Australian Government
Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation AO-2007-049
Final

Engine power loss (fuel tank exhaustion)
102 km north Adelaide, SA
18 October 2007
VH-TMP
Cessna Aircraft Company C404

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Abstract

On 18 October 2007, the pilot of a Cessna Aircraft Company C404 Titan aircraft, registered VH-TMP, 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 indication 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 indication 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.

The Civil Aviation Safety Authority (CASA) advised that a Civil Aviation Regulation (CAR) 215 direction [WRA3130] had been issued to the operator. In late 2007, CASA withdrew Airworthiness Bulletin 28-002.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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

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.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

FACTUAL INFORMATION

Sequence of events

On 18 October 2007, the pilot of a Cessna Aircraft Company C404 Titan aircraft, registered VH-TMP, 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[1] the right engine, the pilot continued to Adelaide Airport and landed without further incident.

The pilot recalled that during the pre-flight preparation of the aircraft at Adelaide, he noted that the fuel-remaining figure in the flight log from the previous day was 260 L (aviation gasoline) and that this matched the fuel quantity gauge readings of 200 lbs (127 L)[2] per side.

At about 0830 Central Standard Time[3], the pilot supervised the addition of 540 L of fuel to the aircraft. The pilot recorded in the flight log that 820 L (1,296 lbs)[4] was the fuel on board at start-up. The fuel quantity gauge indications for the left and right tanks were similar and reflected the amount of fuel added.

At 0935, the pilot departed without passengers for the short flight to Parafield. Seven passengers then boarded the flight to Beverley airstrip, 280 NM (519 km) to the north. The pilot described those two sectors, and specifically the fuel quantity gauge indications, as normal.

The pilot recalled that, at Beverley, the fuel quantity gauges were indicating total fuel of 750 lbs (475 L) with about 50 lbs (32 L) more indicated on one side than the other. Given the minimum fuel requirement for the flight to Adelaide was 640 lbs (405 L), including reserves, the pilot considered that he had adequate fuel.

After about 25 minutes on the ground, the pilot departed Beverley airstrip with three passengers on board. The pilot climbed the aircraft to 9,000 ft and tracked via the flight-planned route to Adelaide Airport. At about 1353, the pilot commenced descent.

The pilot recounted that the aircraft was passing 7,500 ft when the right engine surged and the aircraft yawed. A scan of the instruments showed that the right fuel flow needle was fluctuating, but all other indications were normal. Both fuel quantity indicators were ‘showing a bit over 200 lbs’ (127 L). The pilot turned on the auxiliary fuel pump and enrichened the mixture, but the engine did not respond.

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1 Pilot actions to reconfigure the aircraft, including feathering the propeller and isolating aircraft systems from the engine.

2 The conversions from pounds to litres of Avgas provided in this report are based on a standard fuel specific gravity of 0.72 and are rounded to the nearest litre. The specific gravity of fuel will vary somewhat according to temperature.

3 The 24-hour clock is used in this report to describe the local time of day. Central Standard Time was Coordinated Universal Time (UTC) + 9.5 hours.

4 260 L + 540 L = 800 L – see Operator fuel quantity calculations section regarding procedures.

About 15 to 20 seconds later, the engine stopped producing power. After checking the switches and controls the pilot secured the right engine. This included feathering the right propeller and reviewing his actions with the applicable checklist.

The pilot reported the engine shutdown to the approach controller and advised that he would continue the flight to Adelaide. He also briefed the passengers. The pilot explained that, before making this decision, he considered the availability of services at Adelaide and the proximity of Edinburgh and Parafield airports.

The pilot conducted a single-engine approach and landing with the fuel quantity gauge continuing to indicate 200 lbs in the right tank.

Recent events

On 16 October 2007, 2 days before the incident, the aircraft was flown by another company pilot on a charter flight from Adelaide to the Challenger mine airstrip and return. Before the flight, the pilot refuelled the aircraft with 400 L and at Challenger the pilot added the contents of two 200 L drums, one to each tank of the aircraft.

