Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation
AO-2010-059
Final

Fuel starvation
Mordialloc, Victoria
7 August 2010
VH-KKW, Cessna Aircraft Company 152

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Postal address: PO Box 967, Civic Square ACT 2608
Office: 62 Northbourne Avenue Canberra, Australian Capital Territory 2601
Telephone: 1800 020 616, from overseas +61 2 6257 4150
Accident and incident notification: 1800 011 034 (24 hours)
Facsimile: 02 6247 3117, from overseas +61 2 6247 3117
Email: atsbinfo@atsb.gov.au
Internet: www.atsb.gov.au

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Prepared By

Australian Transport Safety Bureau
PO Box 967, Civic Square ACT 2608 Australia
www.atsb.gov.au

Abstract

At about 1545 Eastern Standard Time on 7 August 2010, while returning to Moorabbin Airport, Victoria after conducting aerial photography work, the pilot of a Cessna Aircraft Company 152 aircraft, registered VH-KKW, experienced a total loss of power that resulted in an emergency landing approximately 200 m short of the airport. The aircraft was significantly damaged. The pilot and single passenger sustained minor injuries.

The investigation found that the pilot, when preparing for the flight, had misread the aircraft's initial fuel state and had subsequently uplifted a lesser quantity of fuel than required for the flight. Although the fuel remaining was greater than the manufacturer's stated unusable quantity, the investigation determined that the accident was the result of fuel starvation. The aircraft was prone to asymmetric fuel delivery allowing one tank to deplete quicker than the other. That action may have led to the aircraft unporting fuel from the low quantity tank during manoeuvring, which allowed air to be drawn into the engine. The investigation identified inconsistencies in the application of the operator's procedures for recording aircraft fuel states.

As a result of the accident, the operator re-designed the flight time and serviceability log to provide clearer application and recording of aircraft pre and post-refuel fuel state. It also advised that it had: introduced a requirement that a formal 'Fuel Required' calculation be made for all flights leaving the circuit or training area, with a copy to be attached to the passenger list/weight and balance data; inspected the seat-locking mechanisms on all club aircraft and reminded all staff/students/members of the importance of ensuring all seats are locked; and reviewed training requirements for engine failure

Pilots are reminded that there is the potential for asymmetric fuel delivery on Cessna 152 aircraft and as well as monitoring fuel use, they need to be alert to such situations, particularly in minimal fuel states.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: 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 that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

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

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine 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.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes appropriate, or to raise general awareness of important safety information in the industry. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

History of the flight

At about 1545 Eastern Standard Time[1], on 7 August 2010, while returning to Moorabbin Airport, Victoria after conducting aerial photography work, the pilot of a Cessna Aircraft Company152 aircraft, registered VH-KKW (KKW), experienced a total loss of power that resulted in an emergency landing approximately 200 m short of the airport. The aircraft was significantly damaged. The pilot and single passenger sustained minor injuries.

The aircraft departed Moorabbin at 1420. During the flight, the pilot conducted a number of sharp, steep bank turns to the right, to facilitate the aerial photography. On returning to the airport, the pilot joined the circuit mid-downwind for runway 35 left. During the pre-landing checks, the pilot noticed that the aircraft fuel gauges were reading very low quantities. On asking the passenger to check the gauges, the passenger confirmed that both the left and right wing fuel gauges were reading zero. Prior to the power loss, the pilot reported experiencing an engine surge and conducting a number of manoeuvres, including rocking the wings in an attempt to maintain fuel delivery to the engine. Shortly after taking these actions, and after turning base and being cleared to land, the engine lost power.

The pilot called the air traffic control tower advising there had been an engine failure and was issued a clearance to land on any runway ahead, '35 left or 04'. The pilot turned toward an adjacent field and maintained a controlled descent with the flaps retracted, until the nose landing gear and main landing gear contacted the roof of a house. That caused the aircraft to pitch down, before impacting the rear yard of the next house and coming to rest between the rear of that house and a swimming pool (Figure 1). The aircraft had been airborne for about 1.5 hours.

Figure 1: Aircraft wreckage

[1] Eastern Standard Time (EST) was Coordinated Universal Time (UTC) + 10 hours.

Injuries to persons

The pilot and single passenger sustained minor injuries as a result of the accident.

Damage to the aircraft

The aircraft was substantially damaged in the accident.

Other damage

The aircraft contacted two houses before impacting the garden of the second house. The first house sustained significant damage to the roof along the ridge line. The second house sustained damage to a flat roofline at the rear of the house and impact damage to the garden and swimming pool handrail.

