuitable for the airline's operations.

At the time of the incident involving VH-SEF, the company:

- had not amended its operations manual to reflect the amendment
- was not using the new forms
- had commenced work on a revised manual.

2 ANALYSIS

Problems with the aircraft's fuel quantity indicating system and limitations in the company's flight crew practices relating to fuel quantity resulted in the aircraft departing Brisbane with only 65 percent of the amount of fuel the crew believed was on board. When the aircraft landed at Bundaberg, the fuel remaining was sufficient for about 10 minutes of single-engine flight, even though the fuel quantity indicating system was showing that substantial fuel remained in the tanks.

The investigation found a number of safety factors that contributed to the fuel quantity system over-reading and leading to the usable fuel in the left tank being exhausted causing the left engine to stop.

Those factors included both maintenance procedures and operational practices that allowed a discrepancy between the indicated and actual fuel on board the aircraft to remain undetected. The maintenance procedures related to the calibration of the fuel quantity indicating system and the condition of some components of that system. The operational practices involved the measurement and recording of the quantity of fuel on board the aircraft by both flight crew and maintenance personnel.

2.1 Fuel on board during the occurrence flight

The likely quantity of fuel on board when the aircraft departed Brisbane for Thangool on 23 September 2005 can be derived by summing the following quantities:

Fuel remaining after landing at Bundaberg	52 lbs/30 L
Fuel used Thangool – Bundaberg (from totaliser)	503 lbs/286 L
Fuel used Brisbane – Thangool (from flight deck log)	780 lbs/443 L
Total	**1,335 lbs/759 L**

That total was 715 lbs/406 L less than the 2,050 lbs that was entered in the flight deck log.

Based on the amount of fuel added before the aircraft departed Brisbane for Thangool (1,127 lbs), the quantity of fuel that was on board at the completion of maintenance, prior to the flight to Thangool, was 208 lbs/118 L[14]. That amount was substantially less than the 850 lbs/483 L maintenance control told the crew was on board and less than the 900 lbs/511 L the pilot in command reported that the cockpit fuel quantity indicator showed before refuelling. The reasons for that discrepancy are discussed later in this analysis.

The difficulties reported by the crew in starting the left engine before the Brisbane to Thangool flight (lack of fuel flow and no rise in exhaust gas temperature) could have been symptomatic of air in the fuel line to that engine. It is possible that, during or after the maintenance activities on 23 September, air entered the line because the fuel level in the left wing hopper tank was close to the fuel outlet to the engine. If that was the case, there may have been as little as 13 lbs/8 L of unusable

14 1,335 lbs minus 1,127 lbs = 208 lbs.

fuel in the left wing hopper tank at the completion of the maintenance. If that was the case, the right tank would have contained 195 lbs (208 lbs minus 13 lbs)[15].

From the refuelling amounts reported by the pilot in command (599 lbs added to the right tank and 528 lbs to the left), the approximate fuel on board when the aircraft departed Brisbane for Thangool was:

Right tank	195 + 599 lbs	= 794 lbs/451 L
Left tank	13 + 528 lbs	= 541 lbs/308 L
Total		1,335 lbs/759 L

Assuming identical fuel usage rates for each engine, and assuming that 780 lbs, as recorded in the flight deck log, was the fuel used from engine start Brisbane to arrival at Thangool, the approximate fuel status after the aircraft landed at Thangool was:

Right tank	794-390 lbs	404 lbs/230 L
Left tank	541-390 lbs	151 lbs/86 L
Total		555 lbs/316 L

Performance data in the aircraft flight manual indicated that about 400 lbs/227 L of fuel would have been consumed from Thangool to overhead Gayndah, including an allowance of 100 lbs for taxy/takeoff. Applying that data to the Thangool fuel status produced the following fuel status for overhead Gayndah:

Right tank	404-200 lbs	204 lbs/116 L
Left tank	151-200 lbs	minus 49 lbs/28 L (tank exhausted)

Neither the position of the aircraft relative to Gayndah when the XFER PUMP warning illuminated, nor the amount of fuel consumed since departure Thangool, could be accurately determined. Further, determination of the actual fuel status when the XFER PUMP warning illuminated could have been affected by:

- the accuracy of the XFER PUMP warning system calibration setting
- the actual fuel used during taxy/takeoff at Thangool
- differences between the actual and flight manual engine fuel usage rates
- the flight crew's engine handling techniques
- the prevailing atmospheric conditions for the flight.

