ACCIDENT

Aircraft Type and Registration:	Piper PA-32-300, G-KNOW
No & Type of Engines:	1 Lycoming IO-540-K1G5 piston engine
Year of Manufacture:	1978 (Serial no: 32-7840111)
Date & Time (UTC):	11 February 2022 at 1300 hrs
Location:	Steyning Valley, South Downs Way, East Sussex
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - 1 (Serious) Passengers - 1 (Serious)
Nature of Damage:	Significant damage to fuselage, wings, engine and propeller. Beyond economic repair
Commander's Licence:	Private Pilot's Licence
Commander's Age:	63 years
Commander's Flying Experience:	698 hours (of which 180 were on type) Last 90 days - 2 hours Last 28 days - 2 hours
Information Source:	AAIB Field Investigation

Synopsis

While the aircraft had sufficient fuel on board for the flight, the fuel tank being used – which was one of four, separate, manually selected tanks – ran out of useable fuel, causing the engine to stop over a hilly area. Relevant emergency checklists were not carried out. The aircraft struck the ground heavily causing serious injuries to both occupants.

The report considers fuel management guidance. It discusses threat and error management techniques in relation to managing significant aircraft characteristics, raising situation awareness and regularly self-briefing emergency procedures.

In response to this accident, the CAA intends to include fuel management awareness in its current safety promotional activities.

History of the flight

Background information

On the day of the accident the pilot and a passenger set out to fly from Lydd Airport to Lee-on-Solent Airport, and back. The accident occurred during the return flight (Figure 1).

Outbound flight

G-KNOW took off from Lydd at 1005 hrs, routing south-west along the coast. It flew south of the Isle of Wight and around its west coast, landing at Lee-on-Solent at 1106 hrs.

Figure 1

Route flown on the day of the accident

Accident flight

G-KNOW took off from Lee-on-Solent at 1239 hrs and followed the coast eastbound, before routing inland (Figure 1). The passenger, who could not fully recall the accident, reported believing they went inland to see a landmark.

Recorded data indicated that at 1258 hrs the aircraft was heading east approaching Steyning on the northern border of the South Downs National Park, at 2,100 ft amsl and 136 KTAS. The passenger recalled the pilot saying they had "a problem" and the aircraft lost engine power. The pilot turned the aircraft right onto a south-westerly heading. Although he could not recall the accident, he believed this was to face into wind and avoid a built-up area ahead. He transmitted a MAYDAY call to Brighton City Airport[1], which was approximately 4 nm to the south-east.

The passenger, who was not a pilot, heard the pilot talking through his actions though could not recall what he said. He recalled the pilot trying to restart the engine around 2 or 3 times and operating the engine control levers[2], especially the mixture control lever (Figure 7). A number of witnesses reported hearing the engine "revving" and "spluttering", before it stopped.

The aircraft glided towards Steyning Valley then at around 950 ft amsl turned left, descending south along its western ridge line, reaching a minimum height above it of around 160 ft (Figure 3). The aircraft turned left towards the rising ground on the opposite side of the valley, already below its ridge line. The passenger described that turn, "Ahead to the right

Footnote

[1] Commonly referred to as Shoreham Airport.
[2] Engine controls: three levers for throttle, propeller, and mixture control.

were trees and ahead to the left was hilly grass. There were a few bad options, it was trying to decide which was least bad, the trees, or where we ended up on the hill".

The aircraft's TAS reduced throughout the descent to 67 kt, with a corresponding rate of descent of around 650 ft/min. The passenger indicated the ground was possibly steeper than it looked, and the aircraft struck it "hard", seriously injuring both occupants.

A helicopter emergency medical services (HEMS) crew heard the emergency on Brighton City's radio frequency and routed to the accident site. The HEMS crew and some witnesses helped the passenger exit the aircraft and extricated the pilot, who was unconscious. Both occupants were airlifted to hospital.

Weather and landscape information

Aftercast information showed there was little or no cloud near the aircraft route. The wind at 2,000 ft amsl when the engine stopped was approximately 4 kt from 230°, with temperature 1°C. Brighton City's surface wind was reported at 1250 hrs as 6 kt from 180°, with temperature 8°C.