Pilot details

Licence category	CPL(A)[2] issued 06 March 2008
Aircraft endorsements	Single engine aeroplane < 5,700 kg MTOW[3] class endorsement Manual propeller pitch control Retractable undercarriage PN68
Ratings	Command instrument (multi-engine Aeroplane) issued 01 May 2009 Instructor Grade 3 (Aeroplane) issued 24 September 2009
Total flying hours	Approximately 683
Total C152 flying hours	178
Flying hours (total) in preceding 90 days	82
Flying hours (C152) in preceding 90 days	23
Aviation Medical Certificate category	Class 1 valid to 24 March 2012
Medical certificate conditions	No restrictions

2 Commercial Pilot (Aeroplane) Licence.

3 Maximum take-off weight.

Aircraft information

Manufacturer	Cessna Aircraft Company
Model	152
Serial Number	152-85802
Registration	VH-KKW
Year of manufacture	1983
Certificate of airworthiness	Issue date: 12 April 2005
Certificate of registration	Issue date: 15 February 2005
Maintenance Release	Valid to hours/date 6,391.9 hrs or 23 April 2011
Total airframe hours	6291

The aircraft had been operating under the aerial work, visual flight rule (VFR) category, and was maintained in accordance with Civil Aviation Safety Authority (CASA) schedule 5. The aircraft had a valid maintenance release with no outstanding defects.

Aircraft fuelling

The pilot reported that another Cessna 152 aircraft had been booked for the flight. That aircraft was found to have a full fuel load, which exceeded the weight limit for the trip and as a result, KKW was used. The pilot advised that both of the fuel tanks of KKW were physically checked with the aircraft dipstick prior to the flight and that there was approximately 55 L of fuel on board.

The pilot estimated the flight duration would be about 1.5 hours. The pilot used a 15% variable reserve[4] plus the fixed reserve requirement of 45 minutes flight time, it was determined that a minimum 2.5 hours of fuel was required for the flight. Using the operator's listed consumption burn rate for the aircraft of 23 L per hour (L/hr), the minimum fuel required was 58 L. The pilot reported that the fuel on board had been ascertained from the dip stick to be 55 L. Taking into consideration the fuel on board and that high bank manoeuvres would be carried out, the pilot elected to load an additional 20 L of fuel. The pilot did not want to exceed an 80 L fuel load because of possible weight issues.

The fuel loading was carried out by the refueller in the absence of the pilot who was completing the flight plan (which was a common practice). A review of the fuel receipt confirmed that 20 L had been loaded into the aircraft at 10 L per wing. At about the time the refueller gave the fuel receipt to the pilot, the photographer passenger arrived and discussion of the flight with the pilot commenced. The pilot did not recall if a post-refuel check of the tanks with the dipstick had been carried out. The passenger did not recall seeing the pilot dip the fuel tanks prior to the aircraft start up. A subsequent review by the pilot of closed circuit television

4 While the pilot reported applying the variable reserve in the planning, it was not required for this category of flight.

footage from the flight planning area confirmed the post-refuel check had not been carried out immediately after the refuel.

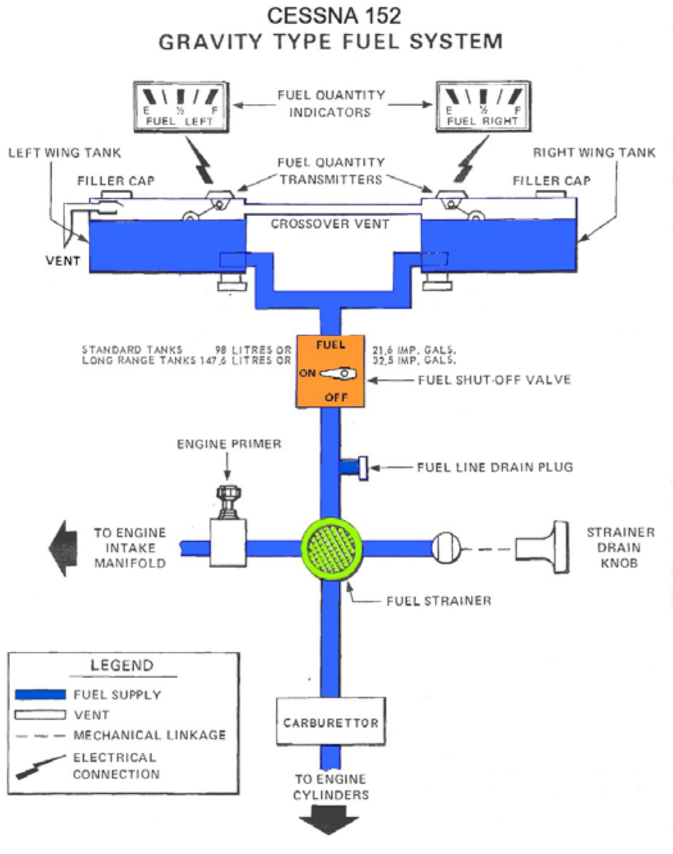
During the run-up checks, the aircraft gauge readings were considered by the pilot to be consistent with the expected 75 L (approximate 55 L on board + 20 L refuel) as calculated. The operator's flight time and serviceability log showed the pilot had entered 80 L as the aircraft's fuel at start up.

Aircraft fuel system

Description and operation

The aircraft fuel system was comprised of two long range (73.9 L) aluminium fuel tanks in the left and right wings. The system was gravity fed with fuel pick-up from the front and rear of each tank. Both tanks supplied fuel to a common line and fuel selector which had an 'ON/OFF' selection. Fuel then passed through a strainer/filter to the carburettor/engine (Figure 2).