Consequently, it was not possible to obtain a more definitive picture of the aircraft's fuel state when the left XFER PUMP warning illuminated. However, the derived information implies that the warning illuminated around the time that the left tank contents reduced to the level at which the transfer lights should have illuminated (70 lbs/40L) as the aircraft approached overhead Gayndah. As such, the derived fuel quantities on board the aircraft on previous flights and at the time of various events are probably a reasonable reflection of the actual situation.

15 If the left engine starting difficulties were due to some other factor, or if there was residual fuel in the left wing collector tanks, then there could have been more than 13 lbs/8 L fuel in the left tank. In turn, that would have meant there was less fuel in the right tank by a similar amount.

2.2 Fuel quantity indicating system errors

Because the quantity of fuel drained from the aircraft at the commencement of the maintenance for the tank leaks on 14 August 2005 was not established, it was not possible to conduct an analysis, similar to that in Section 2.2, for the period before that date. However, the absence of any record of fuel quantity indicating system problems or low fuel quantity events involving the aircraft before then could indicate the fuel quantity indicating system was functioning normally and that the system calibration was within limits prior to that time.

The disruption of fuel quantity indicating system components that was undertaken to access the fuel tanks and repair leaks in the period 14 August to 9 September provided the potential to alter the capacitance of the system. Those activities fell within the definition of 'repairs performed to…fuel wet areas of the aircraft' as contained in Section 2.C. Capacitance measurement – Cockpit Circuit of the aircraft maintenance manual (see Section 1.6). That meant that a calibration in accordance with that section (i.e. a 'dry' calibration) was required. Although the engineer who performed the work could not specifically recall the event, if he followed his usual practice and performed a 'dry' calibration, then it is reasonable to conclude that the fuel quantity indicating system was likely to have been functioning correctly at the completion of that work on 9 September.

Because leaks were still evident when the tanks were filled on 9 September, they were again drained and further work was conducted in fuel wet areas between 9 and 13 September. It is possible that those activities altered the system capacitance from the values calibrated on 9 September. The aircraft log books contained no indication that a further calibration was conducted before the aircraft was returned to service on 13 September. Therefore, it is possible that the anomaly between actual and indicated fuel (1,760 compared with 2,050 lbs) when the aircraft returned to service on that day, was due to the fuel quantity indicating system being out of calibration. With no further maintenance performed on the system before the occurrence flight, it is likely that there was an ongoing anomaly between actual and indicated fuel throughout the 69 flights that were conducted until the time that the fuel quantity indicator was replaced on 23 September.

Because the damage to the fuel probe high impedance wire insulation was symptomatic of in-service deterioration over time, it is possible that its influence on system capacitance altered over time as the condition of the probe(s) changed. The extent of that effect, and its rate of progression, could not be determined. The changes to capacitance values that resulted from movement of system wiring looms that were evident during system examination after the occurrence could also have occurred during normal aircraft operation. Either or both of those conditions could have contributed to the large and apparently random fluctuations in fuel quantity indications that occurred between flights 1 and 69 (see Figure 16).

The intention of the procedure at Section 2.H. of the maintenance manual (see Section 1.6)[16] was to confirm the integrity of the indicator. It was not to calibrate the indicator against the actual capacitance values of the fuel quantity indicating system. As stated in Section 1D of the maintenance manual, replacement of the fuel

16 Maintenance personnel conducted this procedure when the fuel quantity indicator was replaced on 23 September.

quantity indicator required an Indicator Calibration Performance in accordance with Section 2.E. of the maintenance manual to be carried out.

The significant increase in the fuel quantity indication error that was evident from the fuel quantity data, and that is apparent in Figure 16, flights 70 and 71, is a probable consequence of the indicator not being adjusted with reference to the actual capacitance values of the fuel quantity indicating system. Its effect was to increase the amount by which the fuel quantity indicating system was over reading.

