Australian Government
Australian Transport Safety Bureau

Fuel exhaustion and forced landing involving Cessna 441, VH-LBY

39 km east-south-east of Broome Aerodrome, Western Australia on 2 March 2018

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Addendum

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Safety summary

What happened

On 02 March 2018, at 1549 Western Standard Time, a Skippers Aviation Cessna 441 Conquest, registered VH-LBY, departed on a scheduled passenger service from Fitzroy Crossing to Broome, Western Australia with one pilot and nine passengers on board.

During descent, the FUEL LEVEL LOW annunciators illuminated. The pilot observed that both fuel quantity gauges indicated sufficient fuel remaining and continued flying towards Broome. The right engine began surging, followed by similar surging from the left engine. Subsequently, the right engine lost power and the pilot conducted the engine failure checklist.

The pilot declared a MAYDAY and advised air traffic control that, as the left engine was still operating, the aircraft would be able to reach Broome. However, the left engine also lost power and both engines were unable to be restarted. The pilot landed the aircraft safely on the nearby highway. There were no injuries, and the aircraft was undamaged.

What the ATSB found

Due to water contamination in the fuel tanks, the aircraft's fuel quantity gauges were significantly over reading on the day of the occurrence and on previous days. The water contamination had existed for some time without being detected by multiple pilots' fuel quality testing.

Although the pilot routinely compared indicated versus calculated fuel quantities, and indicated versus flight-planned fuel quantities, the pilot did not routinely conduct two other methods stated in the operator's procedures for cross-checking fuel quantity gauge indications.

In addition, although the operator had specified multiple methods of cross-checking fuel quantity gauge indications for its C441 fleet, there were limitations in the design, definition and/or application of these methods. The primary method used (indicated versus calculated fuel) was self-referencing in nature, and not able to detect gradual changes in the reliability of fuel quantity gauge indications. Pilots also did not record (and were not required to record) sufficient information on flight logs to enable trends or patterns in fuel quantity gauge indications to be effectively identified, and pilots did not routinely cross-check information from fuel quantity gauge indications with information from the independent fuel totaliser.

The FUEL LEVEL LOW annunciators likely illuminated approximately 30 minutes before the fuel was exhausted in each tank, and when the aircraft was still within range of suitable alternative airports. However, the pilot disregarded the annunciations, and relied on the (erroneous) fuel quantity indications and continued to Broome until the engines lost power, at which point a forced landing on a highway was the only remaining option.

What has been done as a result

The operator increased the frequency of a fuel quantity comparison checks to a known quantity to ensure continued quantity measurement accuracy, specified clearer requirements for determining discrepancies when using fuel totaliser figures, implemented additional fuel management record keeping and increased management oversight of its Broome operations. It also increased focus on fuel management procedures during training.

Safety message

Accurate fuel management is a critical aspect of flight operations and it is important to utilise all available means in order to gain the highest assurance that fuel quantity measurement is accurate. It is essential that a reliable quantity cross-check is adopted, utilising at least two independent methods and a conservative approach. Pilots also should understand the functionality of the low fuel warning system on their aircraft and treat any warning annunciations as being accurate unless there is overwhelming evidence otherwise.

Further reading is available in the ATSB research report, *Starved and exhausted: Fuel management aviation accidents* (AR-2011-112). This report discusses methods that pilots can use to ensure they will have sufficient fuel to land at their destination.

Contents

The occurrence

Previous sectors

On 2 March 2018, Skippers Aviation was operating a twin turboprop Cessna 441 Conquest (C441), registered VH-LBY, on a four-sector scheduled passenger flight from Broome to Fitzroy Crossing, then to Halls Creek, returning via Fitzroy Crossing to Broome, Western Australia. The flight was conducted as a single-pilot operation under instrument flight rules. No significant weather was forecast for Broome and there was a risk of afternoon thunderstorms at the other destinations.

The pilot flew the same aircraft on the previous day. At the end of that day's flying, the pilot recorded on the aircraft's flight log that the fuel gauges were indicating a total of 1,300 lb[1] usable fuel.[2] Prior to the first flight on 2 March, 600 L (1,050 lb) of fuel was uploaded, which resulted in a calculated fuel on board of 2,350 lb. This amount was sufficient to conduct all four sectors.

After arriving at Halls Creek following the second sector on 2 March, the pilot recorded the fuel quantity gauges as indicating a total of 1,430 lb usable fuel. The pilot stated that the indicated fuel quantities after the first two sectors were consistent with the expected (flight-planned) fuel burns for those sectors. The pilot also reported that the first three sectors were conducted without incident and on schedule.

Prior to departure from Fitzroy Crossing

The aircraft arrived at Fitzroy Crossing after the third sector at 1532 Western Standard Time.[3] The pilot recorded the fuel quantity gauges as indicating a total of 1,300 lb. This indicated that the fuel burn for the third sector was 130 lb, although the pilot recorded 230 lb on the flight log. The flight-planned fuel burn for the third sector was 357 lb, and the pilot was expecting a fuel quantity indication of about 1,110 lb rather than 1,300 lb.

The pilot's flight plan estimated 977 lb was the minimum required for the final sector (included reserves). Noting that the indicated fuel quantity (1,300 lb) was above the minimum required according to the flight plan, the pilot did not consider the difference between the expected fuel quantity and indicated quantity any further.

Departure and cruise

The pilot and nine passengers were on board for the last sector from Fitzroy Crossing to Broome (Figure 1).

The pilot reported that, during the taxi for departure at Fitzroy Crossing, the right fuel transfer pump (R X-FER PUMP FAIL) annunciator illuminated momentarily. The pilot attributed this to fuel moving within the tank during the left turn onto the runway from a downward sloping taxiway. The pilot also noticed an imbalance between the quantity indications (left tank higher than right) and selected the right engine crossfeed (both engines supplied from the left tank). The pilot reported that the quantity indications for both sides were similar prior to take-off.

The aircraft departed Fitzroy Crossing at 1549. The pilot reported that the take-off and climb to flight level 260 (FL 260)[4] were normal.

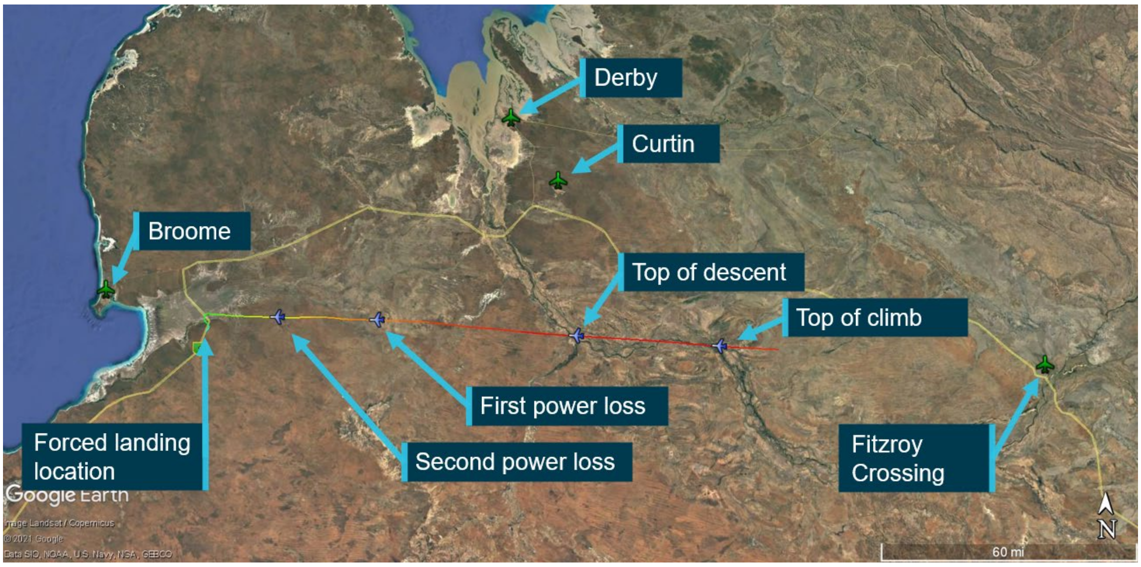
1 The Cessna 441 Pilot's Operating Handbook and instrumentation refers to fuel quantity as a weight in lb. The operator specified a conversion factor of 1.74 (1 L equals 1.74 lb). A quantity of 1,300 lb equated to 747 L.

2 Unless otherwise noted, the indicated fuel quantities in this report include the application of fuel calibration card corrections.

3 Western Standard Time (WST): Coordinated Universal Time (UTC) + 8.0 hours.

4 Flight level: at altitudes above 10,000 ft in Australia, an aircraft's height above mean sea level is referred to as a flight level (FL). FL 260 equates to 26,000 ft.

Figure 1: Aircraft track (just prior to top of climb until landing) and highway



Source: Google Earth, modified by the ATSB

The aircraft reached top of climb at 1607. The pilot stated that, shortly after, the left main boost pump (fuel pump) circuit breaker opened and the left auxiliary boost pump (L AUX BOOST ON) annunciator illuminated (indicating automatic activation in order to maintain fuel supply). After a short delay to allow the fuel pump to cool, the pilot reset the circuit breaker. The pilot recalled that the circuit breaker opened again, so they conducted the main and auxiliary fuel boost pump failure checklist.

At 1613, the pilot contacted air traffic control (ATC) and advised that the aircraft was maintaining FL 260 at about 90 NM from Broome. ATC cleared the pilot to descend when ready to 7,000 ft. About a minute later, the pilot commenced descent. At this point the aircraft was approximately 27 NM south of Curtin Airport and 42 NM south of Derby Airport (Figure 1).

At about this time, the pilot observed a fuel imbalance (right tank higher than left) that was not consistent with the fuel quantity indications on departure and the fuel flow observed during climb. The pilot selected left engine crossfeed (both engines supplied from the right tank), but the right auxiliary boost pump (R AUX BOOST ON) annunciator did not illuminate as it should for this crossfeed selection. The pilot assessed this as an annunciator fault as the left tank quantity showed an expected increase.

The pilot stated that, during the crossfeed, the R X-FER PUMP FAIL annunciator flickered on and then off, prompting the pilot to stop the crossfeed. The R FUEL LEVEL LOW annunciator then illuminated. The pilot observed that both fuel gauges indicated sufficient fuel to continue to Broome. Shortly after, the R X-FER PUMP FAIL and right fuel pressure low (R FUEL PRESS LOW) annunciators also illuminated. A few minutes later, the corresponding left fuel system annunciators also illuminated.

Engine power losses

The pilot recalled that, soon after the annunciators illuminated, the right engine began surging, prompting the pilot to conduct the partial/intermittent engine power checklist. During the checklist actions, the left engine also started to surge. Following completion of checks for the right engine (with no success), the pilot conducted the checks for the left engine. During this activity, the right engine lost power and the pilot then conducted the engine failure checklist.

At 1623, the pilot contacted the Broome tower controller and declared a MAYDAY.[5] The aircraft was approximately 47 NM east of Broome at FL 155. By this time, the aircraft was now a similar distance from Derby and Curtin (Figure 1).

At 1627, the tower controller asked the pilot if the aircraft would still be able to reach Broome. The pilot advised that the left engine was still operating, and they would be able to reach Broome. At this time, the aircraft was descending through 10,800 ft and approximately 38 NM from Broome. However, shortly after, the left engine also lost power. The pilot attempted to restart the left engine. It regained power for a brief time before surging and losing power again. Further restart attempts were made on both engines without success.

