ACCIDENT

Aircraft Type and Registration:	Cirrus SR22, G-CTAM
No & Type of Engines:	1 Teledyne Continental IO-550-N piston engine
Year of Manufacture:	2007 (Serial no: 2740)
Date & Time (UTC):	31 May 2020 at 1345 hrs
Location:	Calshot Spit, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damaged beyond economical repair
Commander's Licence:	Private Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	587 hours (of which 89 were on type) Last 90 days - 11 hours Last 28 days - 6 hours
Information Source:	AAIB Field Investigation

Synopsis

Passing 1,400 ft in a descent towards an airfield the engine started to run roughly and subsequently lost power. The pilot turned the aircraft parallel to the shore and deployed the aircraft's Ballistic Parachute Recovery System. The parachute descent was successful and both occupants escaped from the aircraft uninjured. The loss of power was probably caused by fuel starvation to the engine, but the cause of the starvation could not be determined.

History of the flight

The aircraft was refuelled on the morning of 28 May 2020 at Lee-on-Solent (EGHF), and it was fuelled to tabs that are visible in the tank filler necks. The tab level gives a fuel load of 227 litres and 126 litres were added to the aircraft tanks to achieve this. The pilot selected 'tabs' on the Multi-Function Display (MFD) and reduced the displayed total to 220 litres to provide a contingency margin. The aircraft flew a return trip from Lee-on-Solent to Turweston Aerodrome (EGBT), and the pilot recorded 1 hour 45 minutes in his logbook for these two sectors and stated that the airborne time was 1 hour 13 minutes.

On 31 May the pilot took the aircraft out of its hangar at Lee-on-Solent and conducted pre-flight checks. During these he noted that the aircraft's MFD showed a usable fuel load of 127 litres. The aircraft departed Lee-on-Solent at 1054 hrs and flew to Dunkeswell (EGTU), landing at 1130 hrs. The pilot stated that he used a timer in the aircraft cockpit to remind him to change the fuel tank selection every 20 minutes. Both the occupants had lunch and returned to the aircraft at 1245 hrs to prepare for the return flight. During the checks the pilot noted that the MFD showed a usable fuel of 84 litres. As 43 litres had been used for the flight to Dunkeswell, the pilot assessed that sufficient fuel remained for the return leg.

The aircraft took off at 1305 hrs and climbed to 3,400 ft amsl for the return leg. Throughout these sectors, the pilot stated that he used the fuel leaning functions of the aircraft's engine management controls to achieve a cruise power of approximately 75%. During the flight the pilot altered the planned route to fly close to the Bournemouth Airport overhead. After Bournemouth the pilot descended to 1,700 ft at reporting point OLGUD[1]. The pilot stated that during the descent the fuel remaining display on the MFD[2] showed that there would be 12 USG at OLGUD and 11 USG at Lee-on-Solent. He preferred to use the fuel remaining figure on the MFD as his primary fuel reference during flight, cross-referring to the aircraft fuel gauges as required, although he did not trust the accuracy of the fuel gauges.

After OLGUD, the pilot commenced a slow descent toward Lee-on-Solent and called the airfield on RTF to obtain traffic information. At around 1,400 ft he recalled the engine "coughed a little." His first thought was that he had retarded the fuel mixture rather than the power lever, but on checking he found the lever in the correct position. He did not consider a low fuel situation because of his recent fuel checks. Then, the pilot recalled, the FUEL caution light on the instrument panel illuminated, and the engine began to run very roughly. The pilot did not recall seeing any fuel cautions or warnings on the MFD.

The pilot called Lee-on-Solent and informed them he was running out of fuel. He changed the fuel tank selection and the engine recovered briefly but then faltered again. He did not select the fuel pump switch to BOOST. The aircraft had now descended to 800 ft, and the pilot changed the fuel tank selection again but with no improvement, and he called Lee-on-Solent to inform them he was preparing to ditch. The last altitude the pilot recalled seeing was 600 ft before he turned the aircraft parallel to the shore, briefed the passenger and deployed the ballistic parachute recovery system (BPRS). The routes of the flights detailed in this section are shown in Figures 1 and 8.

On touchdown the aircraft nose went briefly underwater before bobbing back to the surface. The aircraft floated upright with the wings just slightly below the surface and only a small amount of water entering the cockpit. Both occupants left the aircraft through the right door onto the wing. The parachute remained airborne and caused the aircraft to invert as the occupants swam clear. They were assisted by a nearby windsurfer before being rescued by the Hamble Lifeboat. Both were uninjured. The parachute remained inflated and dragged the ditched aircraft to the shore.

Footntoe

1 OLGUD is a reporting point at the west end of The Solent, approximately 2 nm south-east of Lymington.
2 While on the ground the MFD Initial Fuel Page shows fuel quantity in litres. In flight the displays show fuel quantity in USG.

Accident site

The aircraft ditched in the sea 3.4 nm west of Runway 05 at Lee-on-Solent Airport and 0.5 nm south-east of the beach at Calshot Spit (Figure 1). The inverted aircraft washed up on the beach at Calshot.

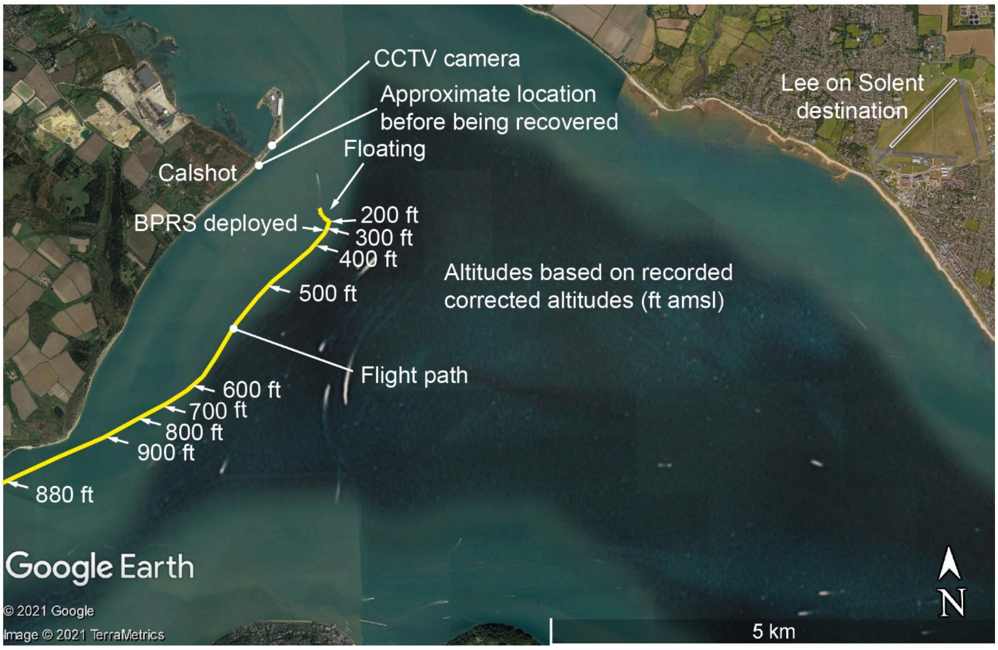


Figure 1

Final flight path and ditching location
Mapping © 2021 Google, Image © 2021 TerraMetrics