The engineers who conducted the 23 September indicator replacement and calibration apparently acted on the assumption that the problem was restricted to the indicator and did not involve any other part of the quantity indicating system. That view arose because of the recent history of indicator malfunctions within the operator's Metro fleet. The fact that the indicator was returned with 'no fault found' was an indication that the fuel quantity indication faults might be due to faults in other areas of the system.

In any case, because of the need to return the aircraft to line operations, there was insufficient time available for a 'dry' calibration to be carried out. There was the option of conducting a 'wet' calibration. However, there was no indication that the engineers considered that option. Even if they had conducted a 'wet' calibration, it would have been incorrect as there was no Capacitance Measurement Record Form in the aircraft maintenance log.

The right fuel transfer pump caution light should have illuminated before the aircraft landed at Bundaberg, because the right tank fuel quantity fell to less than 70 lbs. It is possible that the caution was not triggered because the system was out of calibration. For the same reason, it is possible that there was less than 70 lbs usable fuel when the left fuel transfer pump caution light illuminated. However, the reason for the right transfer pump caution light not illuminating was not established.

2.3 Managing aircraft fuel quantity information during maintenance

At the time of the occurrence, there was no system in place to record changes to the fuel quantity as a result of maintenance action, or to advise flight crew of the aircraft fuel status after maintenance; the practice relied on the memory of maintenance personnel. Information was then passed by word of mouth through a number of individuals until it reached the flight crew. A system of recording changes in the quantity of fuel on board the aircraft during maintenance activities would have highlighted the difference between the actual fuel contents and the gauge indication. It may also have led to the faults in the fuel quantity indication system being detected earlier.

Such a system was included in the new maintenance control manual approved by CASA in November 2004. Had that manual been in use on 13 September 2005, maintenance personnel would have been required to complete the ground run fuel record in the defect deferral log. On that basis, it is possible that the discrepancy between actual and indicated fuel on board when the aircraft returned to line operations on that day would have been detected. Nevertheless, it is also possible that, had flight operations personnel been aware of the proposed new maintenance control manual, their review of the manual might not have been completed in time for the revised maintenance release documents to be brought into use by 13

September 2005. It is, therefore, difficult to draw a conclusion regarding any contribution the delayed introduction of the new maintenance control manual might have played in the occurrence.

2.4 Magna stick usage

From flight crew interviews, there was evidence that Magna stick readings were taken before some flights. However, because there were no entries on the flight deck log records of Magna stick readings, there was no means of verifying the extent of Magna stick usage between 13 and 23 September.

The operations manual included an example where the fuel on board (FOB) and 'drip stick' readings were used for a 3 percent variation check. The manual included use of the Magna sticks as one method of establishing fuel quantity. That section could be interpreted as indicating that the Magna sticks had only to be within 16 US gallons of the derived fuel quantity and did not form part of the 3 percent variation check. However, the flight crew interpretation appeared to be that if the Magna sticks were used, the readings were to be used for the 3 percent check. Limitations in the accuracy of the Magna stick system, and the associated difficulty in achieving 3 percent or less variation when using the Magna sticks led to a culture of flight crew not using that system.

There was no evidence that the value of the Magna stick system as an independent, reliable and readily available means of confirming the integrity of the fuel quantity indicating system was appreciated within the company.

Minimum Equipment List (MEL) 28-1 required the quantity of fuel on board to be determined by Magna stick readings (in the absence of the aircraft tanks being filled to full). The evidence regarding Magna stick usage from flight crew and flight deck logs indicated that during the period from 16 September to before the aircraft entered maintenance on 23 September 2005, the Magna sticks were not used to determine fuel quantity. That meant that the requirements of the MEL were not being met. Compliance with the MEL would probably have led to the discrepancy between the actual and indicated fuel on board being discovered (see also Section 2.6).

The company culture regarding Magna stick usage may have contributed to the MEL 28-1 requirements not being met.