Figure 2: Aircraft fuel system



Fuel tank venting

Venting for the left fuel tank was via an external vent tube protruding into the airstream on the left wing adjacent to the wing strut. A flapper valve was incorporated within the tank at the vent line to prevent over board fuel spillage or syphoning during flight. The right tank was vented through the fuel cap. To equalise the head of pressure between both tanks, a crossover vent line was fitted.

The Aircraft Flight Manual (AFM) Section 2 – *Limitations*, stated that the maximum fuel capacity for Cessna 152 aircraft fitted with long range tanks as being 39 US gallons (147 L). Of that, 37.5 US gallons (142.5 L) was deemed usable fuel for all flight conditions with 1.5 US gallons (5.7 L) being unusable fuel.

Section 2 had the following note:

> Due to cross-feeding between fuel tanks, the tanks should be re-topped after each refuelling to ensure maximum capacity.

The Pilot's Operating Handbook (POH) Section 7 – *Airplane & Systems* descriptions further expands on unusable fuel, in that:

> The amount of unusable fuel is relatively small due to the dual outlets at each tank. The maximum unusable fuel quantity, as determined from the most critical flight condition, is about 1.5 gallons [5.7 L] total. This quantity was not exceeded by any reasonable flight condition, including prolonged 30 second full-rudder sideslips in the landing configuration. Takeoffs have not been demonstrated with less than 2 gallons [7.6 L] total fuel (1 gallon [3.9 L] per tank).

Fuel quantity indication

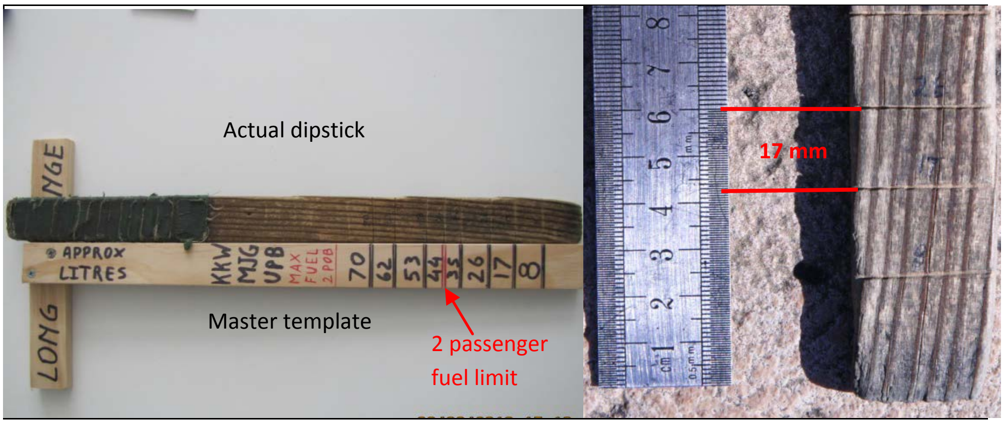
Fuel quantity was indicated by two gauges in the cockpit. Readings were obtained through fuel sender units (fuel quantity transmitters) located at the top of each tank that provided electrical signals to the gauges. The fuel gauges contained two scales: an upper scale in pounds and a lower scale in US gallons (Figure 3). A calibration card decal was installed on the instrument dashboard close to the fuel gauges. That card provided usable litre values for each of the gauge's gallon increments (Figure 4).

Figure 3: Aircraft fuel gauges

Figure 4: Fuel calibration card

A physical check of the fuel quantity was accomplished by placing an incrementally marked 'dipstick' (Figure 5) within each tank and reading the fuel level. The dipstick recorded fuel in litres, which was the unit of measurement used for all fuel calculations in accordance with the operator's procedures.

Figure 5: Aircraft fuel dipstick (and Master template)



The operator held calibrated master dipstick templates (master) for aircraft within the fleet. From the master, individual dipsticks were manufactured and kept with each aircraft. The master for KKW was also the correct calibration for two other C152 aircraft in the fleet (VH-MJG and VH-UPB). KKW's dip stick's scale included 8, 17, 26, 35, 44, 53, 62 and 70 L indications. The graduations were not linear, with dimension between graduations ranging between 11 mm and 25 mm. The maximum recommended fuel per fuel tank for two passengers was identified (in red) on the master dip stick as 44 L.

The operator advised that asymmetric fuel delivery[5] was common on this aircraft type due to the fuel tank venting system and as such, often the fuel remaining would not be equal in both tanks. As a pilot relied on visual recognition of moist wood as the fuel quantity marker, it is possible that fuel moisture remnants from a fuller tank reading might remain visible when observing the lesser tank side. The variation between the 17 L and 26 L increments on the dipstick was 17 mm.

Aircraft fuel records

The operator utilised a flight time and serviceability log for each aircraft. The log showed: date, name, time out (indicated or actual), time in (indicated or actual), engine time, time in (Air Switch or actual), flight time, fuel at start up (minutes), refuel place, refuel quantity (litres), pilot pre-flight inspection (initials), type of flight, number of landings and remarks (Figure 6).