Satellite imagery along the aircraft's flight path indicated that when the engine stopped there were three built-up areas ahead of the aircraft. Fields to the left of the aircraft appeared smaller than those to the right.

Recorded information

GPS navigation unit

The aircraft was equipped with a GPS navigation unit that logged the aircraft's height and position - the ground track of the flight from Lydd to Lee-on-Solent and accident flight is show in Figure 1.

For the flight from Lydd to Lee-on-Solent, the aircraft was airborne for 61 minutes, cruising at a height of about 3,000 ft amsl before descending to 1,500 ft amsl around the Isle of Wight. The aircraft's calculated airspeed[3] for the flight varied around 135 KIAS. The GPS was powered up 14 minutes before takeoff and powered down 3 minutes after landing.

For the accident flight, the aircraft was airborne for 21 minutes, and the GPS was powered up 13 minutes before takeoff. Figure 2 shows that the aircraft's cruise height varied around 2,000 ft amsl and an average calculated airspeed of 130 KIAS.

Footnote

[3] The indicated airspeed (IAS) was calculated from calibrated airspeed (CAS) using the airspeed calibration data in the PA-32-300 pilot's operating handbook. CAS was calculated from the true airspeed (TAS) by subtracting 1 kt per 1,000 ft of altitude. TAS was calculated using the groundspeed (derived from GPS position) and the wind aftercast information.

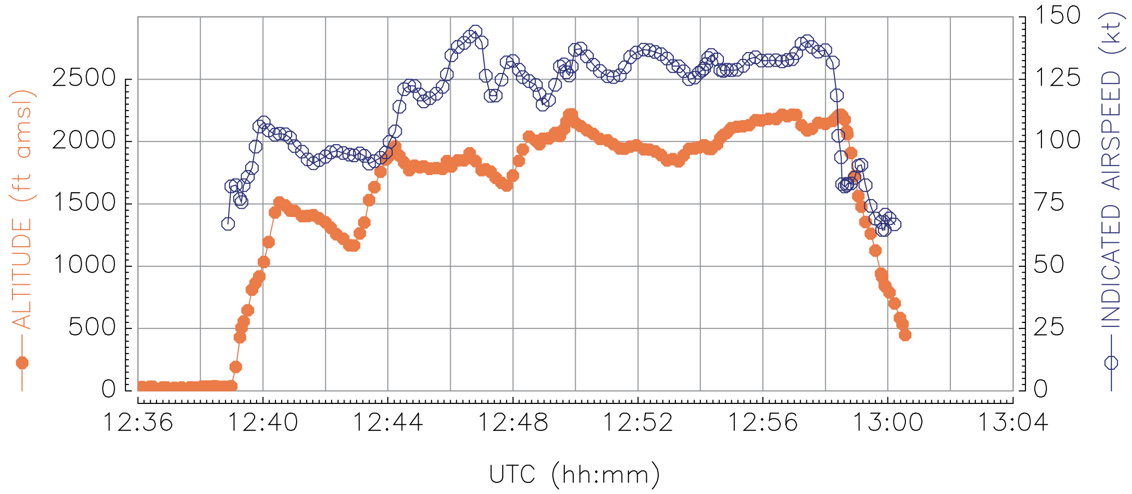

Figure 2

Accident flight GPS altitude and calculated IAS

Figure 3 details the GPS altitude and GPS derived data, and Figure 4 the ground track, for the last three minutes of the flight. The figures start at 1257:30 hrs just before the Mode A squawk[4] changed from 7011 (Southampton listening squawk) to 7000, with the aircraft tracking parallel to the northern border of the South Downs National Park, at approximately 2,100 ft amsl and about 136 KIAS. Points highlighted in the figures are:

UTC (hh:mm:ss)	Description
12:58:00	Altitude remained between 2,100 and 2,200 ft amsl while IAS started to decrease from 137 kt [1].
12:58:22	Start of turn towards southwest [2].
12:58:32	IAS reached about 83 kt and aircraft started to descend [3]. The descent rate peaked at 1,400 ft/min 17 seconds later [4] before reducing to about 850 ft/min.
12:59:04	Aircraft descended through 1,500 ft amsl and IAS increased to 91 kt as the pilot transmitted a MAYDAY call [5].
12:59:47	At about 950 ft amsl the aircraft turned left turn over high ground (240 ft below the aircraft) towards Steyning Valley, and then descended along its western ridgeline at rate of around 600 ft/min and airspeed of about 70 KIAS and slowing [6].
13:00:23	At about 160 ft agl, and near the end of the valley, the aircraft turned left towards the rising ground on the opposite side of the valley [7].