Because MEL 28-1 had been lifted when the replacement fuel gauge was fitted on 23 September, there was no requirement for the crew on the occurrence flight to use the Magna sticks to determine the quantity of fuel on board the aircraft.

2.5 Fuel quantity errors not detected by flight crews

On 23 September, at the last refuelling before the occurrence flight, the pilot in command used the fuel quantity indicator to confirm the fuel on board (900 lbs), as passed to him via the operations controller. He calculated the amount of fuel to be added on that basis. The percentage variation check recorded in the flight deck log indicated that the change in indicated fuel quantity after refuelling corresponded closely to the quantity of fuel added. The process followed by the pilot in command was in accordance with one of the methods specified in the operations manual for establishing fuel quantity.

Another option available to the pilot in command was to compare the FOB entry in the flight deck log from the previous flight (578 lbs), with the indicated fuel quantity before refuelling (900 lbs). Such a check may have prompted further action on his part to confirm the actual fuel state.

Between 13 and 23 September, none of the seven crews that operated the aircraft reported any discrepancy regarding the fuel quantity indicating system. That outcome supported the conclusion that those crews used the same method as the crew on the occurrence flight to determine pre-flight fuel quantity.

On 13 September, when the aircraft returned to flight operations after maintenance on the fuel tanks, there was no previous flight deck log fuel quantity available. Therefore, the crew was required to compare the fuel quantity indicated with the fuel quantity added. The recorded flight deck log start fuel (S/FUEL) of 2,050 lbs was 290 lbs (165 L) greater than the quantity of fuel added, implying that no such check was made and that the flight crew relied solely on the fuel quantity indicator to determine the quantity of fuel on board the aircraft. The absence of an entry in the %VAR column of the flight deck log indicates that no percentage variation check was conducted. Had the crew followed company procedures, the discrepancy may have been detected.

2.6 Monitoring of flight deck logs

The company operations manual provided general non-specific guidance regarding the monitoring of the flight deck logs by the chief pilot. In practice, the monitoring was for economic rather than safety purposes. A more effective program involving error detection and trend monitoring may have enabled the deteriorating fuel on board situation to be detected.

2.7 Flight crew response to fuel transfer warning light

The illumination of the fuel transfer warning light contradicted the information from the fuel quantity indicating system and created the potential for confusion and indecision on the part of the flight crew. However, it was apparent from their actions that they understood the meaning and significance of the fuel transfer warning light. Their decision to divert to Bundaberg was the most appropriate option given the circumstances and the position of the aircraft.

Despite queries from air traffic control, the crew did not report the reason for the diversion or declare an emergency. Had they done so, the controller would have been able to alert the relevant emergency response agencies to the aircraft’s situation. Because no emergency was declared, the opportunity to minimise the possible consequences of the event by alerting relevant emergency response organisations was missed.

3 FINDINGS

3.1 Contributing safety factors

- The fuel quantity indicating system was over-reading.
- Fuel quantity indicating system calibrations following fuel quantity indicator replacements on 13 and 23 September were not in accordance with the aircraft maintenance manual.
- Company procedures and practices did not ensure validation of the actual fuel quantity on board the aircraft.
- There was insufficient fuel on board to complete the intended flight.
- The left engine ceased operating when the usable fuel in the left tank was exhausted.

3.2 Other safety factors

- Faults were present in the fuel quantity indicating system wiring and fuel probes that resulted in system capacitance values varying significantly from standard values.
- There was no system in place for recording changes in the quantity of fuel on board the aircraft that occurred as a result of maintenance activities.
- The complexities of operating and maintaining the fuel quantity indicating system required robust systems to be in place to establish the quantity of fuel on board the aircraft.
- A culture existed amongst company flight crew of not using the Magna stick system to verify aircraft fuel quantity before flight.
- Between 16 September and before the aircraft entered maintenance on 23 September, when Minimum Equipment List (MEL) 28-1 applied, company flight crew were not taking Magna stick readings to verify fuel quantity as required by the MEL.
- The flight crew did not declare an emergency to air traffic control when the left engine ceased operating, or advise the reason for the diversion to Bundaberg.