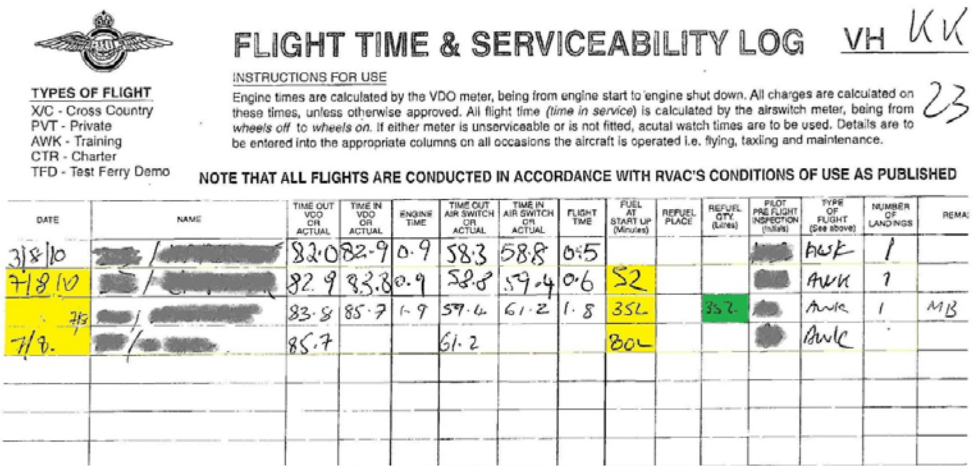
The log for KKW contained three entries for 7 August 2010. The fuel and flight time records for the first flight showed fuel at start up as 52 (highlighted in yellow on the log) and a flight time of 0.6 hours. The second flight showed 35 L of fuel at start up (in yellow), and 35 L refuel quantity (highlighted in green). That flight duration was recorded as 1.8 hours. The operator reported that the pilot from the second flight dipped the fuel tanks post flight and recalled reading 12 L remaining in the left tank and 17 L remaining in the right tank.

5 The uneven delivery of fuel between tanks, considered to be due to the positive pressure from the left tank vent line not equalising across both tanks adequately.

The third flight was the accident flight and showed 80 L (in yellow) at start up.

The column marked ‘fuel at start up’ specified minutes as the unit to be used; however, entries in litres were also found in the column. It was not clear whether the 52 listed for the first flight of the day represented minutes or litres

Figure 6: Operator’s flight time and serviceability log



FLIGHT TIME & SERVICEABILITY LOG VH KK

TYPES OF FLIGHT
X/C - Cross Country
PVT - Private
AWK - Training
CTR - Charter
TFD - Test Ferry Demo

INSTRUCTIONS FOR USE

Engine times are calculated by the VDO meter, being from engine start to engine shut down. All charges are calculated on these times, unless otherwise approved. All flight time *(time in service)* is calculated by the airswitch meter, being from *wheels off* to *wheels on*. If either meter is unserviceable or is not fitted, acutal watch times are to be used. Details are to be entered into the appropriate columns on all occasions the aircraft is operated i.e. flying, taxiing and maintenance. 23

NOTE THAT ALL FLIGHTS ARE CONDUCTED IN ACCORDANCE WITH RVAC'S CONDITIONS OF USE AS PUBLISHED

DATE	NAME	TIME OUT VDO OR ACTUAL	TIME IN VDO OR ACTUAL	ENGINE TIME	TIME OUT AIR SWITCH OR ACTUAL	TIME IN AIR SWITCH OR ACTUAL	FLIGHT TIME	FUEL AT START UP (Minutes)	REFUEL PLACE	REFUEL QTY (Litres)	PILOT PRE FLIGHT INSPECTION (Initials)	TYPE OF FLIGHT (See above)	NUMBER OF LANDINGS	REMA[RKS]
3/8/10	[redacted] / [redacted]	82.0	82.9	0.9	58.3	58.8	0.5				[redacted]	AWK	1	
7/8/10	[redacted] / [redacted]	82.9	83.8	0.9	58.8	59.4	0.6	52			[redacted]	AWK	1	
7/8	[redacted] / [redacted]	83.8	85.7	1.9	59.4	61.2	1.8	35L		35L	[redacted]	AWK	1	MB
7/8.	[redacted] / [redacted]	85.7			61.2			80L			[redacted]	AWK		

The operator provided data showing the fuel burn for the aircraft over the period July 2009 to June 2010. That data indicated that the actual fuel burn was about 19 to 20 L/hr. The data was derived from hours flown and fuel purchased for the aircraft that was averaged over a month.

The most accurate method of calculating fuel usage is by using fixed datums, such as full or empty fuel tanks. Due to weight limitations with two occupants on board, the aircraft was seldom fuelled to full capacity. Conversely, the aircraft tanks were not completely drained during normal operations.

Despite those limitations, the data did indicate that the fuel burn for KKW was slightly lower than the normal specified 23 L/hr for the Cessna 152 type.