A rescuer of the Royal National Lifeboat Institution (RNLI), who was also a pilot, boarded the aircraft and turned off the fuel selector, battery master switch and magnetos. He did not move the fuel pump switch or the mixture lever. The police were also on scene and did not report any fuel leaks or fuel spills. The aircraft was guarded overnight and was then examined the next day by an insurance loss adjuster. Photos taken by the loss adjuster showed the throttle lever fully forward, the mixture lever near fully forward, the fuel pump switch in the OFF position and the fuel selector in the RIGHT-OFF position. An aircraft recovery team opened the inverted fuel tanks via the lower access panels and the loss adjuster reported that both the left and right main tanks contained no more in total than two or three pints of fuel and a small amount of sea water. The inboard collector tanks contained a trace of fuel and some sea water. There was no visible fuel leakage around the aircraft.

The aircraft's wings were cut off and the aircraft was transported to a secure facility. The aircraft had suffered significant damage to its upper fuselage structure and windscreen from being dragged up the beach inverted (Figure 2).

Figure 2

Aircraft after it was righted, the engine cowling removed, and the wings cut off

Aircraft information

The Cirrus SR22 is a four-seat single-engine composite aircraft that was first certified in 2000 and more than 6,000 have since been produced. There are different variants and G-CTAM was a Cirrus SR22 G3 with a 310-horsepower Continental IO-550-N engine and an after-market Tornado Alley turbocharger conversion. The G3 variant has a modified wing with a higher fuel capacity than the G2 and with fuel caps further outboard on the wing. The cockpit features a large Primary Flight Display (PFD) and a MFD. The aircraft is equipped with a whole-plane BPRS.

Maintenance history

G-CTAM, had accumulated 708 airframe and engine hours. The aircraft's last maintenance was a 50-hour check completed on 10 January 2000. During the aircraft's last annual inspection in June 2019, at 668 hours, work on the engine including cylinder removals was carried out to address low compression on four of the cylinders.

Fuel system description

Two main wing tanks and two collector tanks provide for a total capacity of 94.5 USG (358 litres), of which 92.0 USG (348 litres) are usable. When filled to the tabs, below each filler neck, the total usable fuel is 60 USG (227 litres). Fuel is gravity-fed from each tank to the associated 2.8 USG collector tank where the engine-driven fuel pump draws fuel through a filter and selector valve to pressure feed the engine fuel injection system (Figure 3). An electric fuel pump is provided for engine priming when the fuel pump switch is set to PRIME and vapour suppression when set to BOOST. Each wing tank and collector tank has a drain valve to collect water and contaminants. Each wing tank has an air vent at the top of the tank which is connected to an air inlet on each lower outboard wing surface. Each collector tank has a vent line connected to its main tank.

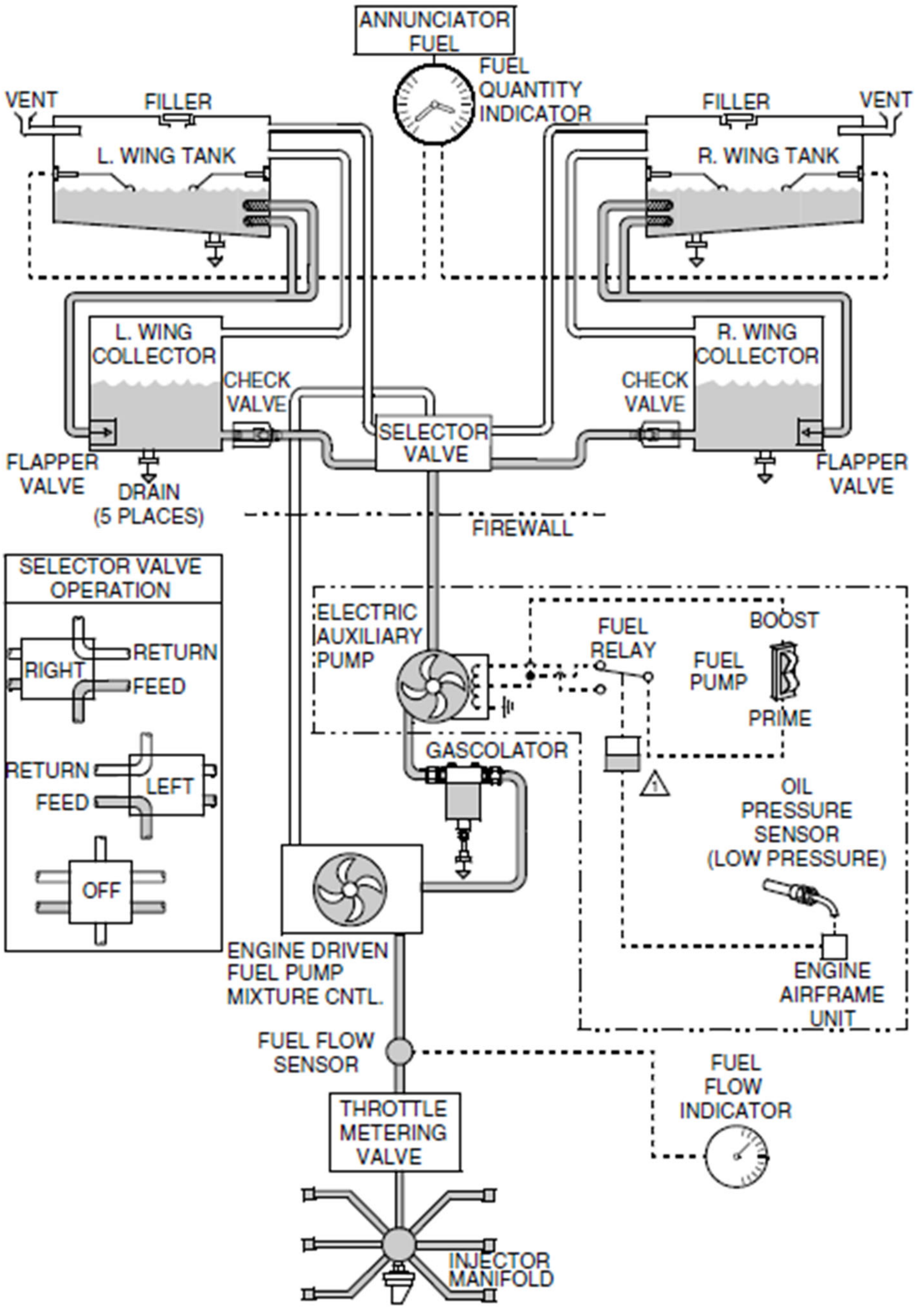


Figure 3

Fuel system diagram for Cirrus SR22 with G3 wing

The fuel tank selector valve is mounted in the centre console (Figure 4). It has four positions: LEFT, RIGHT, RIGHT-OFF and LEFT-OFF. To move the selector to one of the OFF positions requires lifting the circular plunger in the centre of the selector; this design is intended to prevent an inadvertent OFF selection. Fuel is balanced throughout the flight by the pilot alternating the selection between left and right tank. The maximum allowable fuel imbalance is 10 USG.