The pilot later reported the flight on 16 October to have been normal with no apparent fuel gauge faults. He did, however, recall that at about the midpoint of the return flight to Adelaide, the indicated fuel quantities were different. This led the pilot to assume that the engine fuel burns were different, prompting him to cross-feed fuel from the right tank for about 8 to 10 minutes. (A 10-minute cross-feed would lower right fuel tank quantity by 25 L relative to the left tank) That brought the fuel quantity indications to within 50 lbs (32 L) of each other. The pilot completed the flight without incident.

On 17 October 2007, the day before the incident, the aircraft was used for a series of scheduled passenger flights between Adelaide and Kingscote. The pilot of the first flight reported that on the return sector to Adelaide, the aircraft had a noticeable tendency to roll to the left and required right aileron trim input; it wasn't severe, the pilot recalled, but it wasn't normal.

On the ground at Adelaide, the pilot did another pre-flight inspection and confirmed that the flight controls and wing flaps were operating correctly. The fuel gauge indications appeared even and the indicated amounts tallied with the fuel logs. The pilot conducted another flight to Kingscote with no change to the aileron trim settings. As scheduled, the pilot handed over the aircraft to another pilot, and advised him of the anomaly.

The pilot who flew the aircraft on the next flight to Kingscote confirmed the left roll tendency. He tried different trim settings and checked that the flaps retracted evenly, but was not satisfied with the handling characteristics. The pilot notified the operator and, after returning to Adelaide, changed aircraft.

An aircraft maintenance engineer inspected the aircraft's flight control system and did not find any defects. The item had not been entered into the maintenance release so it did not require a sign-off.

Aircraft fuel system

The aircraft fuel system incorporated an integrally sealed (wet) tank in each wing, outboard of the engine nacelles. Each tank had capacity for 643.5 L of usable fuel and 15 L unusable fuel.

The aircraft was equipped with an electrical capacitance-type fuel quantity indication system (FQIS) that was compensated for specific gravity. Each wing tank contained three internally mounted probes, which were electrically connected to a signal conditioner located outside the tank in each wing. The signal conditioner was electrically connected to the fuel quantity gauge in the cockpit (Figure 1). The gauge, located in the upper right instrument panel, displayed each tank's quantity in 50 lb and 30 US Gallon units (Figure 2).

Standard equipment on the aircraft included a dual fuel flow gauge that displayed the approximate fuel flow to each engine (derived from the pressure in each engine's fuel injection system). The aircraft was not fitted with a digital fuel totaliser, nor was it required.

Figure 1: Aircraft instrument panel

Figure 2: Fuel quantity gauge

Post-incident examination of the aircraft

Draining of the fuel tanks yielded 3 L (5 lbs) of fuel from the right tank and 90 L (142 lbs) from the left tank. After draining the tanks, the fuel quantity gauge indicated 150 lbs (95 L) fuel in the right tank and zero in the left tank.

The right fuel quantity indication system was inspected by a suitably qualified LAME[5], who found that one of the electrical circuits in the wiring loom between the signal conditioner and the fuel tank bulkhead, had a high resistance. The main conductor in the circuit was the shielding braid of a wire in the loom. At each end of the circuit, the braid was electrically connected to a plug through a short wire that was soldered to the braid (Figure 3). The engineer found that the soldered connection between both solder-sleeves and the corresponding shielding braid had deteriorated and there were signs of arcing. Resoldering both joints resulted in the gauge indicating correctly. The left fuel quantity indication system was also inspected and no defects were found in the wiring.

5 Licensed aircraft maintenance engineer.

Figure 3: Typical solder-sleeve connection

The maintenance organisation advised that the fuel quantity indication system was calibrated in accordance with the aircraft's maintenance manual using a Barfield test box. During that process, the left signal conditioner was found to be producing incorrect indications and was replaced. The right signal conditioner did not provide consistent indications and was repaired. Subsequent calibration was successful and the aircraft was returned to service.

Applicable maintenance requirements

The aircraft was operated in the regular public transport category and was therefore classified as a Class A aircraft. Such aircraft were required to be maintained in accordance with a system of maintenance approved by the Civil Aviation Safety Authority (CASA). The aircraft's system of maintenance specified that scheduled instrument maintenance was to be performed in accordance with the schedule in section 5 of the system of maintenance manual.

The instrument inspection schedule included the following preamble:

> The instrument systems and components detailed in this schedule shall be inspected or tested so as to ensure that the system or component remains serviceable for the period between inspections subject to normal operation, inservice maintenance and reporting. When carrying out an inspection, the Manufacturers Maintenance Manual & Service Bulletins should be referred to for the complete inspection and test procedures.