Diversion and forced landing

With both engines not providing power, the pilot assessed that the aircraft would not reach Broome and they tracked to the south towards the Great Northern Highway in the vicinity of Roebuck Plains.

At 1633, the pilot notified Broome tower of the 'dual engine failure' and intentions for the forced landing. The aircraft was approximately 22 NM east of Broome at approximately 4,000 ft. The pilot was unable to extend the landing gear normally and conducted an emergency extension of the gear. Although a passenger brief was conducted, the passengers were not instructed to brace for the emergency landing.

The pilot landed the aircraft safely on the highway approximately 21 NM east-south-east of Broome without injuries or aircraft damage (Figure 1).

After landing, the pilot made radio contact with another aircraft in the area, and the pilot of that aircraft relayed their status and requirements to Broome tower. All passengers were subsequently transferred to Broome via road. The aircraft was towed and secured at a nearby truck stop.

A photo of the fuel quantity gauges taken approximately 1 hour after landing indicated about 1,120 lb fuel on board (Figure 2). Subsequent inspections identified that little or no usable fuel was on board.

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5 MAYDAY: an internationally recognised radio call announcing a distress condition where an aircraft or its occupants are being threatened by serious and/or imminent danger and the flight crew require immediate assistance.

Figure 2: Fuel gauges after forced landing

The image shows the fuel gauges indicating a total of about 1,120 lb of fuel on board, about 1 hour after landing on the highway. With the addition of fuel calibration card corrections, the indicated amount should have represented 1,220 lb.
Source: Pilot of VH-LBY following occurrence flight

Context

Pilot information

The pilot held a valid commercial pilot (aeroplane) licence with a multi engine command instrument rating and a valid medical certificate. The pilot joined Skippers Aviation in May 2017 and had been qualified on the Cessna 441 (C441) since June 2017. They had a total of 2,403 hours flight time, of which 402 hours were on the C441. The pilot had also flown a number of single engine aircraft, including the Cessna 172, 206 and 210, and other multi-engine aircraft, including the Beechcraft Baron and Cessna 402 and 404.

The pilot's training records for conversion to the C441, check to line and the most recent instrument proficiency check did not contain any major issues or concerns regarding the pilot's performance or capability.

The pilot was one of four pilots based in Broome that operated C441 aircraft for the operator.

Aircraft information

General information

The C441 is a pressurised twin engine turboprop aeroplane, accommodating up to 11 people. VH–LBY, serial number 0023, was manufactured in 1978. It was first registered in Australia in May 1986 and Skippers Aviation was the registered operator from November 1992. The aircraft had accumulated over 25,000 hours total time in service. The aircraft was one of three C441s based in Broome used by the operator.

Fuel tank system

The C441 fuel system includes fuel tanks as integral portions of each sealed wet wing. Each fuel tank normally supplies the engine on the same side of the aircraft. The total usable fuel capacity is 3,168 lb or 1,800 L (1,584 lb per side). Fuel systems schematics are provided in *Appendix A – Fuel System Schematics*.

Each fuel tank incorporates an open-top hopper tank (located inboard), which accumulates fuel to ensure continuous supply for the two electric boost pumps (main and auxiliary) situated in the bottom of the hopper. The main boost pumps supply fuel under pressure to the respective engine and transfer ejector pumps. If the main boost pump fails, the auxiliary boost pump will automatically activate, and the associated annunciator (L/R AUX BOOST ON) will illuminate.

The transfer ejector pumps in each tank utilise high pressure fuel flow from the respective boost pumps (motive flow) in conjunction with a venturi to produce a high-volume flow. Provided a boost pump is operating (main or auxiliary), the respective ejector pumps will operate continuously to transfer fuel from the lowest points in the forward and rear of each tank into the hopper to maximise the amount of usable fuel available to the engine.

If the boost pumps are off, the transfer ejector pumps will not transfer fuel from the tank to the hopper. If more than 580 lb of fuel is in the tank, the fuel level will be sufficient to overflow into the open-top hopper tank and keep it full. If there is less than 580 lb of fuel in the tank, then fuel will not overflow, and the fuel level in the hopper will lower.

For each fuel tank, the associated X-FER PUMP FAIL annunciator is actuated by a float switch near the top of the hopper tank. The annunciator will illuminate when:

- less than 80 lb of fuel is in the hopper tank (with boost pumps on), or
- less than 580 lb of fuel in the tank, including in the hopper tank (with boost pumps off).

Illumination of the X-FER PUMP FAIL annunciator is usually associated with failure of the respective transfer ejector pumps. That is, a failure to ensure the hopper tank remains full.

However, this feature can also be used on the ground to determine if a tank's quantity is above or below 580 lb by turning the fuel boost pumps off and observing the annunciator. Illumination of the annunciator indicates a fuel quantity in the tank less than 580 lb.

In case of an engine failure or fuel tank imbalance, a crossfeed system allows the pilot to select one of the engines to be supplied from the tank on the other wing. For example, if both engines are operating and the left engine crossfeed is selected, the following would occur without further pilot action:

- interconnection of the output from the two tanks
- left main boost pump de-energised
- right auxiliary boost pump energised (in addition to right main boost pump)
- both engines supplied from the right tank
- excess fuel leaving the right tank transferred to the left tank.

Two drain valves are fitted to the lower inboard surface of each fuel tank and two are fitted to the crossfeed lines to allow samples to be extracted for visual and chemical detection of water and other contaminants. The standard design of VH-LBY did not include drain valves in the hopper floor panel and none were fitted at the time of the occurrence.

The manufacturer advised that the drains were located at low points in the fuel tank system, which was in front of the hopper tanks. It also noted that the pre-flight checklist called for the sumps in each wing, and the two crossfeed line sumps, to be drained and checked for water and contamination before each flight. It stated that draining those fuel sumps before every flight would remove water that has entered the fuel tank and prevent that water from being fed into the hopper tank.

Fuel quantity indications

The fuel quantity indicating system (FQIS) is a capacitance-type system with five probes in each tank, connected to a signal conditioner in each wing that converts probe values to an electrical output. This output is transmitted to two gauges on the instrument panel, which display the quantity of usable fuel in increments of 50 lb (Figure 2, Figure 3).

Each probe is an assembly of concentric tubes acting as plates of a capacitor with fuel or air acting as the normal dielectric medium between plates. The value of probe capacitance is proportional to the submersion of the probe in the fuel. Probes are not adjustable but are subject to regular testing to establish serviceability. The signal conditioner can be adjusted to maximise the accuracy of the quantity indications.

If a contaminant is in contact with the probes, then the quantity indications will be altered based on the capacitance property of that contaminant. Water has a much higher dielectric constant than fuel. Therefore, the presence of water on the probes would likely cause an over reading of the fuel quantity.

The aircraft also has a low fuel warning system, activated by a magnetic float switch co-located with the inboard fuel probe. The L or R FUEL LEVEL LOW annunciator illuminates when the associated tank contains between 150–250 lb of usable fuel and the main and/or auxiliary fuel boost pumps are operating. The low fuel level warning is independent of the fuel quantity gauges.

VH-LBY and the operator's other C441 aircraft were fitted with fuel flow transducers that transmitted information to fuel flow gauges located on the instrument panel. This fuel flow information was also transmitted to the Garmin GNS 530 GPS/navigation system, which had a fuel totaliser function. A fuel on board figure was required to be manually entered prior to flight and/or after refuelling. Following this, the Garmin GNS 530 would then be able to accurately monitor the fuel consumed and calculate the residual fuel at any point. Senior pilots reported that the fuel burn figures produced by the Garmin 530 totaliser function were accurate.

The aircraft was not equipped with a mechanism to directly read the fuel quantity in each tank, such as a drip/magna stick or sight gauge. It was only possible to visually determine the quantity of fuel on board the aircraft by viewing the fuel via the open fuel filler cap when the tanks were full.

FQIS maintenance requirements

The operator's system of maintenance required that the FQIS was calibrated every 12 months. The procedure started with empty tanks and adjusting or verifying the zero indication of the gauges. Following this, fuel was added incrementally, and gauge indications were recorded for each added amount. A calibration card was then compiled, allowing pilots to make applicable corrections to the gauge readings to reflect actual fuel on board.

The last calibration for VH-LBY was conducted in April 2017 and the calibration card was current until April 2018. For both tanks, the card required the addition of amounts of about 10 per cent of the indicated quantity. Similar values were evident in previous calibrations.

In addition to the annual calibration, the operator required a comparison check of the FQIS at intervals of 150 hours flight time. The procedure required the tanks to be drained of all fuel, and then 500 lb per tank added in 100 lb increments. A comparison of gauge indications and fuel added was made to verify accuracy of the FQIS.

The aircraft had been operated for about 66 hours since the comparison check, which was conducted on 6 January 2018.

Post-occurrence actions and maintenance

On the day following the occurrence (3 March 2018), a fuel drain was conducted and a significant but unquantified amount of water was drained. The aircraft was then refuelled with 650 lb of fuel from sealed drums and the subsequent fuel drain did not contain a significant amount of water. The engines were ground run and no fuel leaks were evident. The fuel pump pressure low and fuel level low annunciators were checked to be operating as satisfactory.

Based on this evidence, and an assessment that both engines had likely lost power due to fuel exhaustion, the Civil Aviation Safety Authority (CASA) issued the operator with a special flight permit to allow the aircraft to be flown to Broome. The ferry flight was conducted without incident.

On arrival in Broome, all usable fuel was drained from the aircraft by diverting boost pump output into drums. Accounting for the quantity of fuel added on the highway and consumed during the ferry flight, the operator estimated there was little or no usable fuel on board the aircraft at the time of landing on the highway. The operator also noted that the fuel quantity gauges indicated 370 lb per tank even though all the usable fuel had been drained (Figure 3).

Figure 3: Fuel quantity gauges after defueling in Broome

The image shows the fuel gauges indicating 370 lb per tank, though all usable fuel had been drained from both tanks.
Source: ATSB

The aircraft was inspected in Broome by licenced aircraft maintenance engineers employed by the operator's maintenance organisation, in consultation with observers from the ATSB and CASA. To allow inspection of the fuel tanks and system components internal to the tanks, the fuel drains were opened, and the underwing access panels were removed. As the panel forming the floor of the hopper (and boost pump mount) was removed, fuel was released into a container with some unavoidable spillage onto the floor. It was estimated that about 500 mL of water was in the fuel released from the hopper.

Inspection of the tank interiors showed significant water beading on the internal surfaces and on the fuel quantity probes. A grey substance, later identified as fungus, was also observed in the tanks, although not on the probes.

When tested, the probes did not conform to capacitance specifications. The probes were cleaned and dried overnight. When retested, the probes passed the capacitance test, and the fuel quantity gauges indicated the correct zero fuel state (Figure 4).

Figure 4: Fuel quantity gauges after cleaning and drying the probes

The image shows the fuel gauges indicating zero usable fuel on board, following cleaning and drying of the fuel quantity probes.
Source: ATSB

During the process of removing fuel from the tanks, approximately 1 L per side of fuel was collected for analysis. The sample from the left tank was cloudy with a small amount of settled contaminant. About one fifth of the right tank sample was a distinct contaminant and the rest was clear. Specialist analysis subsequently identified water as the only contaminant.