Figure 4

Fuel selector valve, fuel gauge and fuel pump switch

Fuel quantity indication and alert system

Each wing tank contains two analogue float-type sensors, one outboard and one inboard. These sensors provide fuel level information to the analogue fuel quantity indicator mounted forward of the fuel selector. An amber FUEL caution light located to the left of the PFD (Figure 5) comes on to indicate a low fuel condition. It is triggered by switches in the fuel quantity indicator when both tanks are indicating below approximately 14 USG. If both tanks are equally balanced at about 14 USG, then the light will illuminate at an indicated usable fuel quantity of about 28 USG. However, if one tank is run dry when the other tank is above about 14 USG, then the light will illuminate at a usable quantity of about 14 USG.

The fuel filler cap is located far outboard on the wing, further outboard than on earlier versions of the Cirrus SR22 which had smaller fuel tanks. Because of the wing dihedral, there can be fuel in the main wing tank without it being visible through the filler neck. The aircraft manufacturer estimated that the minimum usable fuel level that would still be visible below the filler neck in a wing is 15 USG with an aircraft that is perfectly level. So, it is possible for the aircraft to have just below 30 USG of usable fuel remaining without it being visible to the pilot.

Figure 5
PFD, MFD and location of FUEL caution light

The aircraft manufacturer stated that the fuel indication system on this aircraft is accurate to within a few gallons when new, but over time the resistive elements in the analogue float sensors can suffer from wear which can result in inaccurate readings. Cirrus SR models manufactured after 2012 have a digital fuel quantity indication system, which uses a more reliable digital magnetoresistive float sensor; it is also available for retrofit on older models.

Multi-Function Display

The aircraft is fitted with an Avidyne Entegra EX5000C MFD. This provides engine management, navigation and fuel management capabilities. The system calculates fuel remaining at upcoming waypoints in the flight plan and displays a time remaining to fuel exhaustion. This information is portrayed in data blocks which are shown to the top left and right of the MFD map. The MFD has an input of fuel flow rate from a Data Acquisition Unit (DAU) which supplies all other engine parameters as well. The pilot enters the fuel quantity via a fuel initialisation page on the MFD and then the system calculations are based on that figure and measured fuel flow. Neither the DAU nor the MFD have any interface to the float-based fuel quantity indication system. The MFD calculates total fuel remaining but cannot calculate or display the distribution of that fuel across the aircraft's tanks as only the total fuel flow to the engine is measured.

Due to the reliance of the MFD on accurate input of fuel quantity, the Pilots Guide for the MFD contains the cautionary note shown at Figure 6.

It is critical that you accurately enter the actual onboard fuel quantity on the Initial Usable Fuel Page to ensure accuracy of the fuel totalizer functions.

Visually check the actual fuel in each tank in accordance with aircraft POH procedures as part of the aircraft pre-flight inspection. After the amount of fuel has been visually confirmed, enter the amount into the Initial Usable Fuel Page.

Inaccurate fuel entry can result in a misleading indication of fuel or time remaining, which could lead to fuel starvation, loss of engine power, and forced landing.

600-00108-000 Rev 06 -71- Entegra EX5000

Engine Page

Be sure to cross-check fuel quantity and fuel remaining during flight.

- **Fuel quantity** is the amount of fuel in the tanks, as measured by the tank probes. See the aircraft POH for any limitations on the fuel measurement.
- **Fuel remaining** is based on a calculation using the initial fuel amount entered by the pilot, and the fuel flow integrated over the time of the flight so far.

If the Check Fuel Remaining Warning (Red) displays, prepare to land immediately!

Figure 6

Caution note from MFD Pilots Guide

The MFD has a message bar which appears at the bottom of the screen whenever a message is posted by any of the system functions. The messages do not trigger any aural warning tone. Messages are displayed in yellow for cautions and red for warnings. For total fuel remaining, a yellow caution is displayed with 28 USG remaining and a red warning with 10 USG remaining. The note in Figure 6 states that pilots should prepare to land immediately should the red fuel warning appear.

Aircraft examination

This investigation began as an AAIB Correspondence Investigation which is why the AAIB did not attend the scene or initially recover the wreckage. However, as there was recorded data on board it was decided to recover the PFD and MFD. Following data analysis, it was decided to recover the aircraft wreckage to the AAIB's facility for further examination. This occurred after the loss adjuster had already arranged for the engine to be removed and stripped for storage. No faults, apart from corrosion, were found during the engine strip, and the engineer who removed the engine reported that he did not find any fuel in the engine fuel hoses. The level of corrosion was as expected from the aircraft's exposure to saltwater following the ditching. No loose connections were reported during the engine removal and engine strip.

The lack of usable fuel found in the fuel tanks did not necessarily indicate that the aircraft had run out of fuel. Sea water was found in the fuel tanks and sand was found inside the fuel selector which indicated that the fuel system had been compromised after immersion in the sea. It was possible that while the aircraft was inverted in the sea, fuel had drained away via the fuel tank vents. As the external part of the vents are located on the lower surface of the outboard part of the wing, the wing's dihedra l could have resulted in an inverted wing's wingtip being lower than its vent pick-up point inside the tank, resulting in a siphoning effect. The aircraft manufacturer stated that there was nothing to prevent the collector tank from draining via its vent tubing into the main tank and then through the main tank vent line to the exterior if the aircraft was inverted. The recorded data also provided evidence suggesting there was usable fuel remaining, so further airframe and engine examinations were carried out.

The fuel selector was removed at the AAIB's facility, and although its rotating mechanism had seized due to corrosion as a result of sea water ingress, once the corrosion was removed the fuel selector operated normally and the central knob functioned correctly to reduce the chance of a pilot inadvertently turning it off while changing tanks. A test fluid was passed through the left and right inlets and there was no restriction to flow in either the left or right position.

The fuel tank drain valves were tested for leaks and no leaks were found. The inboard floats inside the main fuel tanks operated freely. One of the outboard floats provided some resistance to movement, most likely due to corrosion, but this outboard part of the tank would have been dry at the time of the loss of power.

Because the engine had already been removed, the AAIB could not determine if there had been any loose connections forward of the engine firewall, but none were reported by the engineer who removed it.

The recorded data indicated an issue with fuel flow so the engine-driven fuel pump, fuel control unit and fuel flow divider were tested and strip-examined by an approved engine overhaul organisation. Some corrosion was found but no faults were found that would explain a loss of fuel flow.