The instrument inspection schedule contained the following fuel system maintenance requirement: 'Fuel pressure and quantity indication systems'. There was no other detail.

The maintenance controller reported that the aircraft manufacturer's maintenance schedules did not include any requirements for periodic calibration of the fuel quantity indication system. There was also no requirement for periodic calibration of other instrument systems.

A CASA airworthiness directive, *AD/Inst/9 Amdt 6*, dated 8/2003, prescribed the periodic test requirements for instruments in IFR aircraft. An operator could elect to comply with requirement 1, which allowed testing of the altimeters only, or elect to comply with requirement 2, which prescribed the checking of all the instruments and instrument systems. The operator had elected to comply with requirement 1 of the AD.

According to the maintenance controller, compliance with requirement 1 of the AD and the absence of a fuel calibration check in the manufacturer's maintenance schedules or approved system of maintenance schedules, meant that there was no regulatory requirement for a periodic fuel calibration. Nevertheless, the maintenance controller continued to schedule calibration of the fuel quantity indication system at 3-yearly intervals, consistent with previous versions of the AD.

Airworthiness Bulletin 02-023, *Maintenance Requirements for Aircraft Components and Equipment*, dated 27 June 2007, contained the following guidance:

> If the owner elects to follow the new option of the Directives then the aircraft maintenance schedule should include the requirements to maintain the additional equipment, if not, then the earlier option needs to be continued.

Maintenance history of the fuel quantity indication system

The last recorded fuel quantity indication system calibration was dated 18 May 2005. On that occasion, the fuel quantity indicators were reported to be inaccurate and 'numerous wiring and terminal repaired or terminated'. The system components in the right wing were also inspected and cleaned. Calibration of the fuel quantity indication system was carried out and recorded as satisfactory.

According to the maintenance records, the following maintenance was carried out to the fuel quantity indication system between the system calibration dated 18 May 2005 and the incident on 18 October 2007:

- 17 February 2006 (an aircraft logbook entry) - The right fuel quantity system was reported to be intermittently going to full scale. Trouble shooting was

carried out, including inspection of wiring and pins and transposition of fuel signal conditioners. The fault apparently cleared.

- 22 December 2006 (recorded maintenance) - The right fuel indication system was sticking and fluctuating – the system was checked and signal conditioners swapped, but the fault apparently cleared and the system was found to be satisfactory.
- 12 October 2007 (last recorded maintenance) - The right fuel gauge was reported to be over-reading by 150 to 200 lb and to be intermittent. A suitably qualified LAME inspected the aircraft and conducted fault finding including swapping the signal conditioners for test purposes. The fault cleared and there were no further reports of fuel quantity indication system defects.

Pilot information

The pilot reported that he held an Airline Transport Pilot (Aeroplane) Licence and had total flying experience of 2,328 hours. That included 1,318 hours of multi-engine experience, of which 150 hours was on the Cessna 404 aircraft type. He had been flying for the operator for about a year.

Operator procedures

An aircraft operator was required to produce an operations manual with 'such information, procedures and instructions with respect to flight operations of all aircraft operated by the operator as are necessary to ensure the safe conduct of the flight operations…'[6] The *Air Operator Certification Manual*,[7] produced by CASA, included the following comment: 'It follows that CASA's satisfaction with the suitability of information in the Operations Manual, relating to flight operations, is a prerequisite for the issue of the AOC [Air Operator's certificate].'

Part A of the operations manual included a sub-section titled Fuel Documentation, which contained the following statements:

> Any fuel added to company aircraft shall be recorded in the trip record sheet […] in accordance with the procedures of this section.
>
> Fuel remaining, fuel added and fuel used shall be entered into the trip record sheet. At the completion of the day's flight, the total fuel used shall be divided by the aircraft flight time giving an average fuel consumption which shall be entered into the box provided on the trip record.

Another sub-section, titled Fuel Usage Records, contained the following statements:

> Flight crew members shall consistently check the fuel burns against the residual fuel figure for accuracy on every sector.
>
> Fuel on board via the aircraft gauge readings are to be checked by the flight crew prior to every departure by comparing the fuel quantity uplifted, as per the fuel docket/release note, to the quantity remaining at the end of the previous flight.