Fuel system examination and testing

Examination of the aircraft did not find any evidence of fuel leakage from the aircraft fuel lines or fuel system components. Both fuel tank caps were securely fitted with no evidence of in-flight seepage. The aircraft fuel filter was clear of obstruction and there was little evidence of fuel spillage on the ground or in the adjacent swimming pool.

A quantity of approximately 9 L of fuel was retrieved from the right wing tank. The left tank was empty. The orientation of the wreckage presented the right tank as being the lowest point. As such, it could not be determined if fuel had been present in the left tank prior to impact and had gravity transferred to the right tank after the aircraft came to rest.

The aircraft’s fuel dipstick, fuel gauges, left and right sender units and wiring together with the left fuel tank were retrieved by the Australian Transport Safety Bureau (ATSB) for testing. These tests confirmed that the fuel dipstick provided an accurate reading of tank quantity at each increment (Figure 5).

The right sender unit and gauge operated normally, providing an accurate fuel quantity indication in accordance with the current fuel calibration card. The left sender unit was found to contain high levels of corrosion. That unit did not operate smoothly and provided false (fluctuating) readings above its mid-range during testing. It did however, accurately indicate low and zero fuel quantities. While it is possible that corrosion occurred as a result of the sender unit being out of the fuel and in storage for a period of time before testing was carried out, the right sender unit was subjected to the same environmental conditions, but did not display similar corrosion.

Previous occurrence involving KKW

On 11 April 2007, the aircraft was involved in a forced landing on a golf course adjacent to Moorabbin Airport. That incident happened during a training flight with a flight instructor and a single student on board. The aircraft landed safely with no injuries to the occupants. It was reported that the engine surged twice before it finally lost power late on the base leg prior to turning on to final approach.

The pilot reported that the aircraft came to rest with its left wing sitting low. The pilot also advised that, on disembarking the aircraft, he inspected the engine compartment for leaks and dipped the fuel tanks. A quantity of 25 L of fuel was in the right tank and the left tank was empty. A subsequent inspection by the operator's chief engineer confirmed the fuel quantity on board. Gravity had, however, transferred the fuel to the left tank by the time the engineer arrived at the scene.

The operator conducted an investigation into the incident. The aircraft fuel system was drained and the fuel dipstick and aircraft gauges checked for correct calibration. As a result, the operator identified discrepancies with the dipstick accuracy at low fuel level ranges. When the dipstick gave a reading of 45 L, the actual fuel on board was found to be 35 L. The fuel gauges and associated calibration card were also found to be inaccurate within their usable fuel range.

The fuel system was recalibrated with a new calibration card installed in the aircraft and a new calibrated (master) fuel dipstick was also introduced into service (Figure 5).In addition, following the occurrence the operator reported that it had increased the minimum fixed fuel reserve and placed a placard warning in the flight folder of the minimum fixed reserve.

Unusable fuel

While the AFM and the POH stated that 1.5 US gallons (5.7 L) of fuel was unusable, Australian and US accident records show that there have been a number of fuel starvation accidents involving Cessna 152 aircraft, where quantities in excess of the stated unusable fuel have been retrieved from the wreckage. A search of the ATSB database for the period 1 July 2001 to 30 June 2011 found two examples of fuel starvation involving Cessna 152 aircraft. The occurrence summary for 200204401 was:

> The aircraft carried out an emergency landing on runway 10 following a partial engine failure. The aircraft landed safely. Inspection revealed a total of 15 litres of fuel in the left tank and a very low quantity in the right tank.

A 2001 occurrence in Canberra involving a Cessna 150 aircraft was very similar to this occurrence and the summary (200105804) stated:

> On completion of a training exercise the instructor and student were cleared for a visual right circuit to runway 30. Shortly after commencing descent the engine failed, the instructor initiated engine failure actions, adopted a glide attitude and declared a 'Mayday'. ATC tower staff cleared the aircraft for a straight in approach to runway 17, however, the engine then 'caught' and after a few short surges ran normally. The landing was completed under power and the aircraft was able to be taxied to the parking area. A subsequent check of the fuel tanks revealed 10 litres in the left tank and 5 litres in the right tank. The flying school has since advised that the right fuel tank outlet may have uncovered during the descent and that they have implemented a requirement that the aircraft type be operated with a fixed fuel reserve of 30 litres.

The manufacturer did not specifically impose any caveats on the flight profile or types of manoeuvres performed with low fuel loads for the Cessna 152 aircraft, other than advising that the unusable fuel listed was applicable under 'reasonable flight conditions'.

The Cessna Pilot Safety and Warning Supplement (PSWS) Section 6, *Fuel Management – Flight Coordination vs Fuel Flow* provided the following guidance:

> It is important to observe the uncoordinated flight or sideslip limitations listed in the respective operating handbook. As a general rule, limit uncoordinated flight or sideslip to 30 seconds in duration when the fuel level in the selected fuel tank is ¼ full or less. Airplanes are usually considered in a sideslip anytime the turn and bank "ball" is more than one-quarter ball out of the centre (coordinated flight) position. Unusable fuel quantity increases with the severity of the sideslip in all cases.