Recorded information

There are no requirements for this aircraft to be fitted with a flight recorder. Unlike many other aircraft of this type, an optional Recoverable Data Module (RDM) was not installed. Data was recovered from the Avidyne PFD and MFD. The end of the flight was also captured by a CCTV camera.

The avionics had been submersed in sea water and were not operational when recovered. The MFD stored data was on an internal Compact Flash (CF) memory card. This had suffered from corrosion damage but was repaired and the data was recovered using a working MFD. The PFD stored its data on non-volatile memory chips mounted on the unit's circuit boards. These were removed and downloaded. The manufacturer converted the data to a usable format.

The PFD recorded general flight parameters but was not to the latest software standard so did not record engine parameters. The MFD recorded engine and fuel flow parameters as well as the cumulative fuel used during the flight derived from the fuel flow data. The MFD also retained the last calculated figure for total fuel remaining, as displayed to the pilot, based on the last pilot input of total fuel quantity after refuelling and the subsequent sensed fuel flow values. This figure was 11.4 USG (43 litres). The recordings do not include fuel quantities sensed from the fuel tanks. Low fuel warnings generated by either the MFD or onboard systems are not recorded.

The combined PFD and MFD data for the final part of the accident flight is shown in Figure 7. There was a sensor issue with one of the engine cylinder EGTs which is not believed to be relevant to the investigation. The fuel flow data shows an initial dip in fuel flow followed by a transition to a rich fuel mixture (fuel flow of 25 USG/hr) prior to the descent towards Lee-on-Solent. In the descent, there was a decrease to 4 USG/hr, which would have been insufficient to sustain combustion, followed by a recovery of the fuel flow. The decrease occurred again 20 seconds later and this time the EGTs reduced to zero indicating that no combustion was taking place. The fuel flow recovered again for about another 20 seconds before it dropped again and the EGTs reduced to zero again. There was a final recovery and drop-off before the BPRS was activated below 400 ft amsl.

The data was analysed and discussed with the aircraft manufacturer, the engine manufacturer and the turbocharger manufacturer. The consensus view was that the engine's performance was following the fuel flow. When the fuel flow was sufficiently high combustion was occurring and power was being produced, and when the fuel flow dropped sufficiently combustion ceased. The engine-driven fuel pump had been tested and functioned normally and therefore the consensus was that the loss of fuel flow was indicative of fuel starvation, ie the demanded fuel was not always reaching the fuel pump.

The data does not show when the pilot switched fuel tanks and therefore a conclusive analysis of each fuel flow reduction and increase could not be performed. The manufacturers stated that when a fuel tank is almost 'dry' the fuel outlet port can become uncovered and a mixture of air and fuel can be sucked up to the fuel pump, which can cause engine surging. When only air is sucked, combustion ceases. Due to fuel slosh, the port might alternately cover and uncover with fuel. At a fuel flow rate of 20 USG/hr (0.021 litres/second), a supply of 0.42 litres of fuel would be sufficient to run the engine for 20 seconds. It is possible that one or more of the fuel flow reductions and increases observed in the data was caused by fuel slosh. It is likely that at least one of the fuel flow reductions and increases was a consequence of the pilot switching tanks. When a pilot switches tanks after the system has sucked in air from a dry tank, the engine can fail to pick up or can run roughly.

The turbocharger manufacturer stated that the fuel flow measurement is averaged over two or four seconds, so momentary drops in fuel flow due to air entrainment would not show up in the data. Fluctuations in longitudinal acceleration indicate that the engine was probably not running smoothly for very long in between fuel flow drops. The engine-driven fuel pump cannot suck fuel through a large amount of air, whereas the electric fuel pump, which is located below the collector tank and is gravity fed by it, can push fresh fuel up the fuel lines to clear any air. This is why activating the fuel pump is important if a tank has run dry.