Due to the significant water contamination and fungal growth, several engine fuel system components and the main fuel boost pumps were removed for overhaul. The engineers observed minimal component damage, suggesting that water was not present for an extended period.

As part of return-to-service maintenance, the FQIS was calibrated and found to be serviceable. During this process, the left and right fuel level low warning system was checked and found to switch the annunciators on/off at 160 lb per side, which was within the specified range. Additionally, both fuel transfer pump fail annunciators switched on/off when the fuel level reached about 580 lb per side (and the boost pumps were off), in accordance with specifications.

Fuel system maintenance

In January 2018, VH-LBY underwent a scheduled maintenance check. Fuel system related inclusions were a fuel drain and check for evidence of moisture, fuel gauge to fuel quantity comparison check, and various fuel system component inspections. No fuel system related issues were identified during this check.

In February 2018, the left fuel computer was replaced due to intermittent dropouts.

In terms of previous problems with fuel quantity readings, in March 2017 the right fuel gauge was reported as being unreliable. All right-side fuel probes were removed and reinstalled after testing within limits. In February 2017, the left-side fuel gauge was reported as over reading. The inner fuel probe was replaced after being tested as out of limits.

Fuel contamination opportunities

The operator and the ATSB reviewed operational records for VH-LBY since the comparison check on 6 January 2018 to identify the potential source of the water.

On 13 February 2018, VH-LBY was involved in a towing incident, during which the right wingtip was damaged and required repair. Due to hangar availability and maintenance on other aircraft, VH-LBY was not always inside a hangar. Repairs were completed and the aircraft returned to service on 26 February 2018.

During this period, Broome received heavy rainfall associated with tropical cyclone Kelvin. On 17 February 2018, 377 mm was recorded at Broome Airport. It is possible that the aircraft was exposed to some heavy rainfall, allowing the ingress of water through the damage in the right wingtip, but specific information about the extent to which this occurred was not available. There was no evidence that the fuel caps were incorrectly secured or that the fuel cap seals were degraded.

The aircraft was refuelled on 22 February 2018 and on five other occasions before the day of the occurrence. All but one of these refuels were at Broome Airport and there were no reports of any fuel quality issues from the fuel supplier or other operators. One of the operator's other C441 aircraft based in Broome was inspected after the 2 March occurrence and no contamination was found.

Since the aircraft was returned to service on 26 February, and up to the day of the occurrence, the aircraft was operated on 4 days by three pilots. The pilot of the occurrence flight conducted flights on the 1 and 2 March, and the other pilots conducted flights on 27 February and 28 February.

Overall, 12 flights totalling 13.0 flight hours were conducted prior to the occurrence flight. For each of the 4 days, the flight log was signed to certify that the daily inspection had been carried out. No-one reported that fuel drains conducted prior to each flight were anomalous, and there were no indications in the aircraft's technical log or daily flight logs of any problems.

Fuel quality management

Regulatory requirements regarding fuel quality

Civil Aviation Order (CAO) 20.2 (*Air service operations — safety precautions before flight*) (15 May 2006) directed that the operator and pilot in command must ensure that inspections and tests for the presence of water in the fuel system of the aircraft are made. CAO 20.2 provided the following as guidance:

> *Note* It is important that checks for water contamination of fuel drainage samples be positive in nature and do not rely solely on sensory perceptions of colour and smell, both of which can be highly deceptive. The following methods are acceptable:
>
> 1. Place a small quantity of fuel into the container before taking samples from tank or filter drain points. The presence of water will then be revealed by a visible surface of demarcation between the two fluids in the container.
> 2. Check the drainage samples by chemical means such as water detecting paper or paste, where a change in colour of the detecting medium will give clear indication of the presence of water.
> 3. In the case of turbine fuel samples, tests should also include inspection for persistent cloudiness or other evidence of the presence of suspended water droplets, which will not necessarily be detected by methods mentioned in notes 1 and 2. Should any doubt exist of the suitability of the fuel, the checks specified in the aircraft Operators Maintenance Manual should be followed. It is advisable to allow turbine fuel a reasonable period of stagnation before drawing test samples from fuel drain points; this allows settling of suspended water which is a slower process in turbine fuel than in aviation gasoline.

The CAO also stated:

> If, at any time, a significant quantity of water is found to be present in an aircraft fuel system, the operator and pilot in command must ensure that all traces of it are removed from the fuel system, including the fuel filters, before further flight.
>
> *Note* In eliminating water from an aircraft fuel system, it is important that consideration be given to the possibility of water lying in portions of the tanks or fuel lines where, because of the design of the system or the existing attitude of the aircraft, it is not immediately accessible to a drain point.

Operator requirements regarding fuel quality

The operator's *Flight Operations Manual* (FO1) required that a pilot conduct a fuel drain prior to the first flight of the day and following each refuel. The fuel sample was to be visually checked for water and other contaminants. If any water was evident, further drains were to be conducted until water was no longer evident. Once water was no longer visually evident (via draining), a sample was to be chemically tested for water using a water detection capsule. If the water test resulted in a positive detection of water, the aircraft was not to be flown and a defect report raised. Further details of the operator's procedures are provided in *Appendix B – Fuel System Testing*.

The operator did not provide guidance as to what amount of water was considered excessive or out of the ordinary, nor did it require any reporting or recording (in a maintenance log or similar) of any water drained from the tanks. It appeared that the assessment of excessive or out of the ordinary was reliant on an individual pilot's experience and the knowledge gained from instructor pilots during training.

The operator's procedure did not include guidance to allow fuel to stagnate for a period to enable suspended water to settle, or that water may be in areas not immediately accessible via drain points.

Fuel quality management actions and events

In the case of the flights conducted on 2 March 2018, the pilot reported that a fuel drain was conducted during the pre-flight inspection at Broome prior to refuelling but no testing was conducted with the water detection capsules. The pilot did not report any concerns regarding their observations of the fuel samples.

The pilot stated they did not conduct a fuel drain after the aircraft was refuelled (at Broome). The pilot explained during interview that, following the pre-flight inspection at the hangar, they drove to the passenger terminal to conduct check-in duties and ordered fuel once check-in was complete. The pilot was not present at the aircraft during refuelling and the aircraft was towed to the terminal by an engineer. The pilot could not offer any explanation for not conducting the additional water test.

Fuel quantity management

Regulatory requirements regarding fuel quantity

At the time of the occurrence, Civil Aviation Regulation (CAR) 234 (*Fuel requirements*) stated that the pilot in command and the operator had to take reasonable steps to ensure that an aircraft carried sufficient fuel 'to enable the proposed flight to be undertaken in safety'. No specific cross check requirements were stated in the regulation.

The Civil Aviation Safety Authority issued Civil Aviation Advisory Publication (CAAP) 234-1(1) (*Guidelines for aircraft fuel requirements*) in November 2006. With regard to establishing fuel on board, the CAAP stated:

> Fuel gauges, particularly on smaller aircraft may occasionally be unreliable. In addition, except when the tank is full, it is extremely difficult to establish the quantity of fuel in a tank unless the aircraft is perfectly level and the manufacturer has provided an accurately graduated dipstick, sight gauge, drip gauge or tank tab.

In terms of fuel quantity cross-checks, the CAAP stated:

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

Operator requirements regarding fuel quantity

The operator's fuel management requirements were documented in the *Flight Operations Manual* (FO1) and the *Conquest Flight Operations Manual* (FO6). The FO1 section on fuel quantity measurement included the following:

> On aircraft types with a MTOW less than 5700kgs, the PIC must use the acceptable cross check methods to ensure sufficient fuel is on board at take-off for the proposed flight.
>
> It must be understood that the degree of accuracy achieved when taking fuel quantity readings is highly dependent upon the scale provided on the gauge or measuring device and the slope of the tarmac surface.
>
> The following fuel quantity measurement methods are acceptable:-
>
> - Indicated (electrical fuel quantity gauges)
> - Stick Gauge (Magna or drip sticks)
> - Calculated (by adding the refuel quantity to the residual fuel quantity)
>
> The following cross-check methods are acceptable:-
>
> - Check of stick gauge readings against indicated readings,
> - A check of stick gauge against calculated,
> - A check of indicated against calculated,
>
> When a series of flights is undertaken by the same crew and refuelling is not carried out at intermediate stops, cross checks, other than the first flight of the day, may be made by checking the gauge readings against the calculated fuel on board.

As the C441 did not have a stick gauge, only the cross-check of indicated versus calculated fuel quantity was applicable to that aircraft.

FO1 defined 'residual fuel quantity' as the indicated quantity at engine shutdown and, as indicated above, it stated that calculated fuel was the residual fuel plus the amount added during refuelling. Given this definition, the last paragraph of the FO1 procedure provided very limited guidance to pilots. In effect it meant that, if no fuel was added between flights, the indicated fuel quantity at the end of the previous flight should be compared with the indicated fuel quantity prior to the current flight.

By comparing the operator's procedures with CAAP 234, the last paragraph of the FO1 procedure would have provided clearer guidance if it used the term 'computed fuel' rather than 'calculated fuel'. FO1 defined 'computed fuel' as:

> For the purposes of acceptable fuel cross check methods, Computed fuel is defined as the anticipated destination fuel quantity that is derived during flight by use of fuel flow, ground speed and distance to the destination aerodrome.

However, none of the cross-check methods stated in FO1 referred to computed fuel.

In a section about fuel usage records, FO1 stated:

> Fuel on board gauge readings are to be checked prior to departure by adding the fuel quantity uplifted, as per the release note, to the fuel quantity remaining at the end of the previous flight which has been recorded on the Flight Log.

In effect this statement was requiring pilots to conduct the cross-check of indicated fuel quantity (prior to a flight) with the calculated fuel quantity for those flights where fuel was added.

FO6 provided further procedures and guidance for C441 pilots. It stated that 'the acceptable method' of cross-checking fuel quantity indications was as follows:

> - Prior to flight, confirm the difference between the indicated fuel vs the residual figure noted in the flight log from the previous flight are within 5%
> - After re-fuelling, compare the indicated fuel vs calculated and verify the difference is less than 5% of the higher amount.
> - Should the indicated fuel vs residual figure noted or the indicated fuel vs calculated after refuelling difference exceed 5%, the aircraft shall not be flown and an appropriate entry into the Defect Endorsement Log shall be made. The crew should then seek Engineering assistance to rectify the defect.
> - Prior to shutdown on the ground the L-R FUEL X-FER FAIL light will be used as a gross error check vs the indicated amount. The fuel boost pump switches will be position to OFF. If the L or R FUEL X-FER FAIL light illuminates, the associated fuel gauge should read below 580 Lbs or if the L or R FUEL X-FER does not illuminate the associated fuel gauge should read above 580 Lbs.
> - When equipped with a Garmin 530 and the Shadin (fuel totaliser). Enter the total fuel at departure into the "FOB" on the Fuel Planning page in the Garmin 530. After shutdown open the Fuel Planning in the Garmin 530. "FOB" vs indicated amount will be used as a gross error check.
>
> If the crew believes a gross error check was not within an acceptable amount, the aircraft shall not be flown and an appropriate entry into the Defect Endorsement Log shall be made. The crew should then seek Engineering assistance to rectify the defect.