---

6 Extract from Civil Aviation Regulation (1988) 215.

7 Version 5.0: October 2005.

Part B of the operations manual included data and procedures specific to the Cessna 404 aircraft type. The procedures relating to fuel quantity consisted of a description of the minimum fuel requirements for fuel planning and a check of the main tank fuel quantity as part of the pre-flight or daily inspection.

The chief pilot explained that the Cessna 404 fuel tanks did not have any sight gauges or direct reading (drip-stick) type fuel quantity measurement devices, and that each fuel tank had to be almost full before fuel was visible in the fuel filler opening. It was not economically feasible to regularly operate with full tanks, so pilots relied on the fuel gauge readings before and after refuelling. In the operator's experience, the Cessna 404 FQIS had always been reliable.

Operator fuel quantity calculations

The last time the aircraft fuel tanks were emptied or filled was on 20 September 2007, when the aircraft was de-fuelled in preparation for reweighing. Maintenance records show that the aircraft was subsequently refuelled, but the amount added was not recorded. The aircraft re-entered service on 27 September 2007 with 280 L recorded as the fuel on board.

The operator's pilots recorded the aircraft's ongoing fuel quantity status in a table contained in the flight log. The table format and figures recorded on 18 October 2007 are reproduced below (Table 1). For VH-TMP, the Fuel Rem Last Trip (Fuel remaining last trip), Fuel on Dep (Fuel on Departure) and Fuel Used, were all predicated on fuel gauge indications.

Investigators estimated that the departure fuel from Adelaide was 428 L in the left tank and 301 L in the right tank. Those figures were derived from calculations using the remaining fuel at Adelaide, the right tank fuel quantity being zero when the engine failed, and the use of average fuel consumption rates. The disparity was 127 L (200 lbs). (Such a disparity would occur after cross-feeding for about 50 minutes.)

Table 1: Reproduction of VH-TMP flight log fuel calculations for 18 October 2007 (day of incident)

Trip No	Docket No.	Fuel Rem Last Trip	Fuel On Dep	Fuel used	Uplift
1		260	820	30	540
2		790	790	370	-
3		470	470	320	-

The investigation examined the fuel calculations recorded in the flight log between 27 September 2007 and 18 October 2007 (date of incident). In the majority of cases, the 'fuel remaining last trip' figure recorded on the previous day was not entered into the flight log and was not used by the pilot to calculate the next fuel on departure.

On the day of the incident, the 'fuel remaining last trip' (260 L) entered by the pilot was the figure recorded the day before. However, the recorded fuel on departure (820 L) minus the uplift (540 L) equalled a fuel remaining figure of 280 L.

The variation in fuel remaining last trip from end of one day to start of the next was often 10 L, but was occasionally as much as 40 L. The operator advised that the variation resulted from fuel settling after the figure was recorded. There was no operator policy regarding the acceptable level of variance.

In 12 out of the 65 refuellings since 27 September 2007, the fuel uplift recorded by pilots differed from the quantity recorded by the fuel supplier. Overall, the total amount of fuel added since 27 September 2007 was overstated in the aircraft's fuel logs by 141 L.

The operator maintained a record of the average fuel burn derived from the daily total fuel used and total flight time. Between 27 September 2007 and 18 October 2007, the recorded daily average fuel burn ranged from 169 L/hour to 300 L/hour. The daily average fuel burn figures were typically entered by the operator into a spreadsheet to calculate a monthly average fuel burn and an overall average fuel burn (180 L/hour). There was no operator policy regarding an acceptable level of variance from the overall average fuel burn.

Guidance material

The Civil Aviation Safety Authority published Civil Aviation Advisory Publications (CAAPs) as preferred methods for complying with the Civil Aviation Regulations 1988. CAAP 234-1(1) *Guidelines for Aircraft Fuel Requirements* included the following information regarding fuel quantity cross-checking.

> 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 system is known to be reliable.

Airworthiness Bulletin 28-002, *Fuel quantity measurement and verification*, dated 15 May 2006, included the same information.

Related occurrences investigated by the ATSB

ATSB investigation number 200504768

At 1910 Eastern Standard Time on 23 September 2005, a Fairchild Industries Inc. Model SA227AC (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)[8] of aviation turbine 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 of cruise flight.