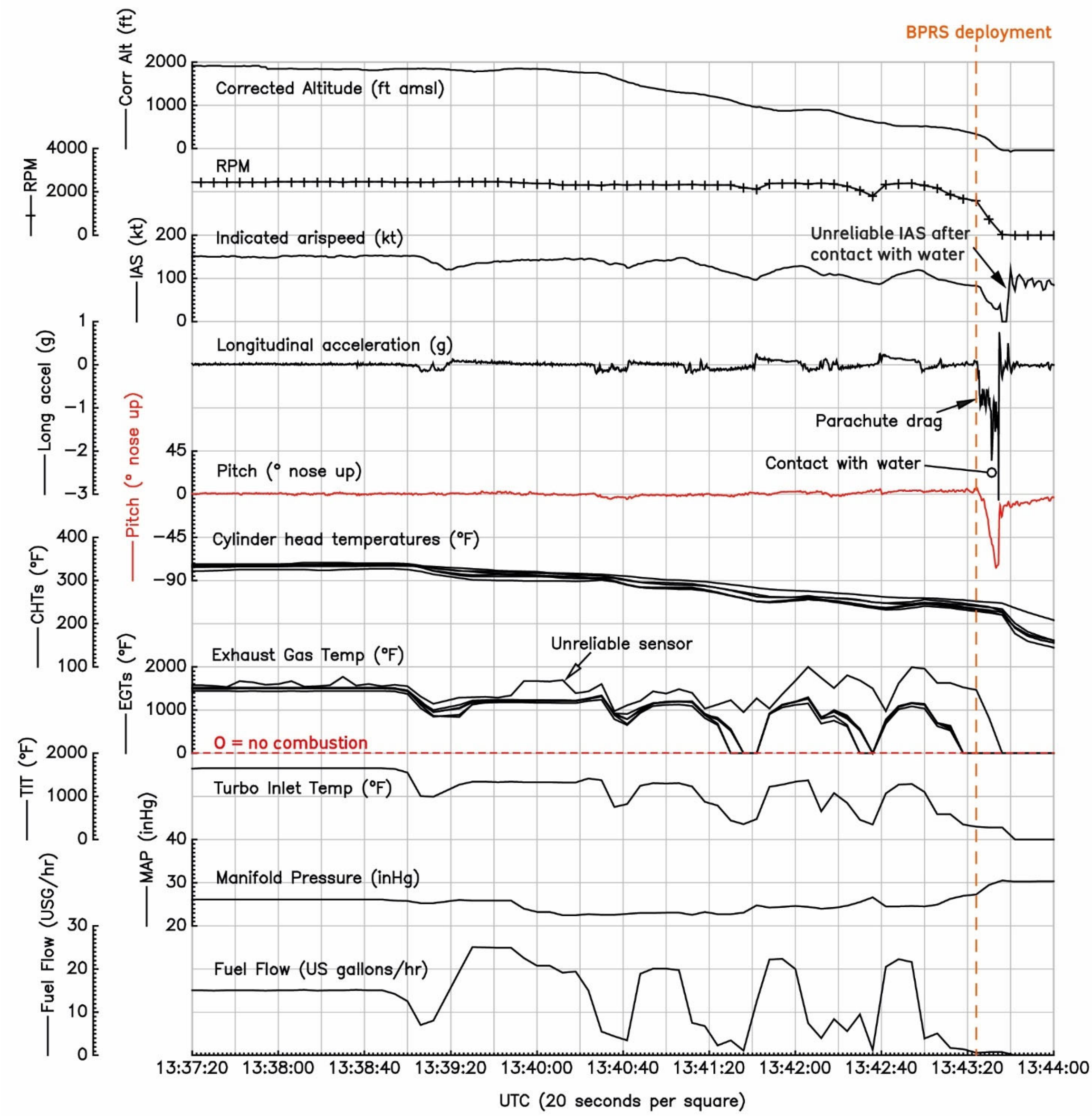
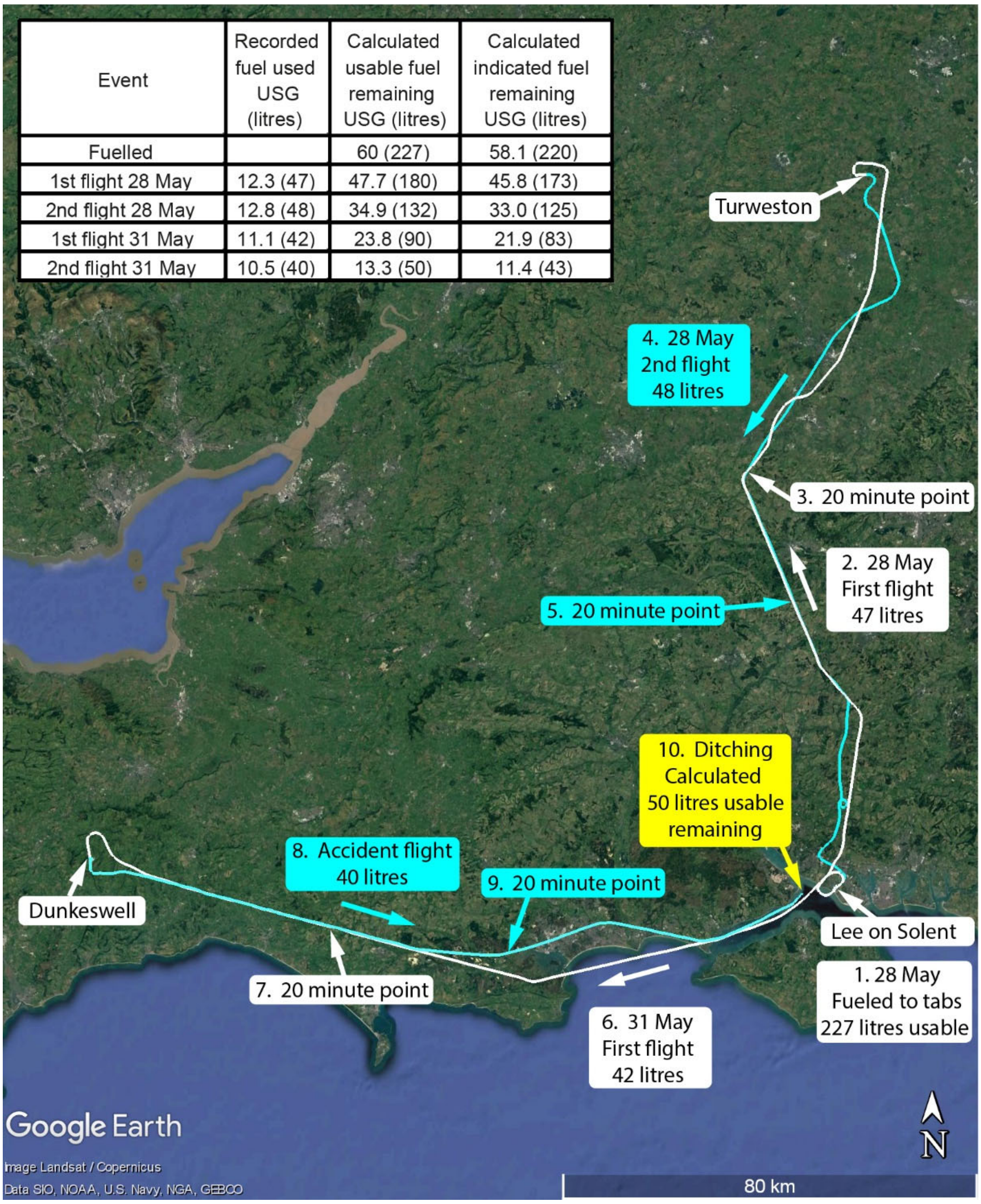


Figure 7

Extracts of PFD and MFD data at the end of the accident flight.

Analysis of the CCTV imagery correlated with the recorded data indicated a time lag in the recorded altitude and altitude rate parameters compared to the accelerometers. The combined data indicated that the BPRS was deployed descending through 340 ±20 ft above sea level. Taking the parameter timings into account, the average descent rate over the last 1.5 seconds before impact with the water was approximately 1,500 ft/min. At the time of contact with the water the pitch of the aircraft was recorded as 74° nose down. The recorded longitudinal acceleration increased by 2 g, the normal acceleration increased by 3 g and the lateral acceleration peaked at 1.5 g, although it was unclear how accurate these values were as the system was unlikely to have been designed or tested for accuracy during dynamic impact situations such as this.

The recorded fuel usage for the four flights flown since refuelling are shown in Figure 8.



Event	Recorded fuel used USG (litres)	Calculated usable fuel remaining USG (litres)	Calculated indicated fuel remaining USG (litres)
Fuelled		60 (227)	58.1 (220)
1st flight 28 May	12.3 (47)	47.7 (180)	45.8 (173)
2nd flight 28 May	12.8 (48)	34.9 (132)	33.0 (125)
1st flight 31 May	11.1 (42)	23.8 (90)	21.9 (83)
2nd flight 31 May	10.5 (40)	13.3 (50)	11.4 (43)

Figure 8

Fuel usage since refuelling

Spot checks of engine rpm, manifold pressure, altitude, airspeed and fuel flow from the recorded data compared favourably to the data in the performance tables in the POH, which indicated that the recorded fuel flow data and derived fuel usage data was reliable, assuming no leaks. If fuelling to tabs was accurate (60 USG / 227 litres) and the recorded fuel flow and fuel used values were accurate, there should have been 13.3 USG (50 litres) of usable fuel available at the time the aircraft ditched.

The pilot stated that he started a timer on takeoff and that he switched tanks every 20 minutes. The four flights since refuelling were all more than 20 minutes long and less than 40 minutes so should have triggered one tank switch each. The tanks were not switched on the ground between flights.