The manual did not define an 'acceptable amount' for the two gross error checks (last two dot points).

In addition, the C441 pre-flight checklist stated:

> Verify current fuel status and ensure balance [between both tanks] is within 300lbs. Enter indicated total fuel quantity on board into the Garmin 530 "Fuel Planning" page after re-fuelling.

The C441 cruise checklist stated:

> Calculate and note destination fuel on current or average estimated ground speed and current fuel flow. Monitor throughout flight. Check balance [between both tanks] is within 300 pounds.

None of the cross-check methods in FO6 referred to computed fuel. In addition, none of the methods stated in FO1 or FO6 referred to the use of estimated destination fuel or estimated fuel burn based on using flight-planned fuel burn figures.

Senior pilots indicated that a pilot should also reference the flight-planned fuel figures as a cross-check, and they described the operator's flight planning software as accurate and reliable. One senior pilot stated that if the difference between the flight-planned fuel burn and the recorded fuel burn was more than 100 lb, they would be attempting to determine the reason for the discrepancy. Senior pilots reviewed the flight plan produced for the four sectors on the day of the occurrence and noted no errors or omissions in its preparation.

Use of flight logs

The operator's pilots used a flight log form to record details of each of the flights conducted on a specific day. In terms of fuel, the form allowed a pilot to record the following in separate columns:

- total fuel quantity at departure
- fuel burn
- residual fuel
- added fuel (in L)
- added fuel (in lb).

In the top row, the residual fuel from the previous flight log could be entered.

FO1 stated:

> The figure placed in the 'Total Fuel QTY at Dept' column of the Flight Log Form shall be the fuel total as described in the aircraft type specific operations manual.

FO6 did not provide any definition of what should be placed in the total fuel quantity column for a C441.

A review of flight logs for VH-LBY from 1 February to 2 March 2018 indicated the following:

- The total fuel quantity was always the residual fuel from the previous flight log entry or, if the aircraft had been refuelled, the total fuel quantity was always the calculated fuel quantity. That is, the amount always matched the residual fuel plus the added fuel (in lb). If the indicated fuel quantity was being recorded, these figures would have at least occasionally varied slightly from the residual or calculated fuel quantity.
- The fuel burn was always the total fuel quantity at departure minus the residual fuel.
- No comments were included in the 'Comments / Observations' section on the flight logs to indicate any differences between the calculated fuel and indicated fuel prior to a flight, or the results of any other cross-checks.

Sectors on 2 March 2018

The pilot prepared a flight plan using the operator-provided flight planning software. Key flight-planned fuel figures for the 2 March are presented in Table 1.

Table 1: Flight plan extract - planned fuel figures 2 March 2018

Sector	Estimated time interval (ETI) (minutes)	Flight-planned fuel burn (lb)	Estimated fuel at destination (lb)
Start fuel			2,350
1	47	509	1,841
2	30	373	1,467
3	28	357	1,110
4	43	479	632

The pilot reported that, prior to the first sector on 2 March, they compared the indicated fuel quantity to the residual quantity recorded in the flight log from the last sector on the previous day (1,300 lb). The pilot stated that the fuel quantity gauges were as expected following this comparison and they carried forward the residual quantity to the new flight log. The actual indicated fuel quantity was not recorded (nor was it required to be).

After the aircraft was refuelled, the pilot recorded the added fuel (1,050 lb) on the flight log. They also calculated the total fuel quantity at departure as 2,350 lb and recorded that figure on the flight log. The pilot recalled that, when checking the gauges after refuelling, the indicated fuel quantity was as expected. The actual indicated quantity was not recorded (nor was it required to be).

At the end of each sector, the pilot recorded the indicated fuel quantities on the back of the flight plan. This included the raw indicated amounts in each tank, the total raw indicated quantity and the total indicated quantity after applying the appropriate calibration card corrections. These notes are reproduced below in Table 2. The pilot's application of the calibration card corrections for the last two sectors contained minor errors. The recorded residual fuel at Halls Creek should have been 1,410 lb and the recorded residual fuel at Fitzroy Crossing should have been 1,310 lb.

Table 2: Pilot's fuel notes regarding indicated quantities on 2 March

(Location)	F (Fitzroy Crossing)		H (Halls Creek)		F (Fitzroy Crossing)	
(Left tank, right tank amounts)	910	740	740	550	700	490
(Raw indicated quantity total)	1650		1290		1190	
(Residual fuel, or indicated total after calibration corrections)	1810		1430*		1300**	

*The pilot's notes contained the information not included in brackets. The information in brackets is provided to assist the reader with interpreting the pilot's notes. *Figure should have been 1410. ** Figure should have been 1,310.*

At some point later, the pilot transferred the residual fuel figures to the flight log. The recorded flight log figures are reproduced in Table 3. The pilot also annotated the residual fuel amounts after each sector on the flight plan next to the estimated destination fuel quantities after each flight.

Table 3: 2 March 2020 flight log extract – recorded fuel figures

Sector	Time (minutes)	Total fuel quantity at departure (lb)	Fuel			
			Burn (lb)	Residual (lb)	Added litres	Added lb
		Brought forward		1,300	600	1,050
1	52	2,350	540	1,810		
2	34	1,810	380	1,430		
3	32	1,430	230*	1,300		
4		1,300				

** This figure should be 130, based on the indicated quantities recorded.*

In terms of cross-checks of the fuel quantities:

- The fuel burn and residual quantity figures for the first two sectors were similar to the flight-planned figures (that is, 1,810 and 1,430 lb compared to 1,841 and 1,467 lb respectively). The pilot reported that the differences were minimal and not a concern. However, there was a large disparity between recorded and planned figures for the third sector (that is, 1,300 lb indicated compared to 1,110 lb estimated).
- The pilot stated that although the 1,300 lb indicated quantity after the third sector was higher than expected, it was greater than the planned minimum quantity required for the final sector (977 lb) so no further investigation was made.
- There was no evidence to suggest that any comparison of (recorded versus planned) fuel burn figures was made. The fuel burn for the third sector was recorded as 230 lb but should have been 130 lb based on the recorded residual fuel figures at the end of the second and third sectors, and 100 lb if the recorded residual fuel figures were correctly derived. This recorded fuel burn was substantially less than the flight-planned fuel burn (357 lb), and the actual flight time (32 minutes) was slightly longer than the planned flight time (28 minutes).
- There was no evidence to suggest that any computed fuel quantity calculations were made during the flight (that is, using fuel flow and time to run during flight or by using actual flight time with an average or block fuel consumption rate).
- Although the pilot was aware of the fuel totaliser capability in the Garmin 530, this was not used to do a gross error check of the fuel quantities as the pilot did not consider this to be mandatory. In other words, the pilot did not use the Garmin 530 to ascertain the fuel remaining after each flight and compare that figure with the recorded residual fuel based on fuel quantity indications. The pilot reported that they had seen other pilots use this gross-error check but

that it was not used regularly. A senior pilot based in Broome also advised that it was possible this cross-check was not routinely conducted by the other Broome-based pilots.

- On completion of each sector, the pilot did not conduct the gross error check that utilised the L/R FUEL X-FER FAIL annunciators to indicate if the tank quantity was above or below 580 lb. Although it was specified in the operator's FO6 manual, the pilot stated being unaware of this gross error check method at the time of the occurrence. A senior pilot advised that it was routinely taught to pilots during line training.

Sectors on 1 March 2018 (day prior to occurrence flight)

The pilot of VH-LBY on the day of the occurrence operated the same aircraft on the previous day (1 March) for two sectors from Broome to Kununurra and return. Key flight-planned fuel figures are in Table 4 below.

Table 4: Flight plan extract – planned fuel figures 1 March 2018

Sector	Estimated time interval (ETI) minutes	Flight-planned fuel burn (lb)	Estimated fuel at destination (lb)
Start fuel			2,700
1	95	865	1,834
2	91	858	976

The recorded fuel figures on the flight log are shown in Table 5.

Table 5: 1 March 2020 flight log extract – recorded fuel figures

Sector	Time (minutes)	Total fuel quantity at departure (lb)	Fuel			
			Burn (lb)	Residual (lb)	Added litres	Added lb
		Brought forward		890	1,031	1,804
1	98	2,694	664	2,030		
2	90	2,030	730	1,300		

For both sectors, the recorded fuel burn derived from the total fuel quantity at departure and residual fuel quantity figures was significantly below the flight-planned estimates, even though the flight times were about the same. For the first sector the recorded fuel burn (664 lb) was 201 lb (23 per cent) less than planned, and for the second sector the recorded fuel burn (730 lb) was 122 lb (14 per cent) less than planned.

Estimated fuel on board during recent sectors

The operator estimated that the fuel burn during the fourth sector on 2 March (occurrence flight) was about 420 lb. Given that about little or no usable fuel was remaining when the aircraft landed on the highway, the aircraft therefore departed Fitzroy Crossing with about 420 lb on board.

Using flight-planned fuel figures, the actual fuel on board for each of the sectors on 1 and 2 March was estimated and compared with the indicated fuel quantities, as shown in Table 6. The estimated fuel quantities would become less reliable as they progressed further back in time. Nevertheless, the comparisons showed that the fuel gauges were over reading throughout both days, and the amount of over reading substantially increased prior to the last sector and after the aircraft landed on the highway during the fourth sector. It also significantly increased after both of the sectors on 1 March. The amount of over reading did not increase on every flight.

Table 6: Indicated and estimated fuel quantities during 1 and 2 March 2018

Date	Sector	Indicated fuel quantity (lb)	Estimated fuel quantity (lb)	Estimated over reading
1 March	Start first sector	2,700*	2,330	370
	End first sector	2,030	1,470	560
	End second sector	1,300	610	690
2 March	Start first sector	2,350*	1,660	690
	End first sector	1,810	1,150	660
	End second sector	1,410	780	630
	End third sector	1,310	420	890
	On highway	1,220**	0	1,070
3 March	After flown and usable fuel drained.	800**	0	800

*Indicated fuel quantities as recorded on the flight log except for minor corrections. Estimated fuel quantities based on using known quantity after last flight and using flight-planned fuel burns for previous flights. All figures rounded to the nearest 10 lb for readability. *The actual gauge readings prior to the first flight each day were not recorded. It is assumed that the calculated fuel quantity (recorded) was close to the indicated fuel quantity. **Calibration card corrections applied to gauge readings.*

Given the estimated fuel quantities, if the pilot had conducted gross error checks utilising the L/R FUEL X-FER FAIL annunciators, the annunciators would have illuminated at the end of sector 2 at Halls Creek and the end of sector 3 at Fitzroy Crossing on 2 March. They also would have illuminated at the end of the second sector on 1 March.

Based on post-occurrence testing, the L/R FUEL LEVEL LOW annunciators would have illuminated when each tank quantity reduced to 160 lb. This amount equates to about 30 minutes[6] of flying time, so the annunciators would have been activated during climb between 5 and 10 minutes after take-off from Fitzroy Crossing if the two tanks had the same quantity of fuel. If the tanks had different quantities, then one of the lights would have come on earlier.

Given the likely quantity of fuel on board, it is possible that the fuel system annunciation observed during taxi was R FUEL LEVEL LOW rather than R X-FER PUMP FAIL. Given that the transfer pumps would have been on at that stage, the R X-FER PUMP FAIL should not have illuminated.