4 SAFETY ACTIONS

4.1 Civil Aviation Safety Authority

On 27 September 2005, the Civil Aviation Safety Authority (CASA) prescribed a temporary direction on the operator regarding the total fuel to be carried on all Metro aircraft flights. On 28 September 2005, CASA rescinded that direction and further directed the operator to amend the company Metro III operations manual with respect to the pre-flight procedure for the check of fuel on board. A copy of that procedure is at Appendix A.

On 28 September 2005, CASA issued the following directions to the operator with regard to aircraft maintenance:

- A formal fuel indication system inspection and calibration check was to be conducted on the operator's fleet of three Metro aircraft in the presence of a CASA airworthiness inspector. Plans for those activities were to be completed within five working days.
- Maintenance control manual procedures were to be developed for recording fuel related maintenance activities. Those procedures were to include provision for engineers to enter the maintenance fuel burn after engine runs and fuel system maintenance in the flight log or the maintenance log. Those procedures were to be communicated as a notice to pilots and to all relevant maintenance organisations. The procedures were to be included as a revision to the company's maintenance control manual.
- Within the next 10 working days, the company's Metro system of maintenance relating to ATA2 Section 28 fuel indicating systems was to be reviewed in conjunction with CASA airworthiness inspectors.
- Within the next 10 working days, the company's Metro minimum equipment list relating to ATA Section 28 fuel indication system defects was to be reviewed in conjunction with CASA airworthiness inspectors.

On 8 March 2006, CASA initiated Project MS 06/01 to amend CAO 20.2, specifically paragraphs 6.1 and 6.2. The proposal involved deleting paragraphs 6.1 and 6.2 and replacing both with a new paragraph 6.1:

> **CAO 20.2**
>
> 6.1 Aircraft operators are required by CAR 215 to provide an operations manual that specifies procedures by which the pilot in command of an aircraft will comply with Civil Aviation Regulations (1988) paragraph 233 (1)(d) [the fuel supplies are sufficient for the particular flight].

On 16 May 2006, the amendment took effect.

On 15 May 2006, CASA published Airworthiness Bulletin (AWB) 28-002, Issue 1, Fuel Quantity Measurement and Verification Process[17], as advisory material to support the interpretation of CAO 20.2 paragraph 6.1. That bulletin stated:

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17 http://www.casa.gov.au/airworth/awb/28/002.pdf.

> 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.

On 26 June 2007, the left engine of an Empresa Brasileira de Aeronáutica S.A., EMB-120ER aircraft ceased operating during a landing approach. The fuel supply to that engine had been exhausted although the cockpit fuel quantity gauge indicated that there was 300 kg fuel in the tank. In its Preliminary Report on that occurrence, the ATSB issued AO-2007-017-Safety Advisory Notice-013[18]. That notice stated:

> 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.

In August 2007, the Civil Aviation Safety Authority advised the ATSB of its intention to review Airworthiness Bulletin 28-002 to ensure that there was no ambiguity in relation to what are appropriate independent processes for fuel quantity checks.

4.2 Operator

On 24 September 2005, the operator advised all Metro III flight crew of the contents of Standing Order #155 via emailed memo and individual telephone calls. On 28 September 2005, the operator issued company Standing Order #155, effective immediately, which amended its Metro III operations manual as follows:

> The following fuel checks must be carried out before every departure and or after every refuelling:
>
> A Magna-Stick Check must be carried out, and its reading noted (take at least 3 readings and use the lowest reading).

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18 See ATSB Transport Safety Investigation Report, Aviation Occurrence Investigation AO-2007-017, Preliminary.