Applying the fuel flow figures to the tank switching method described meant that at the time of the engine problems there should have been approximately 6.6 USG (25 litres) of usable fuel in each tank. The pilot did not believe that he had missed an in-flight switch. However, if one of the in-flight switches had been missed during one of the flights on 28 May, then calculations showed that the tank in use at the time of the engine problems would have run dry and the other tank would have been close to the nominal 14 USG alert level in the location of the engine problems (plus or minus less than 2 USG). 20 minutes into the first flight on 28 May coincided with the transition from a longer stable flight leg to a turn onto a new heading, with multiple corrections afterwards. 20 minutes into the second flight on 28 May was approximately halfway along a stable flight leg. There are potential sources of error with these calculations, such as assuming the nominal 'tabs' fuel quantity was accurately achieved and imprecision in the timing for the remaining fuel tank switch-overs.

POH Checklist

The POH[3] procedure for changing the selected tank states:

> *'Fuel BOOST must be used for switching from one tank to another. Failures to activate the Fuel Pump before transfer could result in delayed restart if the engine should quit due to fuel starvation'.*

On the centre console, in front of the fuel pump switch, there is a label which states:

> *'TURN BOOST PUMP ON DURING TAKE OFF, CLIMB, LANDING, AND SWITCHING FUEL TANKS.'*

The aircraft POH contains checklists for actions in the event of an engine failure in flight. The checklist drill is shown at Figure 9.

The POH states that items which are underlined '*should be memorized for accomplishment without reference to the procedure*'.

Footnote

3 Pilot's Operating Handbook and EASA Approved Airplane Flight Manual for the Cirrus Design SR22 covering aircraft serials 0002 thru 2978 and some others. P/N 13772-001E Revision A10.

Cirrus Design
SR22

Section 3
Emergency Procedures

Engine Failure In Flight

If the engine fails at altitude, pitch as necessary to establish best glide speed. While gliding toward a suitable landing area, attempt to identify the cause of the failure and correct it. If altitude or terrain does not permit a safe landing, CAPS deployment may be required. *Refer to Section 10, Safety Information*, for CAPS deployment scenarios and landing considerations.

• WARNING •

If engine failure is accompanied by fuel fumes in the cockpit, or if internal engine damage is suspected, move Mixture Control to CUTOFF and do not attempt a restart.

1. Best Glide Speed.. ESTABLISH
2. Mixture.. AS REQUIRED
3. Fuel Selector.. SWITCH TANKS
4. Fuel Pump.. BOOST
5. Alternate Induction Air..ON
6. Air Conditioner (if installed)..OFF
7. Ignition Switch..CHECK, BOTH
8. If engine does not start, proceed to *Engine Airstart* or *Forced Landing* checklist, as required.

Figure 9

Engine Failure checklist

The CAA Skyway Code

The CAA Skyway Code[4] is intended to provide General Aviation pilots with practical guidance on issues relevant to their flying. The section dealing with fuel states the following about fuel gauges:

> *'Fuel gauges in most GA aircraft are not sufficiently reliable for the purposes of flight planning or pre-flight checking. Physically examining the fuel levels with a method appropriate to the aircraft type (such as a dipstick) is the best way of assessing the aircraft's fuel state. However, in flight, low fuel gauge readings should never be ignored.'*

It goes on to say the following about fuel totalisers:

> *'A fuel totaliser, if fitted, is a good indicator of fuel burn. However, for the purpose of counting fuel remaining it is completely dependent on the initial fuel level being correct. It only measures fuel consumed by the engine rather than the content of the fuel tanks and would not detect a leak.'*

Footnote

4 https://publicapps.caa.co.uk/docs/33/CAP1535S%20Skyway%20Code%20Version%203.pdf [Accessed September 2021]

Manufacturer's flight test involving switching fuel tanks

According to Federal Aviation Regulation FAR 23.955(e), for aircraft with multiple fuel tanks and reciprocating engines, if engine power loss results from fuel depletion of the selected tank, it must be possible after switching to any full tank to obtain 75% maximum continuous power in not more than 10 seconds for naturally aspirated single-engine aeroplanes. The figure is 20 seconds for turbocharged single-engine aeroplanes provided that 75% of normally aspirated power is regained in 10 seconds. A fuel boost pump can be used to meet this requirement.

The aircraft manufacturer conducted a flight test against this requirement in a Cirrus SR22 G1 with a naturally aspirated engine. The engine was run on one tank until the fuel was exhausted and then the tank was switched to the full tank. This was done three separate times with the boost pump on and three times with the boost pump off. This was then repeated on a subsequent flight with the other tank empty. The results are shown in Table 1.

			Time to regain 75% power (seconds)	
Flight No.	**Tank run dry**	**Tank turned on**	**Using boost pump**	**Without boost pump**
1	Right	Left	8.5	14
1	Right	Left	6.8	8.4
1	Right	Left	6.1	17.5
2	Left	Right	6.6	11.9
2	Left	Right	5.5	45
2	Left	Right	6.1	No start in 1 minute

Table 1

Results from Cirrus SR22 G1 fuel tank switching flight test

As it was not possible to consistently restart the engine to 75% power within 10 seconds with the boost pump off, the POH contains a limitation to engage the boost pump prior to switching tanks, and to engage it as part of the emergency procedures following loss of power.

These tests were not repeated in later models of the Cirrus SR22. A later flight test involving an SR22 G3 only involved switching tanks without running one dry. Another flight test involved an SR20 G3 (which has a lower power engine), which also revealed that the fuel pump was needed to consistently regain power within 10 seconds. The turbo manufacturer stated that the addition of a turbocharger would not affect these performance figures at low altitude.

The aircraft manufacturer had not retained the time-trace data from these test flights, so it was not possible to see the effect on fuel flow when running a tank dry. However, the manufacturer's engineer involved with the flight tests stated that "the engine did not lose power suddenly but coughed and spluttered for maybe up to a 1 minute or maybe 30 seconds".

Ballistic parachute recovery system

The Cirrus SR22 is equipped with a whole-aircraft BPRS, proprietarily called the Cirrus Airframe Parachute System (CAPS). The following are extracts from the POH description of the system:

'The CAPS consists of a parachute, a solid-propellant rocket to deploy the parachute, a rocket activation handle, and a harness imbedded within the fuselage structure.

When the rocket launches, the parachute assembly is extracted outward due to rocket thrust and rearward due to relative wind. In approximately two seconds the parachute will begin to inflate.

Following any nose-up pitching, the nose will gradually drop until the aircraft is hanging nose-low beneath the canopy. Eight seconds after deployment, the rear riser snub line will be cut and the aircraft tail will drop down into its final approximately level attitude. Once stabilized in this attitude, the aircraft may yaw slowly back and forth or oscillate slightly as it hangs from the parachute. Descent rate is expected to be less than 1700 feet per minute with a lateral speed equal to the velocity of the surface wind.