As the pilot related, when the pilot observed the FUEL LEVEL LOW annunciators illuminated, the fuel quantity indications were sufficient for continuation of the flight to Broome. The pilot reported that they had developed a mistrust of the annunciators because of a faint glow during night flights and intermittent activation on various occasions. In contrast, the pilot had no experience of fuel quantity indication faults in the C441 and believed that the system was reliable.

Once the fuel quantity in a tank reduced to below 80 lb, the FUEL X-FER FAIL annunciators would have illuminated. That amount provides for about 15 minutes flying time, so the annunciators would have been activated in the 5 minutes prior to top of descent. In that time period, the aircraft was between 55 and 25 NM to the south of Curtin.

Review of other flight logs

The ATSB reviewed the recorded fuel figures in the aircraft's daily flight logs from 1 February 2018 to 2 March 2018. This included 10 flight logs from 1–13 February (prior to the wingtip damage event) and four flight logs from 27 February to 2 March (following the wingtip damage repair). A small number of maintenance and training/check flights were excluded, and the last sector (occurrence flight) on 2 March was excluded.

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6 For demonstrative purposes, the ATSB utilised a figure of 600 lb per hour as a block fuel consumption rate. This was based on the average planned fuel consumptions from the occurrence flight plan, taking into account climb and cruise segments.

Summary results are provided in Table 6. Based on the review, the following was noted:

- The average recorded fuel burn rate up to 13 February was 533 lb/hour and the average rate after 13 February was 465 lb/hour (Table 6). This difference of 68 lb/hour equated to a reduction in fuel burn rate of 13 per cent. If this rate was applied over the total flight time in the period after 13 February (13.0 hours), this equated to about 880 lb less fuel burned than expected.
- The recorded fuel burn rate on each sector varied significantly. As would be expected, the rate was generally shorter as the length of the flight increased.[7] The average flight duration up to 13 February was 58 minutes and the average after 13 February was 68 minutes.
- To ensure the best comparison, a sample of flight logs was chosen from the period 1–13 February that matched the four flight logs from after 13 February (in terms of the destinations and/or the durations of the sectors). Where there were multiple logs that matched, the data was averaged. This resulted in a matched-sample average fuel burn rate during the period 1–13 February of 509 lb/hour (Table 6). This difference of 44 lb/hour equated to a reduction in fuel burn rate of 9 per cent. If this rate was applied over the total flight time in the period after 13 February, this equated to about 570 lb less fuel burned than expected.
- For each of the four flight logs after 13 February, the matched sample had a higher fuel burn rate (ranging from 7 to 12 per cent). The rates were also lower than another matched sample from flights in October 2020.

Table 7: Flight times and fuel burn rates for periods before and after 13 February 2018

Sample	Sectors	Flight time (minutes)	Flight time per sector (minutes/sector)	Fuel burn rate (lb/hour)
1–13 Feb: all normal flights	32	1,844	57.6	533
1–13 Feb: matched sample	11	754	68.5	509
27 Feb to 2 Mar: all normal flights	11	753	68.5	465

With regards to specific flights:

- For flights of the same duration, there was a notable variance in recorded fuel burns (both before and after 13 February), which increased the difficulty of identifying patterns in recorded fuel burns for specific sectors. However, the most notable outlier was the third sector on 2 March, when the fuel burn was substantially lower than the average for similar flights both before and after 13 February.
- Estimated fuel burns for all the flights were derived from using the fuel planning figures from 1 and 2 March and the recorded flight times for each sector. Based on this approach, a small number of flights during 1–13 February had recorded fuel burns significantly lower than expected fuel burns, and there was no obvious pattern in these flights. For flights after 13 February, the last 3 of the 4 sectors on 27 February, the last of the 2 sectors on 28 February, and the first of the 2 sectors on 1 March had recorded fuel burns significantly lower than the expected fuel burns (ranging from 21 to 29 per cent lower).
- As already noted, the fuel burn was substantially higher that the flight-planned burn for the third sector on 2 March and a similar result would have occurred for the fourth sector had the flight been completed successfully.

Operator fuel usage monitoring

A requirement to monitor fuel usage existed within FO1, which stated:

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7 The fuel burn during start and taxi can be similar regardless of flight duration, and there is a higher fuel burn rate during climb than during cruise. Actual fuel burns prior to and after each flight were not known and not able to be subtracted.

> The FOM monitors the actual fuel burn data and makes adjustment to the Champagne Flight Planning Software where necessary.

Although FO1 did not state how this was to be achieved, nor at what frequency, the chief pilot explained that they undertook this duty on a monthly basis. The chief pilot explained that this was a broad review of fuel usage but on a few occasions the review required follow up maintenance to confirm usage data.

There were no fuel usage anomalies recorded or reported from the flights after 13 February until the occurrence flight. The exact date on which the last fuel usage monitoring was conducted for VH-LBY could not be determined.

Other fuel management occurrences

AO-2007-017[8]

On 26 June 2007 at 0639 Western Standard Time, an Empresa Brasileira de Aeronáutica S.A. EMB-120ER aircraft, registered VH-XUE and operated by Skippers Aviation, departed Perth on a contracted passenger charter flight to Jundee Airstrip (Western Australia). On final approach to Jundee Airstrip, the aircraft drifted left of the runway centreline. As the flight crew initiated a go-around, the aircraft aggressively rolled and yawed left, causing the crew control difficulties.

The left engine had sustained a total power loss following fuel starvation, because the left fuel tank was empty. The left fuel quantity gauge was indicating 300 kg at the time. A fuel probe in the left fuel tank had failed, which resulted in the left fuel quantity indicator over reading. The aircraft was not fitted with a fuel low level warning system (nor was it required to be).

The investigation concluded that the practices used by the operator’s EMB-120 pilots for measuring and logging of fuel quantity were inconsistent. The aircraft was fitted with dripless measuring sticks and a fuel totaliser, but these devices were not being effectively used for cross-checking the fuel quantity gauge indications and aircraft were rarely refuelled to a known quantity. Fuel quantity cross-checks largely relied on checking the indicated quantity after refuelling with the calculated quantity (residual plus refuel quantity), with significant discrepancies in this amount not always being adequately explained.

Following the occurrence, the operator revised its procedures, which included using a dripless measuring stick each day and improving its recording practices and the checking of flight logs.

AO-2007-049[9]

On 18 October 2007, the pilot of a Cessna C404 Titan aircraft, registered VH-TMP, was conducting a charter flight from Adelaide Airport to Parafield Airport, Beverley Airstrip, and return to Adelaide (South Australia). 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 the associated fuel quantity gauge was indicating 150 lb (95 L). 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 (FQIS) was carried out

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8 ATSB Investigation AO-2007-017, *Fuel starvation Jundee Airstrip, WA – 26 June 2007 VH-XUE Empresa Brasileira de Aeronáutica S.A., EMB-120ER*

9 ATSB Investigation AO-2007-049, *Engine power loss (fuel tank exhaustion) 102 km north Adelaide, SA 18 October 2007 VH-TMP Cessna Aircraft Company C404*

and, during that process, the left and right signal conditioners were found to be unreliable and were replaced or repaired.

The investigation concluded that the operator's pre-flight fuel quantity measurement procedures were predicated solely on FQIS readings, with no provision for regular independent checks of fuel quantity. Problems with the accuracy of recording details on the flight logs was also identified. 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.

Safety issues identified

During the AO-2007-017 investigation, the ATSB issued safety advisory notice (SAN) AO-2007-017-SAN-013, which stated:

> 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.

Investigations AO-2007-017 and AO-2007-049 also identified safety issues concerning regulatory guidance for fuel quantity measurement as follows:

- Regulatory guidance regarding the measurement of fuel quantity before flight lacked clarity and appropriate emphasis and did not ensure that the fuel quantity measurement procedures used by operators included two totally independent methods. (AO-2007-017)
- 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. (AO-2007-049)

In 2016, the ATSB started an investigation into the fuel exhaustion and subsequent collision with terrain of a McDonnell Douglas Corporation 369 helicopter.[10] The final report stated:

> A search of the ATSB database for the period from 2003 to 2017 found 76 reports of 'fuel exhaustion', which included four accidents with fatalities, three accidents with serious injuries and two accidents with minor injuries, with some accident reports including more than one injury classification. The operations represented in the occurrences included sport aviation, private, aerial work, training, charter and air transport–low capacity. From the 76 occurrences, 26 were for commercial operations, and all reports were for aircraft not greater than 5,700 kg MTOW…
>
> The presence of commercial operators indicated that the applicable fuel regulations may be less than adequate, and shows that commercial operators may not implement effective fuel policies and training to prevent fuel exhaustion events.

The final report also included the following safety issue:

> The current legislation does not require commercial operators of aircraft not greater than 5,700 kg maximum take-off weight to provide instructions and procedures for crosschecking the quantity of fuel on board before and/or during flight. This increases the risk that operators in this category will not implement effective fuel policies and training to prevent fuel exhaustion events…

It was noted that CASA had commenced a review of regulatory requirements and guidance in 2016 in response to the safety issues:

> The Civil Aviation Safety Authority (CASA) has started project CD 1508OS, which was published on their website 20 January 2016. The project contains the proposed changes to Civil Aviation Regulation (CAR) 234, the issuance of a CAR 234 Legislative Instrument, and revised Civil Aviation

[10] ATSB investigation AO-2016-078, Fuel exhaustion and collision with terrain involving McDonnell Douglas Corporation 369, VH-PLY, 36 km NW Hawker, South Australia, on 17 July 2016

Advisory Publication (CAAP) 234-1(2): Guidelines for aircraft fuel requirements, CAAP 215-1(2): Guide to the preparation of Operations Manuals, Volume 2, appendix B9: Fuel management, and the Air Operator's Certificate (AOC) handbook Volume 2 – Flying Operations – Section 6: Fuel policy and related requirements. Once made into law, the amendments to the existing CAR 234 will commence on 8 November 2018.

A key outcome of the amendment is providing clarity about the regulatory requirements that apply to fuel by having those requirements set out in a legislative instrument. This overcomes difficulties with the previous arrangement, where requirements were set out in guidance material 'called up' by regulation, in that the requirements were often not readily recognised as having the force of law. CASA 29/18 – Civil Aviation (Fuel Requirements) Instrument 2018 sets out the legislative requirements that:

- specify the matters that must be referenced by the operator and the pilot in command in determining the quantity of usable fuel required for a flight
- specify the quantities required to commence a flight and also to continue a flight
- require that inflight fuel management be conducted, and
- specify the contingencies to which additional fuel calculation must be applied.

To assist industry and CASA understanding of the changes to the fuel requirements in legislation, the amendment to guidance material CAAP 234-1(2) will be published. It will contain enhanced guidance on the generally applicable fuel related areas of the legislative instrument. CAAP 234-1(2) will differentiate between requirements and guidance.

The updated regulatory material was published November 2018 (8 months after this occurrence).

Emergency procedures

The emergency landing area was a single carriageway road with two-way traffic. The road was only just sufficiently wide for the aircraft to land on (Figure 5). For comparison, the runway at Broome Airport is 45 m wide and other aerodromes the operator used C441 aircraft normally had runways of 30–45 m wide (and occasionally a narrow runway of 23 m wide). The wingspan of a C441 is about 15 m.