> This reading must then be compared to the gauge reading.
>
> If there is any discrepancy between the two, the Lower reading must be used for all fuel calculations and the Higher reading must be used for all weight and balance calculations.
>
> Remember Magna-Sticks are only useful when fuel tanks are less than half full (2,171 lbs) but have at least 201 lbs in them. Whenever possible, limited fuel loads to no more than 2,170 lbs to allow an accurate Magna- Stick reading.
>
> Accurate readings are obtainable only when the airplane is on a reasonably level ramp because the Magna-Stick indications depend upon the level of the fuel in the tank. Avoid inaccurate readings caused by binding of the indicator stick in its bushing by tapping the bottom surface of the wing around the Magna-stick as and before taking readings. Due to the slope of some of our parking bays (i.e. Armidale) accurate reading will not be obtained. Therefore, so long as there is no unexplained discrepancy between planned fuel remaining upon arrival and the actual fuel remaining upon arrival, the aircraft may depart without completing a Magna-Stick Check, provided a Magna-Stick Check is completed before departure from the next port that contains a level parking bay.

On Wednesday 28 September, the operator issued company Standing Order #156 as follows:

> Effective immediately, before every departure the Pilot in Command MUST complete the attached form [see Attachment A]. The completed form MUST be returned with the FDL [flight deck log] at the completion of the days flying.
>
> I would also like to remind all pilots of the obligation to carry out a 3% check before each flight as per CAO [Civil Aviation Order] 20.2.6.1.
>
> If the difference is calculated exceed 3%, maintenance control must be notified before further flight.
>
> With regard to the Metro, the procedures stated in Standing Order 155 must also be completed.

With regard to the CASA directions of 28 September on Metro aircraft maintenance, the operator reported that the following action had been taken:

- A notice to pilots and engineers was issued to direct engineering organisations that maintain the companys Metro aircraft to record fuel burns and uplifts in the captain's report area of the current FDL, in advance of a new style FDL being released.
- An internal task force was convened on 6 October 2005 to review, in conjunction with CASA, the company's system of maintenance and minimum equipment list for the Metro aircraft with regard to ATA Section 28 items.
- A notice was issued to pilots and engineers stating that the preferred method of calibration (complete system calibration) and not the alternative method (abbreviated method) was to be used whenever maintenance action that required fuel system calibration was conducted.
- A complete fuel indication system check and fuel system calibration was scheduled for completion on two of the company’s Metro aircraft by 11 October 2005. Fuel system calibration of the occurrence aircraft would be undertaken

once repairs had been completed. All calibration checks would be conducted in the presence of a CASA airworthiness inspector.

In early 2006, the operator completed the development of a new Flight Deck Log, including a revised and expanded fuel management section. That document was approved by CASA and became effective on 15 April 2006. Procedures for use of the log, fuel management, and fuel quantity measurement were incorporated into the company operations manual. The procedures included instructions for completion of the log by maintenance personnel 'whenever maintenance is carried out on an aircraft that includes ground running of engines or the removal of fuel from the aircraft'.

The operator then introduced a flight deck log monitoring program in which sample logs were examined for accuracy and completeness on a regular basis. Where discrepancies were detected, the flight crew involved were advised and counselled.

4.3 Australian Transport Safety Bureau

During the early stages of the investigation, the ATSB identified a safety issue regarding chafing of high impedance wiring in Metro III fuel tank probes. The Bureau briefed CASA on the issue and subsequently issued the following safety recommendation to the Authority on 22 December 2005:

Recommendation R20050013

> The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority alert operators and review the continuing airworthiness of all Australian registered Fairchild Industries SA227 model aircraft, or other aircraft model types using fuel immersed capacitance-type fuel sensors (probes), with specific regard to possible high impedance wire chafes within the fuel tank.

CASA responded to the recommendation on 23 February 2006. A summary of that response, which has been published on the ATSB website, is as follows:

> **Interim Decision**
>
> Following the preliminary review of data available the decision was made not to ground the Australian fleet on the following basis:
>
> • No Previous history of defects/incidents over a significant time.
>
> • The fuel quantity indicating system [fuel quantity indicating system] is a low power system, current limited [0.2 amperes according to the manufacturer, which was equal to 3.2 watts] to minimise the possibility of a spark of sufficient energy to ignite the fuel being allowed to form in the event of a short circuit.
>
> • The abrasion and arcing had occurred at some time, the evidence indicated that it occurred at very low power but there was no indication whether it was an old event, recent or ongoing.
>
> • The down time for operators would be significant in that all ten probes would have to be removed (inspection in situ is not possible). Reinstallation would require resealing (and associated cure time) and possible recalibration of the fuel system. Estimated total down time would be 48 hours.
>
> **Conclusion**

Considering the age of the aircraft and the uncertain maintenance regime that existed for the majority of its operational life causal factors that may have contributed to this defect are numerous, as an example:

• Orientation of the probe in the fuel tank and the subsequent susceptibility to wire deflection due to fuel surge during refuelling or aircraft manoeuvring.