Faults were found in a number of components of the fuel quantity indication system. The maintenance manual procedures for calibration of the fuel quantity indication system had not been followed correctly on two occasions in the previous 10 days. The result was that the fuel quantity indication 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 changes to publications regarding fuel quantity measurement and verification for transport category aircraft.

The final report is available from the ATSB website www.atsb.gov.au

ATSB investigation number AO-2007-017

At 0639 Western Standard Time on 26 June 2007, an Empresa Brasileira de Aeronáutica S.A., EMB-120ER aircraft, registered VH-XUE, departed Perth, WA, on a contracted charter flight to Jundee Airstrip, WA. There were two pilots, one cabin attendant, and 28 passengers on the aircraft. The co-pilot was the handling pilot for the flight.

When the aircraft was on final approach to runway 08 at Jundee, it diverged to the left of the centreline and slowly rolled to the left. When the crew initiated a go-around at about 300 ft above runway elevation, the aircraft yawed and rolled left 'aggressively'. The aircraft veered left from a heading of about 070 degrees to about 190 degrees and descended to an estimated 100 ft above ground level.

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8 The conversions from kilograms to litres of Avtur provided in this section of the report are based on a fuel specific gravity of 0.8 and are rounded to the nearest litre. The actual specific gravity of fuel will vary somewhat according to temperature.

Together, the pilots were able to steady the aircraft's flight path. The wing flaps and landing gear were retracted.

Both pilots reported that during their efforts to regain control of the aircraft, there were indications of a left engine failure. The crew completed the checklist actions for an engine failure in flight after which there was a significant improvement in aircraft performance. The crew diverted to Wiluna and landed without further incident.

The crew reported that, at the time of the power loss, the fuel gauges were indicating just over 200 kg (250 L) of aviation turbine fuel per side.

Aircraft maintenance engineers, who later examined the aircraft, reported that the left cockpit fuel quantity gauge displayed 300 kg (375 L) and the right gauge displayed 150 kg (188 L). A physical check revealed that the left tank contained no fuel, and the right tank contained 150 kg (188 L) fuel. Further examination revealed a fault in the outboard-most fuel quantity measurement probe from the left tank.

The operator amended its fuel quantity management procedures and the Civil Aviation Safety Authority issued a series of directions to the operator.

The Australian Transport Safety Bureau (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.

The investigation is continuing. The preliminary report and an interim factual report are available from the ATSB website www.atsb.gov.au

ANALYSIS

Introduction

In this event, the pilot departed Adelaide without knowing that there was less fuel than required to complete the flight, resulting in right engine power loss after the right fuel tank contents were exhausted. While the engine power loss occurred on descent into Adelaide and was managed successfully by the pilot, there was potential for a worse outcome if the phase of flight or meteorological conditions had been different.

The main factors in the low level of fuel in the right fuel tank were the insidious over-reading of the aircraft's right fuel quantity indication system (FQIS) and the operator's reliance on that system for determining the aircraft's fuel quantity on board. In the following analysis, the investigation examines the nature of the FQIS fault and the efficacy of the operator's fuel quantity measurement procedures and practices.

Fuel quantity indication system inaccuracy

On 16 October 2007, while VH-TMP was being operated on a charter flight, the pilot (not the incident pilot) noticed an indicated fuel imbalance and cross-fed fuel for about 10 minutes, reducing the quantity of fuel in the right tank relative to the left tank. Given the lateral imbalance experienced by pilots of the aircraft the next day and the fuel tank exhaustion event the following day, the right fuel quantity indicator was probably over-reading from the cross-feed event onwards.

The right fuel quantity indication remained incorrect and undetected until after the engine power loss, when it was over-reading by 200 lbs (127 L) in the air or 150 lbs (95 L) on the ground. The post-incident maintenance discovered that the over-reading was the product of a high-resistance solder joint in part of the system wiring, possibly in combination with a defective signal conditioner.

There was no apparent catalyst for the high resistance in the wiring joints or the defective signal conditioner. Such defects can be difficult to detect during scheduled and unscheduled maintenance activities, as the previous troubleshooting attempts demonstrated. Although the operator considered the Cessna 404 FQIS to be reliable, wiring and component defects can occur at any time without noticeable symptoms. One or both of those defects were probably responsible for the previous right FQIS faults, which were cleared without any defects being identified. FQIS maintenance is discussed in a following section.