The manufacturer did not provide any advice on asymmetric fuel delivery due to the aircraft tank venting configuration. However, the PSWS warned:

> In certain manoeuvres, the fuel may move away from the fuel tank supply outlet. Pilots can prevent inadvertent uncovering of the tank outlet by having sufficient fuel in the tank selected and avoiding manoeuvres such as prolonged uncoordinated flight or sideslips which move fuel away from the feed lines.

Regulatory requirements

The Civil Aviation Safety Authority (CASA) produced guidance material for the aviation industry that described CASA-preferred methods of complying with the Civil Aviation Regulations (CARs) 1988. Civil Aviation Advisory Publication (CAAP) 234-1 (1) *Guidelines for Aircraft Fuel Requirements* identified conditions that should be considered when calculating fuel required, including forecast weather, air traffic delays and allowing for alternate aerodrome variations. The CAAP indicated the variable and fixed fuel reserves respectively for piston engine aeroplanes and airships flying in the private, aerial work, charter and public transport categories while operating under VFR or instrument flight rules (IFR). While there were no variable fuel reserve listings for private and aerial work categories, the variable fuel reserve recommended for the charter and public transport categories were quoted as being 15 % of minimum required. The fixed reserve recommendation for piston aircraft under VFR or IFR operations was defined as being an additional 45 minutes flying time.

Asymmetric fuel delivery

Asymmetric (uneven) fuel delivery was a well known phenomenon in single engine Cessna aircraft. The Cessna Pilots Association, (CPA) Santa Maria CA, highlighted the issue in a 1993 Tech Note #003 *Uneven Fuel Feeding in Single Engine Cessnas*. The CPA describe the problem as being common on the 150/152, 172 and pre-1979 182 aircraft models.

The reason for asymmetric fuel delivery was attributed to the design of the fuel venting system, which allowed for a greater head of pressure in the left tank than the right, promoting faster delivery of fuel from the left tank. The CPA advised that due to the long and shallow design of the fuel tanks, their sensitivity to tank/ head pressure was increased. While the design incorporated a crossover vent line between the tanks, equalisation of head pressure could not be assured. The CPA highlighted that when the fuel tanks were filled above a certain level (typically half full), there was also the capability of fuel sloshing from the left tank to the right tank through the crossover vent line. That action resulted in the right tank retaining a higher level of fuel than the left, while still supplying the engine.

The CPA also identified the following factors which may contribute to asymmetric fuel delivery: an aircraft out of rig condition, blocked vent lines and fuel line restrictions.

In conclusion, the CPA determined that while measures could be made to reduce asymmetric fuel delivery, it could not be eliminated without a significant modification to the fuel system.

Meteorological conditions

Aerodrome conditions at the time of the accident were reported as being fine and dry with light (about 10 kts) northerly winds. Visibility was considered 10 km or greater. Weather was considered not to be a factor in this event.

Additional information

Carburettor icing

The flight conditions and temperature of the day indicated that the potential for carburettor icing may have existed. Depending on the figures used, an overly conservative estimate may indicate the possibility of moderate carburettor icing at cruise power. At 1,000 ft AMSL[6] there was a risk of carburettor icing at descent power.

The pilot reported carburettor heat was not initially selected when turning onto base because of the unexpected engine stoppage. As the pilot started heading towards the runway, full carburettor heat was selected with no effect on the engine operation.

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6 Above mean sea level.

Engine malfunction/stoppage

There was no evidence that the engine had malfunctioned due to any mechanical or electrical problem. The investigation did not find any defects with the aircraft or engine systems that could explain the loss of power experienced by the pilot.

The aircraft did not contain selectable fuel tanks, with both fuel tanks supplying a common fuel line to the engine. The unporting of fuel from one tank however, was capable of leading to engine stoppage under certain manoeuvres due to the ingestion of air into the common fuel line.

Pilot seat movement

The pilot reported that during the latter stages of the flight, uncommanded rearward movement of the pilots' seat occurred on two occasions. The passenger confirmed the pilot's seat had slid back and that assistance to the pilot was required to correct the movement on the second occasion.

Upon examination of the wreckage, the pilot's seat was found locked in its track. Despite the seat being inverted, investigators were not able to reproduce uncommanded movement of the seat. The seat was removed and the track and seat inspected. Minimal wear of the seat locking mechanism was found; however, elongation of the locating holes in one region of the track was identified.

While such an event could have a catastrophic effect on the operation and handling of the aircraft, the pilot was able to continue the approach with minimal adverse effect resulting.

ANALYSIS

Introduction

On returning to the aerodrome after an aerial photography flight, the pilot of VH-KKW experienced engine problems. The engine surged a couple of times before losing power. The pilot conducted a forced landing, about 200 m short of the airport, into the rear yard of a house. A number of factors will be analysed in this section to assist in understanding the reason for the loss of engine power.