• Deflection of wiring during the aircraft incident.

• Operation of the aircraft in a high vibration condition eg out of balance propeller, extended ground taxi.

• Resonant airframe vibration.

There is no indication as to whether this is an old defect, recent failure or a continuing issue. No evidence exists that would indicate a fleet trend. From the data available, I agree with the finding of the TC [type certificate] holder in that this is an isolated incident. Whilst the potential for fire is always present when an ignition source and a volatile fuel are brought together, there is minimal risk that the arcing that occurred could cause a fire in the aircraft considering the low power and the high flash point of the Jet A1 fuel in use.

Recommendation

An Airworthiness Bulletin is to be issued recommending greater scrutiny of the fuel quantity indicating system, particularly the fuel quantity probes, during scheduled and unscheduled maintenance. Operators will be encouraged to report any anomalies found in an attempt to identify possible trends. This would include verification of the fuel quantity indicating system reading against physical quantity of fuel present.

On 30 May 2006, the ATSB advised CASA that on 24 May 2006 high impedance wire chafing had been found on a fuel probe from a Metro aircraft with a total time in service of 13,471.7 hours. CASA reviewed the issue and provided the Bureau with a report of that review. The report stated:

Following the review CASA maintains that:

1. CASA's original findings are valid.

2. The risk of fuel tank explosions due to electrical shorting of the fuel probes in the SA227 is negligible.

3. The Metroliner SA227 is not covered by SFAR [Special Federal Aviation Regulation] 88 or recent amendments to FAR [Federal Aviation Regulation] 25 issued by the FAA [US Federal Aviation Administration].

4. The SDR [Service Difficulty Report] records on this defect needs to be reviewed in light of conflicting anecdotal evidence to the contrary.'

The review also included proposed actions to revise Airworthiness Bulletin 28-1 to better represent fuel related hazards and to develop and publish additional educational material on the matter.

The ATSB classified the recommendation as CLOSED – PARTIALLY ACCEPTED.

On 8 August 2007, CASA advised that it had conducted initial briefings to operators of the aircraft type who were urged to submit service difficulty reports (SDRs) as appropriate to enable CASA to identify any trends. Since the original SDRs for VH-SEF and VH-ANW there had been no further reports of fuel probe defects. There had been three reports of chafing of fuel system wiring outside of the fuel tanks. CASA also advised that the recommendation referred to in its ‘Interim Decision’ advice of 23 February 2006 would be implemented following release by the ATSB of the subject investigation report.

The ATSB has re-classified the recommendation as CLOSED – ACCEPTED.

5 APPENDIX

Procedure for pre-flight checks for fuel on board

Aircraft registration VH……………….. Date………../2005
Flt No……………… Location…………….

Fuel on arrival (Gauge)……………………………………..lbs
Calculated fuel on arrival (Dept fuel –fuel used)…… ……lbs)
Total fuel required……………………................................lbs
Uplift Required……………………..…………………………lbs

Actual uplift……………………………………lbs (…………………ltr)
Calculated fuel for departure…………………..lbs
Indicated fuel for departure……………………lbs
Difference calculated/indicated………………..%

Signed…………………………………………(Pilot in Command)

CAR 220 and 234 and CAAP 234-1 (March 91) require pilots to ensure adequate fuel is carried for the proposed flight.

CAO 20.2.6.1 and 6.2 specify the manner in which checks are to be carried out to ensure there is not a discrepancy greater than 3% between two separate methods of ensuring the fuel is on board.
The table above allows a check in accordance with CAO 20.2

Note that whilst fuel is shown in kilos on the load sheet, and uplift is ordered in litres **all flight log calculations are to be done in pounds**.