The Cirrus Airframe Parachute System (CAPS) is designed to lower the aircraft and its passengers to the ground in the event of a life threatening emergency. However, because CAPS deployment is expected to result in damage to the airframe and, depending upon adverse external factors such as high deployment speed, low altitude, rough terrain or high wind conditions, may result in severe injury or death to the aircraft occupants, its use should not be taken lightly. Instead, possible CAPS activation scenarios should be well thought out and mentally practiced by every SR22 pilot. The following discussion is meant to guide your thinking about CAPS activation. It is intended to be informative, not directive. It is the responsibility of you, the pilot, to determine when and how the CAPS will be used.'

The POH offers a range of scenarios in which the use of the BPRS is suggested. One of those is as follows:

'Landing Required in Terrain not Permitting a Safe Landing

If a forced landing is required because of engine failure, fuel exhaustion, excessive structural icing, or any other condition CAPS activation is only warranted if a landing cannot be made that ensures little or no risk to the aircraft occupants. However, if the condition occurs over terrain thought not to permit such a landing, such as: over extremely rough or mountainous terrain, over water out of gliding distance to land, over widespread ground fog or at night, CAPS activation should be considered.'

While there is no absolute limit on altitude for deployment of the BPRS the POH gives the following advice on its use:

> *'**Deployment Altitude***
>
> *No minimum altitude for deployment has been set. This is because the actual altitude loss during a particular deployment depends upon the airplane's airspeed, altitude and attitude at deployment as well as other environmental factors. In all cases, however, the chances of a successful deployment increase with altitude. As a guideline, the demonstrated altitude loss from entry into a one-turn spin until under a stabilized parachute is 920 feet. Altitude loss from level flight deployments has been demonstrated at less than 400 feet. With these numbers in mind it might be useful to keep 2,000 feet AGL in mind as a cut-off decision altitude. Above 2,000 feet, there would normally be time to systematically assess and address the aircraft emergency. Below 2,000 feet, the decision to activate the CAPS has to come almost immediately in order to maximize the possibility of successful deployment. At any altitude, once the CAPS is determined to be the only alternative available for saving the aircraft occupants, deploy the system without delay.'*

The pilot stated that he had been taught during training on the aircraft to deploy the BPRS by 400 ft above the surface and to deploy it in preference to attempting a forced landing.

According to the aircraft manufacturer there have been 10 CAPS activations over water in Cirrus SR aircraft (including G-CTAM). In all but one of these accidents all occupants survived. One accident resulted in one fatality and three serious injuries following deployment in a spin at a height of 528 ft where the aircraft hit the water 4 seconds after activation. One of the accidents resulted in a serious injury and the remaining eight did not result in any serious injuries.

Manufacturer's online training programme

The aircraft manufacturer has produced a CAPS training programme which discusses many issues related to the system. This is free of charge to all pilots and can be accessed here: https://learning.cirrusapproach.com/learning-catalog. In the training the manufacturer suggests a CAPS briefing format to be used for every flight and suggests pilots adopt a "CAPS available" call when the aircraft climbs through 500 ft agl. It also addresses pilot decision making and examines a variety of scenarios for use of the CAPS. For the engine failure case the training package recommends immediate deployment of the CAPS should the failure occur between 500 ft agl and 2,000 ft agl (600 ft agl and 2,000 ft agl for SR22T Generation 5 or later), regardless of the terrain.

The aircraft manufacturer stated that the guidance in the online training programme is based on their research of many successful CAPS activations over the years since the POH guidance was first published, and research of unsuccessful forced landings which resulted in injuries or fatalities.

Survivability

The BPRS, although deployed at low altitude, performed as expected and the aircraft hit the sea with a rate of descent of approximately 1,500 ft/min, and a nose-down pitch attitude of 74° (enough time did not pass from activation of CAPS until impact with the sea for the rear riser snub line to be cut and for the aircraft to adopt a more level attitude). While still a significant descent rate, this was preferable to a ditching at the normal approach speed of approximately 80 kt. After touchdown, the aircraft remained upright long enough for both occupants to escape onto the wing, but the parachute remained inflated and caused the aircraft to invert as they swam clear. The inversion of the aircraft would have significantly impeded their escape had it occurred immediately after touchdown.

Aircraft performance

Using the engine management function of the MFD to achieve best fuel performance in the cruise gives a power setting of approximately 75%. In ISA conditions at 4,000 ft, this equates to a calculated burn rate of 17.5 USG (66 litres) per hour. The recorded data indicated the aircraft had burned 15 USG (57 litres) per hour in the cruise. Time to climb to 4,000 ft would be approximately three minutes and burn 1.3 USG (5 litres). The aircraft had completed four takeoff and climb events and a total of 143 minutes of airborne time since the refuel to 226 litres described by the pilot. Based on these figures, the total in-flight fuel burn would have been approximately 43.4 USG (164 litres). Recorded data showed a total fuel burn of 177 litres.

Analysis

Cause of the loss of power

The final loss of power was preceded by large fluctuations in fuel flow from 20 USG/ hour down to near zero. Both times that the fuel flow dropped to 1 USG/hour, the EGT's dropped to zero, indicating that combustion briefly ceased, before recovering as the fuel flow recovered. During the earlier fuel flow reduction to 3 USG/hour the EGT's did not drop to zero but at this low fuel flow rate combustion would have also ceased. The consensus view after discussion with the representatives of the aircraft, engine and turbocharger manufacturers was that the engine was producing power when the fuel flow was normal. The engine-driven fuel pump was tested after the accident and functioned normally and therefore it was most likely that the demanded fuel was not always reaching the fuel pump. This was consistent with the evidence from the engineer who removed the engine stating that there was no fuel in the fuel hoses in the engine. It is therefore probable that the loss of power was caused by fuel starvation, due to either a fuel leak or another mechanism.

Possible cause of fuel starvation if there was no fuel leak

If a selected fuel tank is used until there is no more usable fuel remaining, a loss of power will ensue due to fuel starvation. This may be preceded by engine power fluctuations as the engine-driven fuel pump alternately picks up fuel or sucks in air as the fuel pick-up point in the tank becomes exposed. The aircraft manufacturer's engineer stated that the engine coughed and spluttered for a while when they ran a tank 'dry' during flight tests. The flight tests also revealed that if a pilot changes fuel tanks after this has happened, the engine can take a long time to recover if the electric fuel pump is not set to BOOST; and in one test the engine failed to recover.

If the fuel tanks were filled to tabs as described, and if there had been no fuel leaks, then according to the recorded data there should have been about 13 USG (49 litres) remaining. Only about 0.5 USG of fuel was recovered from all the fuel tanks, but because the aircraft had been inverted the remaining fuel could have escaped via the air vents. According to the POH 2.5 USG of fuel is unusable, so if both tanks had been run 'dry' and no fuel had escaped post-impact, there should have been closer to 2.5 USG of fuel remaining. This was another indication that fuel probably escaped post impact.