Fuel state

Examination of the aircraft wreckage found a quantity of about 9 L of fuel on board. The lack of evidence of fuel spillage around the wreckage or evidence of fuel leakage from the fuel lines and fuel system components, indicate that the quantity retrieved was a true representation of the fuel on board prior to the aircraft impacting the ground. Further, the lack of evidence of any in-flight leakage or seepage from the fuel caps and tank drains would indicate that the fuel remaining was representative of the surplus fuel quantity, after engine fuel burn over the period of its operation.

Fuel log

The operator's fuel log displayed a number of inconsistencies with regard to its use in the recording of the aircraft's fuel state and did not clearly show final fuel state or fuel remaining post flight. The 'fuel at start up' column specified minutes as the data unit; however, entries identified as litres were found. That practice presented problems with the interpretation of figures that did not show the unit of measure. For example; it is not known whether the 52 listed at start up for the first flight of the day was indicating minutes or litres. This represents a significant safety risk as 52 minutes of fuel would equate to about 20 L and inversely 52 L would be in excess of 120 minutes of flight duration.

The third (accident) flight showed the start up figure as being 80 L, which was believed to be the approximate total fuel on board. Based on the reported fuel quantity in each tank at the end of the previous flight (12 L left, 17 L right) and the 10 L added to each tank prior to the accident flight, it was most probable that the total fuel quantity on board at the start of the accident flight was 49 L. The investigation could not reconcile the difference between the pilot's fuel log record of 80 L, but it is likely that that the dipstick was misread.

Another safety factor identified with regard to fuel recording was the tendency to round figures up. The pilot believed that about 75 L of fuel was on board the aircraft; however, 80 L was recorded in the log. While weight factors may influence over estimation of loads, the criticality of having insufficient fuel is a more significant issue.

Fuel usage

The operator's documentation prescribed that, for calculation purposes, an average fuel burn rate of 23 litres per hour (L/hr) was to be used for the aircraft. Data provided by the operator indicated that the actual fuel burn was about 20 L/hr. From the above data and given that the aircraft had been airborne for approximately 1.5 hours, it can be estimated that for normal flight manoeuvring the aircraft would have required a minimum of between 30 and 35 L of fuel. This flight however, incorporated a number of steep banks to facilitate aerial photography. Such manoeuvres would have used a slightly higher fuel burn rate.

Given that 9 L of fuel was recovered from the aircraft and allowing for the higher fuel burn rate during the steep banking, it is reasonable to consider that the quantity of fuel on board the aircraft, at departure from the aerodrome, would have been in the region of 45 to 50 L and not the 75 L the pilot believed to be on board.

If the '52' in the first of the three fuel log entries for 7 August 2010 is assumed to be litres, subsequent calculations using the annotated flight times and a fuel burn of 23 L/hr, indicate there would have been about 29 L on board the aircraft prior to the accident flight refuel. That figure was confirmed by the second flight pilot, who dipped the tanks post flight and observed 12 L in the left and 17 L in the right. Those figures support the view above, that the aircraft had about 30 L on board before the refuel and 50 L after the addition of 20 L by the refueller.

Pilot actions

The pilot's pre-flight dip of the fuel tanks determined approximately 55 L was on board the aircraft. How that figure was derived is not known, but that misreading, despite the pilot being familiar with the aircraft type and fuel dipstick use, was a significant factor in the development of the accident.

While it was normal practice to conduct a post-refuel dip of the tanks to confirm the final fuel state of the aircraft prior to takeoff, that action was not carried out. The pilot initially believed the post-refuel dip of the tanks had been carried out. It is likely that the pilot was distracted by the arrival of the passenger at the time the refuel was completed. That distraction interrupted the pilot's usual sequence process, resulting in the post-refuel tank dip being missed.

It is likely that the pilot's expectation in relation to the fuel quantity influenced what was observed when checking the aircraft fuel gauges. Consequently, the pilot later reported that the quantity was as expected; about 75 L.

Based on the pilot's belief that the aircraft had about 55 litres of fuel on board prior to refuelling, the flight planning undertaken regarding the flight duration and fuel required was well within the operator's and Civil Aviation Safety Authority's requirements. The minimum quantity required for the flight, based on the pilot's use of a 15% variable reserve and a 45 minute fixed reserve was 57 L However, the actual low fuel quantity on the aircraft meant that, including the pilot's requested uplift, the total fuel on board was about 49 L.

Fuel quantity indication

Dipstick

The fuel dipstick incremental scale was not uniform in either size or volume. Within the range, the incremental increase was between 8 and 9 L, but the dimensional variation between each increment was significantly different. The dipstick had 8, 17, 26 and 35 L increments.

The variation between the 17 and 26 L increments was only 17 mm. It is possible that had the pilot checked the right tank first, fuel moisture remnants from that high sided reading remained visible when the pilot observed the left (lower reading) tank, which obscured the left tank's true indication.

Double reading of a high tank indication, combined with a rounding-up mindset could significantly increase the perceived fuel quantity.