While the fuel cross-feed on 16 October 2007 was a significant factor, the investigation did not consider it sufficient to explain the relatively low amount of fuel in the right tank on departure from Adelaide for the incident flight. The operator's fuel quantity measurement and operational practices were such that the actual quantity of fuel on board was only rarely verified. That, and the recurrence of right FQIS faults, indicates that a subtle fault might have developed in the FQIS prior to 16 October 2007 and led to a gradual decrease of fuel in the right tank. The operator's fuel quantity measurement practices are addressed in the following section.

Fuel quantity measurement practices

The operator's written procedure was for pilots to check the aircraft fuel gauge readings of fuel on board prior to each departure by 'comparing the fuel quantity uplifted, as per the fuel docket/release note, to the quantity remaining at the end of the previous flight.'

The pilots flying VH-TMP were not always accurately recording the fuel quantity uplifted, rendering suspect any comparison with the pre-refuelling fuel quantity indication. In addition, the pilots were often not referring to the recorded quantity remaining at the end of the previous flight when determining the fuel on departure. That was indicated in the flight logs examined by the investigation and was explained by the chief pilot as being due to the overnight shift that occurred in fuel gauge indications.

In any event, the fuel quantity remaining at the end of the flight was usually obtained by reference to the fuel quantity gauges. As described in ATSB Safety Advisory Notice 013, '[…] 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.'

The investigation considered that the operator's pre-flight fuel quantity measurement procedures for VH-TMP (which were predicated solely on fuel quantity indication system readings and with no provision for regular independent checks of fuel quantity) contributed to the incident. The pilots' non compliance with aspects of the operator's fuel quantity measurement procedures, though not operationally sound, was not considered to be contributory.

The operator's reliance on the fuel quantity gauge indications in VH-TMP was influenced by the inability to visually verify fuel tank quantities when less than full, and the need to operate with varying fuel quantities. Another influence was the absence of inbuilt direct-reading fuel quantity indicators to cross-check fuel tank quantities and lack of a digital fuel totaliser to accurately track fuel consumption. Misplaced confidence in the reliability of the Cessna 404 FQIS was also a factor.

The operator generally calculated a monthly average fuel consumption rate using the daily average fuel consumption rate recorded by the pilots. This monthly average fuel consumption rate had potential value in establishing the aircraft's average fuel consumption rate. However, the wide range of daily average burn rates that were recorded (169 to 300 L/hr) with no follow-up action, showed that the calculation of average burn rates was not effective in detecting inaccurate fuel quantity indicators.

The operator's requirement for pilots to check fuel burns against the residual fuel figure for accuracy on each sector, was not effective in VH-TMP's case because the fuel burns and residual fuel figure were both derived from the fuel quantity gauge indications.

Regulatory aspects

The operator's procedure to check the aircraft fuel gauge readings of fuel on board prior to each departure by 'comparing the fuel quantity uplifted, as per the fuel docket/release note, to the quantity remaining at the end of the previous flight' was consistent with one of the cross-check methods listed in Civil Aviation Advisory

Publication (CAAP) 234-1(1). That method was item 3, 'After fuelling, and having regard to previous readings, a check of electrical gauge or visual readings against the refuelling installation readings; […]'

As already described in the previous section, the operator's pre-departure check was not adequate to detect gradually developing errors in gauge indications. That means that cross-check method 3 in CAAP 234-1(1) was also not adequate in detecting gradually developing errors in gauge indications.

The CAAP is advisory only and the operator had a responsibility to ensure that the fuel quantity measurement process was sound. However, inclusion of cross-check method 3 in the CAAP gave the method credibility and the opportunity for the operator to consider its use an appropriate procedure.

While the investigation did not examine the Air Operator Certificate (AOC) assessment process conducted on the operator by CASA, it is reasonable to assume that issue of their AOC meant that CASA was satisfied with the operator's fuel quantity measurement procedures. It follows that CASA did not identify the absence of a regular and independent source of fuel quantity information as a concern.