The pilot did not recall any fuel cautions or warnings on the MFD, and it was not possible to confirm from retrieved data whether or not they appeared. The MFD low fuel caution comes on at 28 USG remaining so should have been illuminated prior to departure from Dunkeswell. Regardless of whether it illuminated, the pilot is likely to have been aware that he had less than 28 USG prior to departure because the 84 litres he noted before departure is 22 USG. The MFD red fuel warning would not yet have appeared as it illuminates when the system has calculated there are 10 USG remaining.

The pilot recalled the separate FUEL caution light illuminating just as the engine began to run roughly. Since the light illuminates when the fuel quantity in each tank is below about 14 USG, it would be possible for one tank to be empty and the caution light to illuminate when the second tank reached about 14 USG. The pilot stated that he changed tanks every 20 minutes to minimise fuel imbalance and avoid such a situation.

In theory, a larger tank imbalance could have been achieved by missing one of the timed tank switches during one of the four flights since the aircraft was last fuelled. If one of the in-flight switches had been missed, then calculations showed that the tank in use at the time of the engine problems would have run dry and the other tank would have been close to the nominal 14 USG alert level in the location of the engine problems, plus or minus less than 2 USG. In this scenario it would be more likely that the low fuel caution illuminated after the pilot switched tanks to address the rough running, whereas the pilot recalled it illuminated before he switched tanks. The only fuel indicators that could have differentiated between the contents of the left and right wing tanks were of an older, less reliable design, and not trusted by the pilot. As they linked into the low fuel caution system, this could explain the light not illuminating when it should have.

If one tank was empty with all the remaining fuel in the other tank, then it would be expected that the engine would recover when the tank was changed. However, this did not always occur in flight tests with the electric fuel pump off because air gets sucked into the fuel system when a tank is run dry. The pilot chose to switch tanks before deciding to deploy the BPRS, and the POH states that the fuel pump must be set to BOOST whenever the tank is changed. The pilot did not select the pump on, however, and this would likely have had an impact on the engine's capacity to recover had there been fuel in the tank to which the change was made.

Although it is not clear which of the reductions in fuel flow corresponded with the first fuel tank switch, the engine recovered for a short period despite the electric pump not being selected to BOOST. However, the pilot reported that he switched tanks again because the engine faltered again. If fuel remained in the tank he first switched to, it is possible that he did not leave enough time for the engine recovery to stabilise, or that it would have stabilised more quickly with the electric pump set to BOOST. Had he waited longer with the pump on, it is possible he might not have felt the need to switch back to the original tank.

Possible cause of fuel starvation if there was a fuel leak

Another possibility for the cause of fuel starvation is that both tanks ran dry due to a fuel leak upstream of the fuel flow sensor (between the sensor and the fuel tanks). The MFD only shows fuel used as measured by the fuel flow sensor so any fuel lost upstream of the sensor would not be detected by the MFD. For this to have happened the last fuel tank switch before the engine started faltering (about 11 minutes earlier), would have needed to have occurred just as that tank was about to run dry. Also, in the fuel leak scenario the FUEL caution light should have come on much earlier in the flight, in which case it was either not noticed or one of the gauges was indicating at least 14 USG while the tank was actually empty.

The fuel leak scenario demonstrates the importance of not relying on the MFD figures. The only way to detect a fuel leak in flight is by direct reference to the fuel gauges and comparing their indications to expected fuel figures along the route or MFD figures. The risk of running both tanks dry as a result of a fuel leak can be mitigated in the following ways:

1. Cross check the MFD figures with the fuel gauges to look for discrepancies between fuel remaining and fuel quantity.
2. Replace faulty fuel flow sensors if the fuel gauges are not reading accurately.
3. Calibrate the fuel gauges so you know the indications which correspond with actual quantities.
4. Carry more fuel so that there is always visible fuel in both tanks before departure, thereby increasing confidence in the reliability of the starting quantity.

Decision to deploy the BPRS

The event began at a relatively low altitude of 1,400 ft amsl, so little time was available to the pilot to action drills and attempt to resolve the engine issue. By the time the pilot had informed Lee-on-Solent of his situation and attempted a fuel tank change, the aircraft had descended to 800 ft amsl. The pilot attempted another fuel tank change, but this still had no effect. Believing that he would be unable to glide to land, the pilot deployed the BPRS in accordance with the training he received for engine failures in Cirrus aircraft, and the last altitude he recalled seeing was approximately 600 ft amsl. Data retrieved from the aircraft indicated that the BPRS was deployed descending through 340 ±20 ft above sea level.

The aircraft hit the sea in a nose-down attitude of 74° because there had not been time for the rear riser snub line to be cut, which would have pitched the aircraft back up to an approximately level attitude. This indicated that the system was deployed below a height that would have enabled the deployment sequence to complete.

The aircraft hit the sea at about 1,500 ft/min (15 kt) vertical speed, and despite the nose-low attitude the occupants were not injured and were able to egress successfully.

Guidance in the POH on use of BPRS

The guidance on the use of BPRS/CAPS in the POH says that, following an engine failure, CAPS activation should be considered if the forced landing would be on extremely rough or mountainous terrain, over water, over widespread ground fog or at night. There is a different emphasis in the manufacturer's online training programme which advises pilots to activate CAPS immediately following an engine failure between 500ft/600ft and 2,000 ft regardless of the terrain.

The POH states that below 2,000 ft CAPS should be activated almost immediately, but it does not provide a minimum safe altitude to deploy CAPS following an engine failure. It states that the height loss from level flight deployments has been demonstrated as less than 400 ft, but it does not provide a figure of the height loss when the aircraft is already descending in a glide descent following an engine failure. However, the online training programme provides a clear minimum safe height for activating CAPS after an engine failure.

The aircraft manufacturer stated that it would convene a panel to discuss updating the CAPS guidance in the POH to reflect the guidance in the CAPS online training programme, gained through in-service experience of CAPS deployments.

Conclusion

The aircraft suffered a loss of power, probably due to fuel starvation, but the cause of the fuel starvation could not be determined. It is possible that one fuel tank ran dry, and that the engine did not fully recover when the fuel tank was switched because the fuel pump had not been set to BOOST and the pilot had not kept this tank selected for long enough. However, the possibility of a fuel leak causing both tanks to run dry could not be ruled out. The pilot, believing that it would not be possible to glide to land, deployed the BPRS and the aircraft descended by parachute into the sea. Both those on board escaped uninjured.

The investigation highlighted the importance of setting the fuel pump switch to BOOST when changing fuel tanks, the importance of checking the fuel gauges for fuel quantity and any imbalance, and ensuring the serviceability of the fuel indication system. This is because neither the fuel totaliser system of the MFD nor the low fuel indication system can warn the pilot that a tank is about to run dry. Furthermore, if the fuel level in each tank is below about 15 USG, then due to the wing dihedral the pilot cannot visually check the fuel tank contents.

Safety action

The aircraft manufacturer stated that it would convene a panel to discuss updating the CAPS guidance in the POH to reflect the guidance in the CAPS online training programme.

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