Fuel gauges

The aircraft fuel gauges did not provide representation of litre quantities nor were the gallon increments able to be easily converted to litres due to the inaccuracy of the system. The calibration card did show indicative litre values at each of the gallon indications, but the calibration card showed that at 6 gallons the left tank would have 30 L of useable fuel and the right tank would have 25 L. The next gauge increment, 12 gallons, represented 55 L and 53 L left and right tanks respectively.

Considering that the aircraft had in the region of 30 L (pre-refuel), the additional 20 L uplift would have given about 50 L total (not the 75 L the pilot believed to be on board). Allowing for uneven fuel distribution of the 50 L, both fuel gauges should have read around or just under, the 6 mark. Had the tanks contained 75 L (as required), the gauges should have read between the 6 and 12 increments. However, due to the discrepancy between the two tanks and the differing values of each gauge, both gauge readings could have been closer to the 6 than the 12.

Aircraft fuel systems

The aircraft contained a gravity-fed fuel system that incorporated an airstream vent to the left tank and a cap vent to the right tank. As a result of the design, the head of pressure in the left tank would increase quicker than the right tank, allowing faster delivery of fuel from the left tank than the right. To reduce the tendency for this asymmetric delivery and to equalise the pressure in the tanks, a crossover vent line between the tanks was fitted. If however, asymmetric delivery does occur, the possibility of one tank becoming depleted of its useable fuel quantity exists and, subject to the types of manoeuvres being undertaken, cross-feed transferring of fuel to that tank may not occur. The result of such an event would be the un-porting[7] of the fuel line to the engine and a subsequent loss of power due to fuel starvation.

The manufacturer did not provide guidance to operators regarding the minimum fuel state or manoeuvres that should not be undertaken to prevent such an outcome.

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7 Removing the useable fuel level from the fuel line outlet.

Carburettor icing

The pilot reported that the engine ceased to function before the pilot had the chance to apply carburettor heat when turning onto base. However, the application of carburettor heat shortly thereafter, combined with the residual heat from exhaust air, should have been sufficient to melt any small amounts of ice, if present, and enable an engine re-start, having the magnetos selected ON and with a windmilling propeller.

While conditions did present a risk of carburettor icing on descent to land, the investigation considered that this was unlikely to have occurred.

Unusable fuel

The manufacturer maintained that the aircraft was capable of using all but 1.5 US gallons (5.7 L) of its total fuel under reasonable flight conditions.

The manufacturer also indicated that the unusable fuel quantity increased during uncoordinated flight and sideslips that resulted in the turn and bank ‘ball’ moving more than ¼ ball out of centre and which occurred for more than 30 seconds.

A search of the ATSB’s database found only two examples of previous Cessna 152 fuel starvation occurrences. However, there was a 2001 occurrence involving a Cessna 150 in which the circumstances appear to be very similar to this accident. Of note was the action taken by the operator of that aircraft to prescribe a fixed fuel reserve of 30 L.

While the chances of an asymmetric fuel situation causing a problem is low, pilots are reminded that as well as monitoring fuel usage, they need to be alerted to the potential for increased unusable fuel quantities in certain circumstances and the particular risks associated with operations at minimal fuel states.

FINDINGS

From the evidence available, the following findings are made with respect to the total power loss experienced by the pilot of a Cessna Aircraft Company 152 aircraft, registered VH-KKW, and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The aircraft fuel tanks contained a lower than planned fuel quantity.
- The pilot misread the dipstick fuel quantity on board the aircraft during the pre-flight check.
- The pilot did not conduct a post re-fuel dip of tanks.
- An asymmetric fuel delivery condition probably existed on the aircraft leading to unporting of the fuel line to the engine.

Other safety factors

- Data contained in the operator's flight time and serviceability log was inconsistent.
- The unusable fuel quantity for the Cessna 152 is probably greater than that specified by the aircraft manufacturer under certain flight conditions.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

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

Proactive safety action

Royal Victorian Aero Club

While the investigation did not identify any organisational or systemic issues that might adversely affect the future safety of aviation operations, the Royal Victorian Aero Club (RVAC) advised the ATSB that following the accident, it had re-designed the flight time and serviceability log to provide clearer application and recording of aircraft pre and post-refuel fuel state.

Also RVAC also advised that it had:

> Immediately introduced a requirement that a formal 'Fuel Required' calculation be made for all flights leaving the circuit or training area. A copy [is] to be attached to the passenger list/weight and balance data.
>
> Inspected the seat-locking mechanisms on all Club aircraft and remind all Staff/Students/Members of the importance of ensuring all seats are locked.
>
> Reviewed training requirements for engine failure

APPENDIX B : SOURCES AND SUBMISSIONS

Sources of information

The sources of information during the investigation included the:

- pilot of VH-KKW
- passenger of VH-KKW
- Royal Victorian Aero Club (RVAC)
- Cessna Aircraft Company.

Submissions

Under Part 4, Division 2 (Investigation Reports), 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. Section 26 (1) (a) of the Act 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 Civil Aviation Safety Authority, the RVAC, the pilot and the aircraft manufacturer.

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

Fuel starvation – Mordialloc, Victoria, 7 August 2010
VH-KKW, Cessna Aircraft Company 152