Fuel quantity indication system maintenance

The investigation found that the scheduling of maintenance for the FQIS was not clearly defined. While the CASA-approved system of maintenance lacked specific detail in relation to FQIS maintenance, the preamble to the instrument inspection schedule indicated that the FQIS was to be inspected or tested in accordance with the *Cessna 404 Service Manual* so that it remained serviceable for the period between inspections.

The *Cessna 404 Service Manual* contained procedures for FQIS adjustment and change of components, but did not specify the periodicity of such procedures. Airworthiness directive AD/Inst 9 had previously specified 3-yearly adjustment or calibration of the FQIS, but Amdt 6 allowed an operator to opt out of that requirement, an option selected by the operator. Airworthiness Bulletin AWB 02-023 could be interpreted to mean that the operator should have included the fuel calibration in the aircraft maintenance schedule. In regard to VH-TMP, the maintenance controller had retained the 3-yearly fuel calibration task.

Although the scheduling of FQIS maintenance was not clearly defined, there was no evidence that it contributed to the development of this incident or was at significant risk of contributing to other occurrences. There was, however, a risk that other instrument systems were not being maintained to the standard they once were. That risk was outside the scope of this investigation, so it was not evaluated any further.

The previous troubleshooting of the right FQIS cleared the faults, but was not successful in finding the underlying defect (the solder joint and, possibly, the signal conditioner).

FINDINGS

From the evidence available, the following findings are made with respect to the fuel exhaustion event involving Cessna Aircraft Company C404, registered VH-TMP, 102 km north of Adelaide, SA on 18 October 2007 and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The Cessna Aircraft Company C404 fuel tank characteristics precluded a visual verification of fuel tank contents when the fuel tanks were less than full, and due to operational requirements, the operator usually operated with less than full fuel tanks.
- The aircraft was not equipped with an inbuilt direct-reading fuel quantity indicator, nor was it equipped with a device, such as a digital fuel totaliser, to accurately measure fuel consumption.
- The operator's pre-flight fuel quantity measurement procedures for VH-TMP were predicated solely on fuel quantity indication system readings, with no provision for regular independent checks of fuel quantity. *[Safety issue]*
- While VH-TMP was being operated on a charter flight on 16 October 2007, the pilot (not the incident pilot) noticed an indicated fuel tank imbalance and selected both engines to draw fuel from the right tank (c*ross-feed) for* about 10 minutes, reducing the relative quantity of fuel in the right tank.
- From 16 October 2007 onwards (and possibly before), the right fuel quantity indication system was over-reading by up to 200 lbs (127 L), due to a high-resistance solder joint wiring, possibly in combination with a defective signal conditioner.
- On 18 October 2007, the pilot determined the amount of fuel on board VH-TMP by only using the fuel quantity indication system, resulting in the aircraft departing Adelaide with about 127 L less fuel than planned, right fuel tank exhaustion and engine power loss.
- Guidance promulgated by the Civil Aviation Safety Authority in Civil Aviation Advisory Publication 234-1 regarding aircraft fuel requirements allowed for a fuel quantity cross-check to be conducted after refuelling and without reference to an independent source of onboard fuel quantity information. *[Safety issue]*
- The Civil Aviation Safety Authority issued the operator of VH-TMP with an Air Operator Certificate without the operator having a regular and independent source of onboard fuel quantity information to cross-check the information provided by the fuel quantity indication system.

Other key findings

- Following the loss of engine power, the pilot managed the situation successfully and conducted a single engine approach and landing.
- Although the scheduling of fuel quantity indication system maintenance was not clearly defined, there was no evidence that this contributed to the development

of the incident or was a significant risk to Cessna Aircraft Company C404 operations in general.

- In the 2 years before this occurrence there were two serious incidents involving a Metro III (ATSB 200504768) and a Brasilia (AO-2007-017)[9] that were similar in that the flight crews relied on the fuel quantity indication system to determine the quantity of fuel on board before the flight.

9 Fuel quantity guidance/practices/procedures issues will be part of the final investigation report.

SAFETY ACTION

Operator

Fuel quantity measurement procedures

Safety issue

The operator's pre-flight fuel quantity measurement procedures for VH-TMP were predicated solely on fuel quantity indication system readings, with no provision for regular independent checks of fuel quantity.