Figure 5: The emergency landing area

Source: Broome Advertiser

The operator's aircrew emergency procedures manual highlighted the risks to an individual during an emergency landing and included the following detail on the brace for impact position:

> Passengers must be encouraged to correctly fasten their seat belts and practice the brace for impact position in a prepared emergency landing.
>
> If a seat belt is not worn in an impact, the body continues moving forward at the same speed as the aircraft was moving before the impact.
>
> Even with a seat belt fastened, the deceleration causes the head and limbs to fly forward until they make contact with something stopping their movement, (that is, the seat or bulkhead in front). In most cases, this leads to traumatic injury preventing movement away from the aircraft and/or death. The brace for impact position is a compact position allowing the body to move very little during the impact and post impact deceleration. This position should increase the chance for survival...
>
> The brace for impact position must be held until the aircraft completely stops.

In the case of the 2 March 2018 forced landing on the highway, the pilot did not instruct the passengers to adopt the brace-for-impact position.

Safety analysis

Introduction

The Cessna 441 (C441) aircraft departed on a scheduled passenger flight from Fitzroy Crossing to Broome without sufficient fuel to reach the destination. This was not identified by the pilot and subsequently the fuel tanks were exhausted and both engines lost power.

Although the weather was suitable for visual flight rules and the aircraft was within range of a highway, the pilot was faced with a dual engine failure, a situation that is not usually addressed in multi-engine training and checking. The pilot successfully landed the aircraft on the nearby highway and there were no passenger injuries or aircraft damage.

A fuel exhaustion event on scheduled passenger transport flight is a serious incident. Accordingly, this analysis will discuss the accuracy of the fuel quantity indication system (FQIS), the procedures and practices used to check the fuel quality, the procedures and practices used to check the fuel quantity, and the effectiveness of the fuel low level warning system.

Fuel quantity indication system error

Post-occurrence inspection of the fuel system identified water contamination of the fuel tanks. The presence of water on the probes had a significant effect on probe functionality, resulting in over reading of the fuel quantity in the tanks. The FQIS functioned appropriately after the water was removed.

More specifically, following the engine power losses and forced landing, the fuel quantity gauges indicated 1,120 lb. On return to Broome, having drained all usable fuel on board, the gauges indicated 740 lb. In addition, prior to the occurrence flight, the gauges indicated about 1,310 lb (after applying fuel calibration card corrections) when there was only about 420 lb of usable fuel on board.

The source of the water contamination could not be definitively determined. It is likely to have occurred at some point during the period 13–26 February, when wingtip damage was being repaired. A review of the aircraft’s flight logs identified that recorded fuel burns after this period were consistently lower than fuel burns prior to this period.

Based on the available information, the water was unlikely to have been introducing during refuelling. It is possible that it was associated with the aircraft sitting in a humid environment for a period of time and, because the tanks were close to empty (about 590 lb total fuel on board), condensation forming in the tank.

It is reasonable to presume that the influence of the water on the fuel quantity gauge indications increased over time. If there had been a substantial step change in the gauge indications (more than the fuel added), then it is likely that this would have been detected when the aircraft undertook a test flight following the repair. However, there was no indication in the flight logs of a substantial discrepancy.

Nevertheless, it is also unlikely that the amount of over reading increased in a linear manner over time. The limited information available suggested that there may have been larger increases in over reading when the fuel levels were lower, which would be consistent with less water on the probes when the fuel tanks were at higher levels.

Fuel quality management

Considering the level of water contamination found after the occurrence, and the length of time the water had been in the aircraft, it is unclear why this problem had not been detected through fuel quality testing. Fuel drains were required to be conducted by the operator’s pilots prior to the first sector each day and following each refuel. This should have resulted in at least nine inspections prior to the occurrence flight. However, none of these checks appeared to identify an unusual amount of water.

The pilot reported conducting a fuel drain during prior to the first sector on the day of the occurrence but did not report observing water in the fuel and did not test the sample using the water detection capsule. A final opportunity to detect contamination was available following aircraft refuelling. However, the pilot did not conduct a fuel drain and chemical test following the refuel, which reduced the opportunity to detect contamination.

At the time of the occurrence, fuel in the hopper area of each fuel tank of VH-LBY could not be sampled because the standard fuel drains were located elsewhere (including the low points of the fuel system). Although fuel was able to circulate throughout the tank, the hopper was designed to limit the outflow of fuel. As such, it is possible that some fuel samples were not representative of the fuel in the hopper. Nonetheless, not all of the water contamination was found to be in the hopper tanks.

Fuel quantity management

Overview

The operator had several processes in place to check the functionality of the FQIS on its C441 fleet, including several methods that pilots could use to cross-check the fuel quantity gauge indications with other sources.

One reliable and independent method of cross-checking fuel quantity gauge indications is to use some form of direct reading of the fuel quantity; however, no direct reading mechanisms were available for the C441.

Another reliable and independent method of cross-checking fuel quantity gauge indications is to fill the tanks to capacity or to empty the tanks of usable fuel and add a known quantity of fuel. Due to the nature of the operator's flights, its C441 aircraft were rarely refuelled to capacity during normal operations. However, the operator required each of its C441's fuel tanks to be refuelled to a known quantity (500 lb per side) every 150 flight hours. Unfortunately, the last check on VH-LBY was done 66 hours prior to the occurrence (and 53 hours prior to the likely start of the FQIS error).

The operator's fuel management procedures were also supported by regular maintenance inspections to confirm FQIS accuracy. However, in this instance the error had developed in between maintenance inspections.

Ultimately, detecting the FQIS error in this case relied on the operator's procedures for cross-checking fuel quantity gauge indications, and its pilots use of those procedures.

Check of indicated versus calculated fuel quantities prior to a flight

The primary cross-check method for the C441 fleet specified in the operator's manuals was a check of the indicated fuel quantity against the calculated fuel quantity (or residual fuel, indicated at the end of the previous flight, plus the refuel amount). This is a relatively simple and commonly used cross-check method in the aviation industry, which can only be used when fuel is added.

However, this cross-check method is not an independent check of the FQIS. It is simply checking the difference in the fuel quantity gauges after fuel has been added. In other words, the check is self-referencing the same source of information. Although it may detect some types of FQIS error, it is generally not adequate to detect gradually developing errors in gauge indications.

The extent to which the method could have been effective on this occasion was difficult to determine because of limitations in the way the C441 pilots were recording information on the flight logs. The operator required pilots to confirm that the difference between the residual quantity recorded on previous flight log and the indicated quantity prior to flight was within 5 per cent of higher amount. After refuelling, pilots were to confirm the difference between the indicated quantity and calculated quantity (sum of residual/indicated plus added fuel) was within 5 per cent. These comparison checks were not recorded, nor required to be recorded. Consequently, pilots were not able to identify any differences or trends in indicated readings over time, or in the indicated versus calculated readings over time.

On the day of the occurrence, the pilot refuelled the aircraft prior to the first sector. The pilot reported that the fuel quantity gauge indications were verified as required before and after refuelling. The residual fuel figure from the previous day was within comparison check limits and therefore carried forward on the flight log, facilitating the continuity of the FQIS error.

Check of indicated versus computed or planned fuel quantities

The operator's *Flight Operations Manual* required pilots to compare the indicated fuel with the computed fuel on board (although the manual mistakenly used the word 'calculated' instead of 'computed'). This meant comparing the indicated fuel quantity at the end of a flight with a value based on the indicated quantity at the beginning of the flight and the computed fuel burn during the flight.

In addition, during cruise, C441 pilots were required to compute the destination fuel using current or average groundspeed and current fuel flow, but there was no requirement for this to be recorded. The pilot of the occurrence flight did not appear to use this method, and the extent to which other pilots were using it was unclear.

The operator's pilots did report that they regularly compared flight-planned fuel burns with recorded fuel burns (based on fuel quantity gauge indications) after each sector. The pilot of the occurrence flight reported that, following each of the first two sectors that day, there was no notable discrepancy between the recorded fuel burns and the flight-planned fuel burns. However, the recorded fuel burn for the third sector based on fuel quantity gauge indications was substantially lower than the expected fuel burn based on the flight plan. Even so, in the absence of relevant information from other sources, the pilot rationalised that this discrepancy was not significant, given that the indicated fuel quantity was significantly more than the minimum required for the flight.

The ATSB noted that there appeared to be significant variability in recorded fuel burns and the associated fuel burn rates, both before and after the FQIS error started. The exact reasons for the size of this variability are not clear, but its effect would be to make it difficult for a pilot to detect when a discrepancy was meaningful. The fuel quantity indications on the aircraft also needed significant corrections from the fuel calibration card, which complicated any calculations. Nevertheless, in the case of the sector prior to the occurrence flight, the discrepancy was substantial and should have prompted further inquiries by the pilot about the fuel quantity indications.

At that stage, the pilot had limited other options available to verify the amount of fuel on board. However, they could have discussed options with a senior pilot or elected to add more fuel.

Check of indicated quantity versus fuel totaliser reading at end of a flight

The operator's procedures required that C441 pilots enter the indicated fuel on board into the Garmin GNS 530 system at the beginning of each sector, and then compare the fuel quantity gauge indications with the fuel totaliser indication (of fuel on board) at the end of a sector. In effect, this cross-check method, using an independent source, provided a means of detecting whether there was a change in the reliability of the fuel quantity gauges during a flight (or a longer period).

The operator had not specified a threshold level or 'acceptable amount' for this check. Accordingly, if a pilot followed the procedure, it was unclear what level of difference between the gauge indications and the totaliser indications warranted action.

More problematically, the procedure was not always being used. The pilot of the occurrence flight reported that they did not think it was mandatory, based on observing other pilots, and did not use it themselves. A senior pilot also agreed it may not have been used regularly by other pilots.

If the pilot of the occurrence flight had used the procedure, then it would have identified a significant discrepancy after the third sector on the day of the occurrence. It is also likely to have detected discrepancies on the two sectors they conducted the previous day. In addition, if the method was being regularly used, it is likely that it would have identified discrepancies on some sectors conducted by the operator's pilots on previous days.

Check using the X-FER PUMP FAIL annunciators

The operator's procedures also required that C441 pilots, prior to engine shutdown after a flight, switch the fuel boost pumps off to check whether either of the X-FER PUMP FAIL annunciators would illuminate. If they did, then this meant there was less than 580 lb in that tank. This check was coarse in nature, and would only detect a problem in some cases, depending on the indicated fuel quantity.

Although the procedure was clearly stated in the operator's operations manual, the pilot of the occurrence flight reported not being aware of this requirement and so was not conducting these checks. Post-occurrence fuel quantity calculations suggests that this gross error check would likely have identified the indication error on arrival at Fitzroy Crossing after third sector and possibly at Halls Creek after the second sector on the day of the occurrence. It is likely it would also have detected a problem after the last sector the previous day.

Summary

In summary, the operator had specified multiple methods for its C441 pilots to use to cross-check fuel quantity indications. However, there were limitations with the design, definition and/or application of these methods. In particular, the primary method used (indicated versus calculated) was self-referencing in nature, and not able to detect gradual changes in the reliability of fuel quantity gauge indications. In addition, the operator's pilots did not record sufficient information on flight logs to enable trends or patterns in fuel quantity gauge indications to be effectively identified, and the pilots did not routinely cross-check fuel gauge indications with the information from the independent fuel totaliser.