Footnote

4 From Secondary Surveillance Radar recordings.

The ground-track distance from point [1] to the accident site was about 3.65 nm. From point [3], when the aircraft's speed reduced to 83 KIAS, the distance was 2.54 nm, with a corresponding height loss of about 1,760 ft.

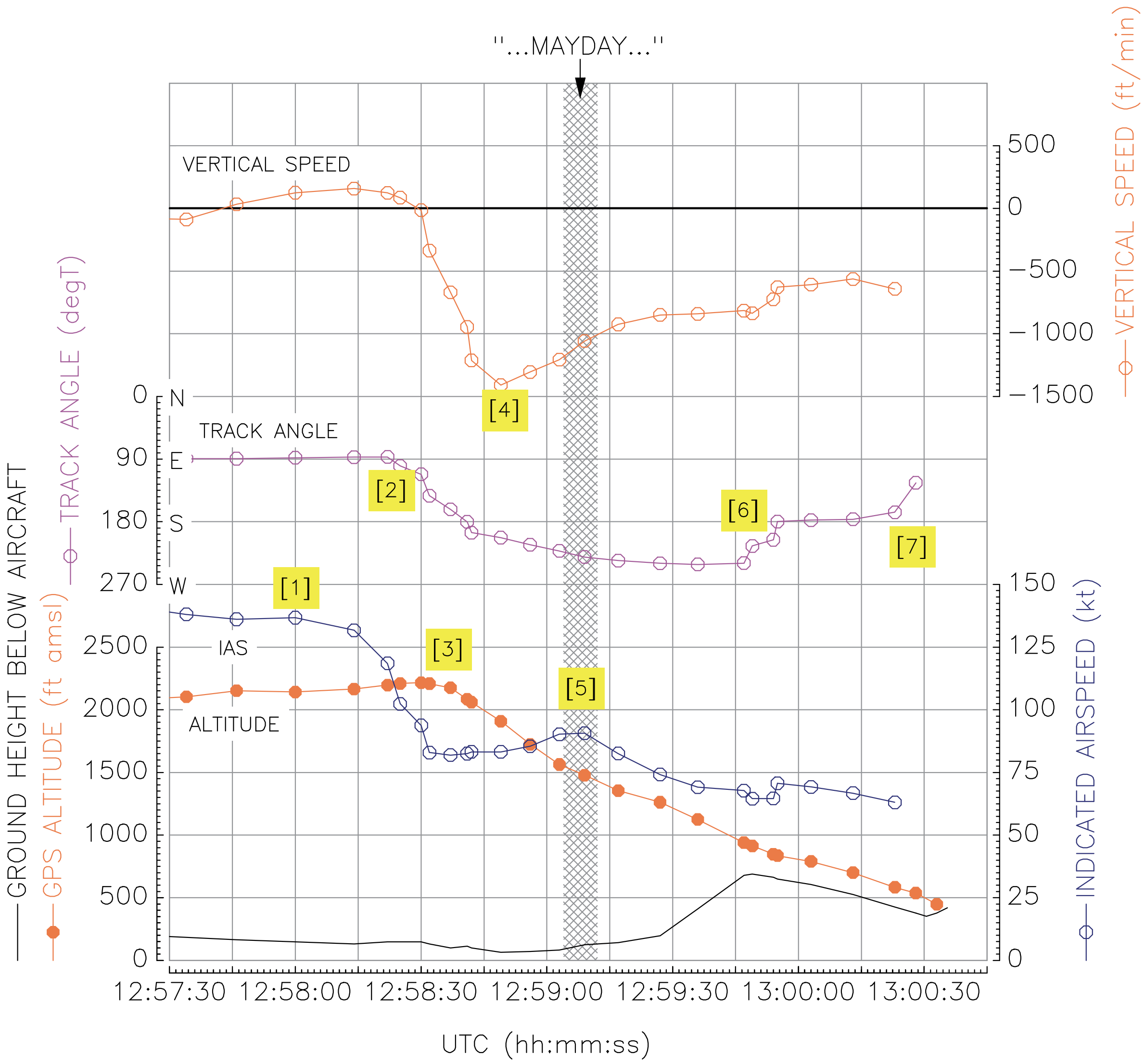

Figure 3

GPS altitude and derived data for last 3 minutes of the accident flight

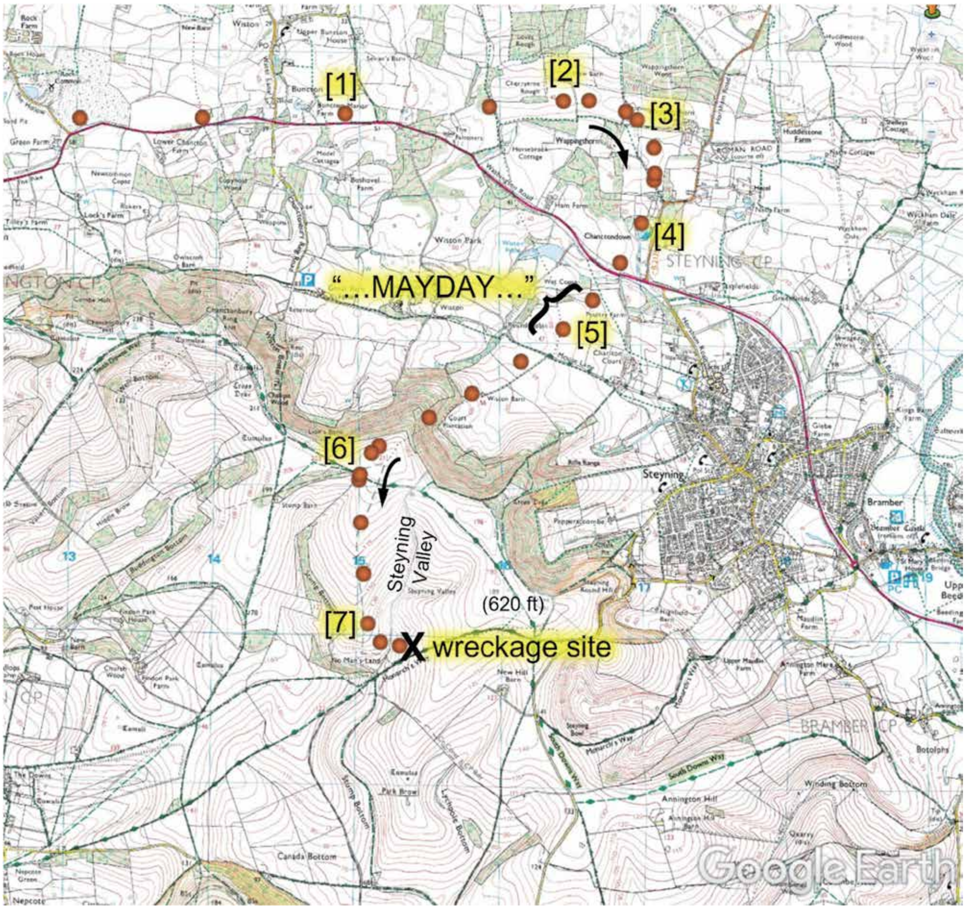

Figure 4

Ground track for last 3 minutes of the accident flight

'Switch fuel tanks' alarm

A switch fuel tanks alarm (fuel alarm) feature of the GPS unit was active and setup to display a 'Switch fuel tanks' message on the unit's screen every 15 minutes (Figure 5). The message could be cancelled by touching it and would be displayed again 15 minutes after it was last displayed (ie if a message was left on for 10 minutes before being cancelled it would display again after another 5 minutes). The GPS unit also allowed an audio alert – a single beep – which would sound at the same time the message was displayed; however, this option had been selected off.