Action taken by the operator

On 22 October 2007, the aircraft operator issued a memo to all pilots to direct that all fuel dockets/receipts be retained and filed. Pilots were also reminded that the fuel added on the trip card should reflect the fuel on the receipt and that accuracy was required in completion of the trip card and maintenance release.

The operator made a sight gauge for the Cessna 404 by attaching a fitting to a clear plastic hose to allow connection of one end to the inboard fuel drain of either fuel tank. As known amounts of fuel were added, marks were added to each engine nacelle to indicate various fuel levels.

The operator also amended its operations manual, effective from 1 November 2007. In Part A, the Fuel Documentation sub-section was expanded with the following text:

> Fuel dockets/receipts shall be checked by the Pilot in Command who shall ensure that the documentation reflects the quantity and grade of fuel delivered to the aircraft. The Pilot in Command is also responsible to ensure that the correct quality control measures have been certified on the delivery docket and is retained/returned to the main base for retention.
>
> In addition the pilot in command shall ensure that a secondary means of verification of fuel on board has been used to cross check the electric fuel indication system as per CAR 215 direction instrument no. WRA3130 appendix 12 (refer Part B of applicable aircraft).

In Part B of the operations manual, the following text was added to the Cessna 404 fuel planning procedures:

> Secondary verification of fuel is required prior to departure and after every refuel in the C404. The minimum fuel load for all operations shall be 300 lts. Visual verification of 300 lts can be achieved by using the visual site tubing located in the right hand wing locker.
>
> PROCEDURE: press rubber ended valve on to under wing fuel drain, outboard of engine cowl, while holding open end above wing and against fuel markings on cowl to achieve a reading when fuel has stabilised in the tube. NOTE confirmation via Turn and Bank co-ordinator that the aircraft is on level ground and wings level is required prior [to] procedure.

> If a discrepancy exists, of greater than 20 lts between the anticipated end fuel load, after refuelling (that is the end figure from the previous flight and the fuel added) a special occurrence report will be submitted to the chief pilot for investigation.

Similar text was added to the fuel planning procedures applicable to the operator's other aircraft.

Civil Aviation Safety Authority

Fuel quantity cross-check guidance

Safety issue

Guidance promulgated by the Civil Aviation Safety Authority (CASA) in Civil Aviation Advisory Publication 234-1 regarding aircraft fuel requirements allowed for a fuel quantity cross-check to be conducted after refuelling and without reference to an independent source of onboard fuel quantity information.

Action taken by CASA

The Australian Transport Safety Bureau briefed Civil Aviation Safety Authority (CASA) personnel on the circumstances of the occurrence. CASA advised that:

- A Civil Aviation Regulation (CAR) 215 direction [WRA3130] had been issued to the operator to ensure that a secondary means of verification of fuel on board was used to cross check the electric fuel indication system.

The Civil Aviation Safety Authority is also considering:

- Advising Air Safety Auditors of the circumstances of the incident and the need for operators to have fuel quantity measurement procedures that provide a high level of assurance that the required fuel is actually on board an aircraft
- Reviewing the information in Civil Aviation Advisory Publication 234-1(1) *Guidelines for Aircraft Fuel Requirements* that refers to fuel quantity cross-checking

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

APPENDIX A : SOURCES AND SUBMISSIONS

Sources of information

The sources of information during the investigation included:

- the pilot
- the operator
- the aircraft's maintenance organisation
- the aircraft's maintenance controller
- the aircraft's maintenance records
- Cessna 404 Service Manual
- airworthiness directive *AD/Inst/9 Amdt 6*
- airworthiness Bulletin 02-023 *Maintenance Requirements for Aircraft Components and Equipment*
- Cessna 404 *Pilot's Operating Handbook*
- *Air Operator Certification Manual*
- Civil Aviation Advisory Publication (CAAP) 234-1(1) *Guidelines for Aircraft Fuel Requirements*
- ATSB investigation number 200504768
- ATSB investigation number AO-2007-017

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the Executive Director may provide a draft report, on a confidential basis, to any person whom the Executive Director considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the Executive Director about the draft report.

A draft of this report was provided to:

- the Civil Aviation Safety Authority (CASA)
- the pilot
- the operator
- the maintenance controller
- the maintenance organisation

A submission was received from CASA. The submission was reviewed and, where considered appropriate, the text of the report was amended accordingly.