In the case of the occurrence flight, the pilot had not been applying two of the operator's cross-check methods (that is, the use of the fuel totaliser and the use of the X-FER PUMP FAIL annunciators). Using either or both of these methods would have identified discrepancies, which should have resulted in the pilot concluding that the FQIS was not functioning correctly.

Low fuel level warning

Illumination of the L/R FUEL LEVEL LOW annunciators on the C441 indicated that 150 to 250 lb remained in the associated tank. This would be approximately 30 to 50 minutes flight time for each engine. The annunciators on VH-LBY were found to be serviceable during post-occurrence inspections and were illuminating at approximately 160 lb remaining in each tank, or roughly 30 minutes flight time.

The fuel level low annunciators are independent of the FQIS and of each other (left and right). Landing as soon as possible would be the most conservative response to a fuel level low annunciation.

Although the pilot reported that the annunciators illuminated in the 10 to 15 minutes prior to the first engine failure, analysis suggests it likely that the annunciators had been illuminated well prior, sometime during the climb. In that timeframe, the aircraft was within range of suitable airports to which a diversion could have been effected.

The pilot considered the FQIS to be reliable but based on experience did not trust the annunciators. As such, the pilot believed there was sufficient fuel on board and continued to Broome and disregarded the fuel level low annunciations. Overall, the pilot's response to the various fuel system annunciations was consistent with confirmation bias, or a tendency for a person to seek information that confirms or supports their hypotheses or beliefs, and discounting or not seeking information that contradicts those hypotheses or beliefs (Wickens and others 2013). This was likely influenced by not completing all the required fuel quantity cross-checks during previous sectors, resulting in the pilot having little information available (other than the annunciators) to doubt the fuel quantity indications.

Briefing prior to an emergency landing

During the emergency landing, the pilot did not instruct the passengers to adopt the brace-for-impact position.

In a recent cabin safety bulletin, the Civil Aviation Safety Authority (2020) advised:

> Passenger survival rates are improved when they are informed about the correct use of equipment and the actions they should take in the event of an emergency, such as how to assume an appropriate brace for impact position.
>
> The brace position has been determined to be the most effective protective position for passengers and crew to adopt to mitigate the potential for injury during impact.
>
> The “brace for impact” position is an action where a person pre-positions his/her body against whatever he/she is most likely to be thrown against, and which may significantly reduce injuries sustained.
>
> The brace position serves two purposes:
>
> a. it reduces flailing by having the forward-facing occupant flex, bend, or lean forward over his/her legs in some manner
>
> b. it reduces secondary-impact injuries by pre-positioning the body, predominantly the head, against the surface that it would otherwise strike during that secondary impact, thus reducing the momentum of the head and other parts of the body.

The highway that the aircraft landed on was not specifically designed for aircraft operations but provided a more suitable surface in comparison to unprepared land nearby. Nevertheless, any emergency landing increases the potential for further complications. In this case there was some increase in risk compared to landing on a prepared runway or airstrip, including due to the potential for road traffic to be on the highway, and particularly when no engine power was available.

In summary, because the passengers did not adopt the brace-for-impact position, this increased the risk of injury during the emergency landing. It is likely that the pilot was experiencing a high workload during the approach and emergency landing, but pilots in such situations should ensure, when time is available, that passengers are appropriately briefed for any emergency landing and instructed to brace for impact.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include 'contributing factors' and 'other factors that increased risk' (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition 'other findings' may be included to provide important information about topics other than safety factors.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the fuel exhaustion and forced landing involving Cessna 441, VH-LBY, 39 km east-south-east of Broome Airport, Western Australia on 2 March 2018.

Contributing factors

- Due to water contamination in the fuel tanks, the aircraft's fuel quantity gauges were significantly over reading on the day of the occurrence and on previous days. This ultimately resulted in the aircraft departing for a flight without sufficient fuel to reach its destination.
- **Although the operator had specified multiple methods of cross-checking fuel quantity gauge indications for its C441 fleet, there were limitations in the design, definition and/or application of these methods. These included:**
  - **The primary method used (indicated versus calculated fuel) was self-referencing in nature, and not able to detect gradual changes in the reliability of fuel quantity gauge indications.**
  - **Pilots did not record (and were not required to record) sufficient information on flight logs to enable trends or patterns in fuel quantity gauge indications to be effectively identified.**
  - **Pilots did not routinely cross-check information from fuel quantity gauge indications with information from the independent fuel totaliser. (Safety issue)**
- Although the pilot routinely compared indicated versus calculated fuel quantities, and indicated versus flight-planned fuel quantities, the pilot did not routinely conduct two other methods stated in the operator's procedures for cross-checking fuel quantity gauge indications.
- The recorded fuel burn for the previous (third) sector based on fuel quantity gauge indications was substantially lower than the expected fuel burn based on the flight plan. However, in the absence of relevant information from other sources, the pilot did not regard this as being an indication of a fuel quantity indicating system problem.
- The pilot disregarded the L/R FUEL LEVEL LOW annunciators, which likely illuminated approximately 30 minutes before the fuel was exhausted in each tank, and when the aircraft was still within range of suitable alternative airports. The pilot relied on the (erroneous) fuel quantity indications and continued to Broome until the engines lost power, at which point a forced landing on a highway was the only remaining option.

Other factors that increased risk

- Although the pilot stated that they conducted a fuel quality check prior to the first flight of the day, they did not conduct another check after refuelling (as required by the operator's procedures), increasing the risk of undetected fuel contamination.
- The pilot did not instruct the passengers to brace for impact prior to the emergency landing.

Other findings

- Following the complete engine power loss, the pilot assessed the aircraft would not reach Broome Airport, identified a suitable landing area, and conducted a forced landing without injury to the passengers or damage to the aircraft.

Safety issues and actions

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues. The ATSB expects relevant organisations will address all safety issues an investigation identifies.

Depending on the level of risk of a safety issue, the extent of corrective action taken by the relevant organisation(s), or the desirability of directing a broad safety message to the aviation industry, the ATSB may issue a formal safety recommendation or safety advisory notice as part of the final report.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

The initial public version of these safety issues and actions are provided separately on the ATSB website, to facilitate monitoring by interested parties. Where relevant, the safety issues and actions will be updated on the ATSB website as further information about safety action comes to hand.

Fuel quantity assessment methods

Safety issue description

Although the operator had specified multiple methods of cross-checking fuel quantity gauge indications for its C441 fleet, there were limitations in the design, definition and/or application of these methods. These included:

- The primary method used (indicated versus calculated fuel) was self-referencing in nature, and not able to detect gradual changes in the reliability of fuel quantity gauge indications.
- Pilots did not record (and were not required to record) sufficient information on flight logs to enable trends or patterns in fuel quantity gauge indications to be effectively identified.
- Pilots did not routinely cross-check information from fuel quantity gauge indications with information from the independent fuel totaliser.

Issue number:	AO-2018-019-SI-01
Issue owner:	Skippers Aviation
Transport function:	Aviation: Air transport
Current issue status:	Closed-Adequately addressed
Issue status justification:	The ATSB is satisfied that Skippers' amendments to, and increased focus on, fuel management policy and procedures addresses the safety issue risk with regard to the limitations of its fuel quantity assessment methods.

Proactive safety action taken by Skippers Aviation

Action number:	AO-2018-019-NSA-067
Action organisation:	Skippers Aviation
Action status:	Closed

During the investigation, Skippers Aviation advised that:

- A company memorandum was issued directing all Conquest pilots to ensure that the minimum fuel to be uplifted was the total minimum as calculated by flight plan. The only exception was if this quantity would exceed full tanks or if a fuel quantity gauge calibration was conducted. This was an interim measure until the circumstances of the occurrence were ascertained. This was removed following confirmation of fuel exhaustion and no other mechanical cause.
- The fuel quantity comparison check frequency was increased to every 30 +/- 7 days. The check required fuel tanks to be filled to capacity to enable a comparison check of gauge

indications against a known quantity. The gauges were required to indicate with 5% of the known capacity of the tanks to pass the check.

- Weekly reporting requirements (from Broome base to Perth headquarters) were implemented. This included various operational matters to provide increased oversight of Broome operations.
- The Broome Senior base pilot increased surveillance of Broome line pilots.
- Flight operations increased audits of Broome operations to monitor standards and compliance.
- Fuel usage record keeping requirements were amended. Indicated and calculated fuel quantities were to be recorded after each landing and each refuel.
- A tolerance of 100 lb was introduced for pilots to reference when comparing corrected indicated quantity to quantity derived from the totaliser figures.
- Following consultation with relevant authorities, additional fuel drains were installed in the hopper tanks to enable fuel quality testing if fuel within the hoppers.

In April 2021, during the directly involved party process, Skippers confirmed that the actions previously advised had taken place (or were continuing). In addition, Skippers advised that, during line-oriented flight training there is an increased focus on:

- The Gross Error Check (580 lbs transfer pump fail annunciator) after shutdown and prior to start up with fuel boost pumps off.
- Input of Fuel on Board figure in Garmin 530 and cross checking against fuel gauges after each sector to compare burn figure.
- Fuel System knowledge in general but Fuel Level Low and Transfer Pump Fail annunciators in particular.
- Fuel quality checking.
- A fuel emergency scenario on every flight.

Safety action not associated with an identified safety issue

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. The ATSB has been advised of the following proactive safety action in response to this occurrence.

Safety action by Skippers Aviation

In April 2021, during the directly involved party process, Skippers Aviation advised that:

- There was a strong focus on Broome as an operating base, with the chief pilot now visiting multiple times per year, and regular audits being carried out.
- Communication between Broome and Perth had been enhanced.
- Emergency procedure training now emphasised brace commands.

Safety action by the Civil Aviation Safety Authority

In the 18 months following the occurrence, the Civil Aviation Safety Authority (CASA) conducted additional surveillance of Skippers Aviation through a series of visits, interviews and observation flights. Surveillance encompassed Airworthiness, Flight Operations, Cabin Safety, Ground Operations and Safety Systems. CASA noted that the operator had demonstrated improvements in the operations of its Broome base and recommended returning to a normal oversight level. No findings were issued on completion of the surveillance.

General details

Occurrence details

Date and time:	2 March 2018 16:20 WST	
Occurrence category:	Serious incident	
Primary occurrence type:	Fuel exhaustion	
Location:	39 km east-south-east of Broome Aerodrome, Western Australia	
	Latitude: 18º 2.4300' S	Longitude: 122º 35.0220' E

Aircraft details

Manufacturer and model:	Cessna Aircraft Company 441	
Registration:	VH-LBY	
Operator:	Skippers Aviation Pty Ltd	
Serial number:	4410023	
Type of operation:	Air Transport Low Capacity - Passenger	
Activity:	Commercial air transport - Scheduled, domestic	
Departure:	Fitzroy Crossing, Western Australia	
Destination:	Broome, Western Australia	
Persons on board:	Crew – 1	Passengers – 9
Injuries:	Crew – 0	Passengers – 0
Aircraft damage:	None	

Sources and submissions

Sources of information

The sources of information during the investigation included:

- the pilot of the occurrence flight
- the operator (Skippers Aviation Pty Ltd)
- the Civil Aviation Safety Authority
- Airservices Australia.

References

Civil Aviation Safety Authority 2020, *Cabin Safety Bulletin No.6 – Brace positions*, available from www.casa.gov.au.

Wickens CD, Hollands JG, Banbury S & Parasuraman R 2013, *Engineering psychology and human performance*, 4th edition, Pearson Boston, MA.

Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the following directly involved parties:

- the pilot of the occurrence flight
- the operator (Skippers Aviation Pty Ltd)
- the Civil Aviation Safety Authority
- Textron Aviation (Cessna).

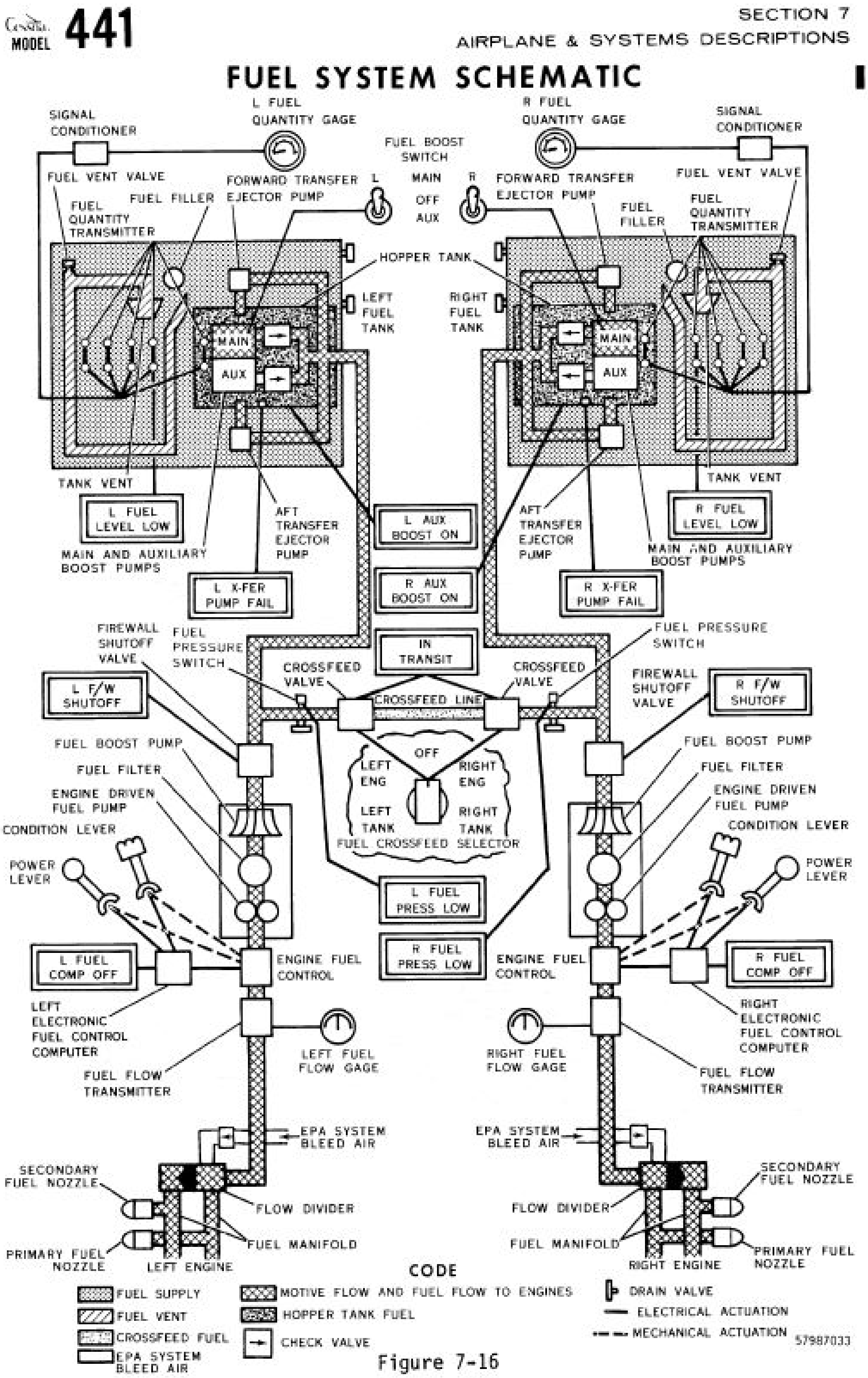
Submissions were received from:

- the pilot of the occurrence flight
- the operator (Skippers Aviation Pty Ltd)
- the Civil Aviation Safety Authority
- Textron Aviation (Cessna).

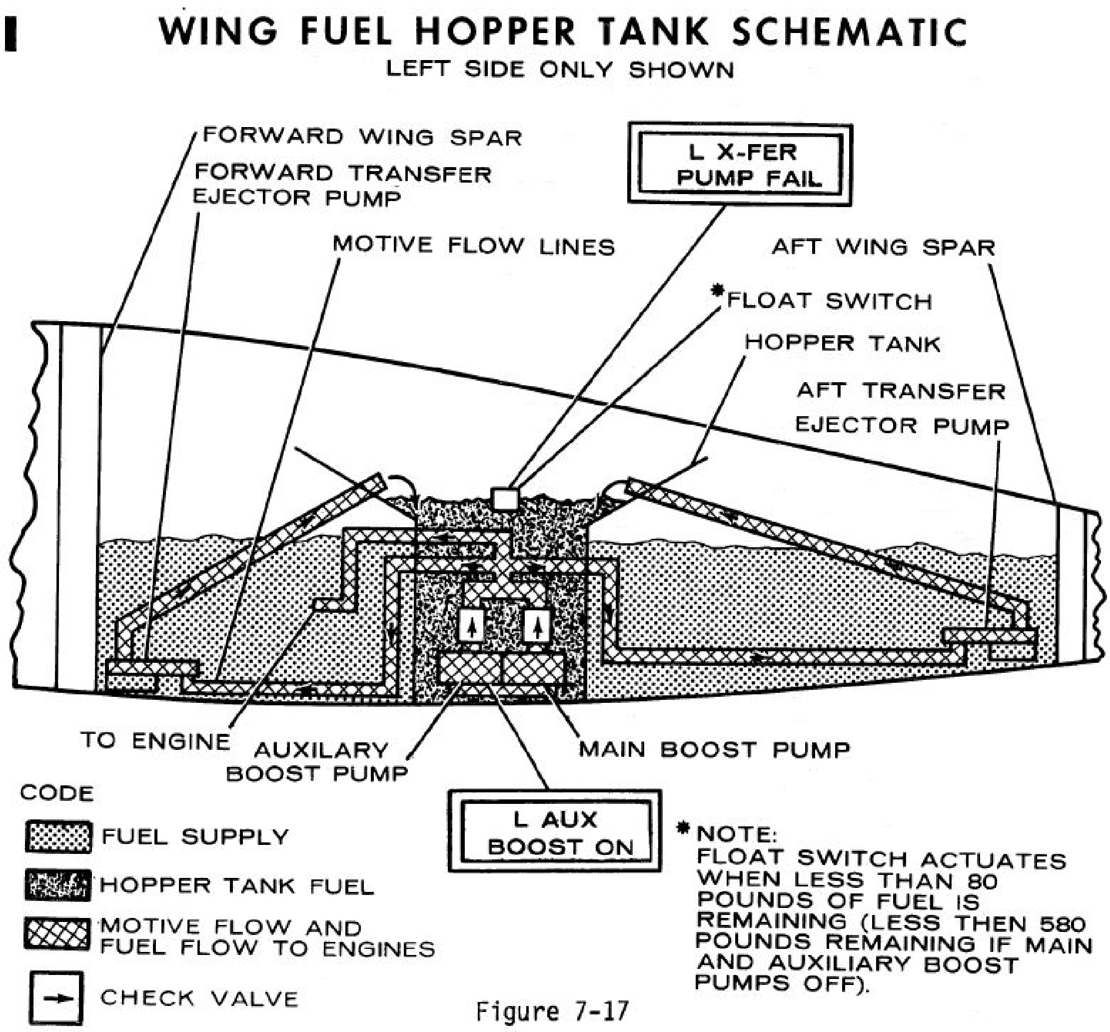
The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Appendices

Appendix A – Fuel system schematics



Source: C441 Pilot's Operating Handbook



Source: C441 Pilot's Operating Handbook

Appendix B – Fuel system testing procedures

Skippers Aviation Pty Ltd
FLIGHT OPERATIONS MANUAL **Section 8**
Fuel Policy and Planning

8.8 Fuel System Testing

Unless conducted as part of the aircraft's Approved System of Maintenance or as directed by CASA, the PIC shall ensure that a fuel system drain is taken before the first flight of the day and on completion of each re-fuelling. This fuel sample, taken with the aircraft on a reasonably level surface, will then be tested for the presence of water or other contaminants.

When draining fuel from aircraft wings in windy conditions, it is highly probable that some fuel may be blown away from the drain receptacle if sufficient care is not taken.

To reduce the possibility of injuring yourself or others in the area, or causing damage by spilling fuel on baggage or other equipment:-

- Only drain the fuel when wearing the correct Personal Protective Equipment, goggles, gloves etc,
- Position yourself upwind of the drain prior to draining the fuel,
- Ensure that no other personnel are in the vicinity, particularly down-wind of the fuel drain, in case some of the fuel is blown away from the receptacle,
- Ensure that baggage or other equipment that might be affected by a fuel spill is not in the immediate area, particularly downwind of the drain activity,
- Should you not feel confident that the drain can be completed without causing a spray of fuel that would affect yourself or others, obtain maintenance assistance.

The Fuel System must be deemed as free of water and contaminants prior to initiating a flight:-

- Drain a small amount of fuel from the aircraft's fuel system or bulk fuel storage facility collection/drain points into a clear transparent container.
- Visually check for any demarcation of fluids indicating water contamination. If water is evident, continue draining until water is no longer visible.
- If water is not evident, then draw a 5 ml sample into the syringe through a water detecting capsule. The water detecting capsule must come from a water detector container that has a use by date stamped on it. The date can sometimes be stamped on the base of the container;
- If a distinct green colour is obtained, the fuel is to be considered contaminated and is to be rejected and the aircraft is not to be flown until the contaminated fuel is removed from the aircraft

The waste fuel drum is located outside hangar one. The waste fuel drum is painted blue and has a steel cover over the opening. This is to prevent contamination of other drums with "waste fuel". Crew are to dispose of fuel samples in the waste fuel drum only.

Source: Skippers Aviation Flight Operations Manual

Australian Transport Safety Bureau

About the ATSB

The ATSB is an independent Commonwealth Government statutory agency. It is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's purpose is to improve the safety of, and public confidence in, aviation, rail and marine transport through:

- independent investigation of transport accidents and other safety occurrences
- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia, as well as participating in overseas investigations involving Australian-registered aircraft and ships. It prioritises investigations that have the potential to deliver the greatest public benefit through improvements to transport safety.

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

Purpose of safety investigations

The objective of a safety investigation is to enhance transport safety. This is done through:

- identifying safety issues and facilitating safety action to address those issues
- providing information about occurrences and their associated safety factors to facilitate learning within the transport industry.

It is not a function of the ATSB to apportion blame or provide a means for determining liability. At the same time, 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. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Terminology

An explanation of terminology used in ATSB investigation reports is available on the ATSB website. This includes terms such as occurrence, contributing factor, other factor that increased risk, and safety issue.