Engine monitoring unit

Installed in the instrument panel was a JP Instruments EDM-730 engine monitoring unit (EMU) capable of displaying and recording engine and fuel parameters such as cylinder head and exhaust gas temperature, turbine inlet temperature and fuel flow. The unit's firmware, which had not been updated since the unit's manufacture in 2013, was such that once the internal memory was full it stopped logging new data. After downloading the memory, it was found that it had stopped logging new data in August 2017, so data for the accident flight had not been recorded. (A subsequent firmware update included a change to the recording function such that it would have overwritten the oldest data with new data.)

All times are UTC

Figure 5

GPS unit's 'Switch fuel tanks' alarm message

Additional information about the accident

The pilot

A family member of the pilot reported that in hospital after the accident he said "…running rough… battery dead… engine stopped". Otherwise, the pilot could not remember the day of the accident.

Eye witnesses

The passenger recalled the pilot had inspected the fuel tank quantities, both visually and on the gauges, and checking fuel samples, before both flights. The pilot performed engine ground checks[5] without any apparent abnormalities.

The passenger said the pilot explained some technical aspects to him prior to the outbound flight, including using the fuel selector lever to switch between tanks regularly. He recalled the pilot operating that lever during the flights but could not recall when. He did not remember noticing any fuel alarms which may have occurred.

The passenger described that after the engine stopped, the pilot "was occupied with re-starting the engine, then the MAYDAY call, then the heading we were given, then figuring out if we could make it, and then when we realised we wouldn't, where best to set the aircraft down".

A number of eye witnesses indicated that after the accident there was a strong smell of fuel near the aircraft, and it was trickling from a wing tip.

The HEMS pilot

The HEMS pilot reported that before helping G-KNOW's occupants out he turned the fuel selector "two positions, fully left, to the OFF position". He turned the magneto and starter

Footnote

5 Checking engine functionality at a high power setting prior to takeoff.

switch from BOTH to OFF. Referring to the electrical switch panel[6], he recalled believing the master switch and fuel pump were already OFF, and that he turned the anti-collision light, landing light, and pitot heat OFF.

Accident site

The aircraft force landed on an eastern face of Steyning Valley, on rising ground that varied from approximately 15° gradient, at the first point of impact, to 11°; where the aircraft came to rest. The initial ground impact marks show the left-wing tip hit the ground first. The impact on the left-wing tip was followed by the left main landing gear (MLG) striking the ground causing it to break free and bounce forward and right of the aircraft heading. The aircraft then rolled right resulting in an impact on the right MLG, which struck with such force that it resulted in a downward bend of the right wing at approximately 50% span. The aircraft's lower left front fuselage then struck the ground with sufficient impetus to drive the engine upwards, bend the nose landing gear aft and cause the tail structure to fail and partially separate just aft of the rear cockpit. Damage to the aircraft was consistent with a high sink rate on impact. After the fuselage impact, the aircraft bounced, shedding various pieces of structure including the left tip tank and right MLG. The aircraft came to rest at a fence line, (Figure 6), where the right-wing tip struck a fence post, disrupting the fuel tank.

Figure 6

Ground impact marks, wreckage trail and damaged aircraft

Footnote

6 A set of switches located to the left of the pilot's seat.

Aircraft information

G-KNOW was a PA-32 Cherokee 'Six' which is a stretched version of the four seat Piper PA-28 family of single engine monoplanes. Featuring six seats, a fixed tricycle landing gear and all metal construction, the aircraft was powered by a six-cylinder, fuel injected, 300 hp Lycoming IO-540 piston engine. Constructed in 1978, the aircraft had flown 3,297 hours since new. The Airworthiness Review Certificate was due to expire on 28 March 2022.

Aircraft fuel system

G-KNOW's fuel system layout comprised of two metal main fuel tanks (main tanks), one in each wing, and two resin-impregnated fibreglass wing tip tanks (tip tanks). The fuel tanks were manually selected by moving a fuel selector lever located below the centre console to one of five positions. The lever could be positioned to OFF, left tip tank (LEFT TIP), left main tank (LEFT MAIN), right main tank (RIGHT MAIN) and right tip tank (RIGHT TIP). The lever was connected via a rod to a fuel selector valve located below the floor underneath the two forward passenger seats in the rear cockpit. The valve had five detents, each one corresponding to one of the fuel tank selections. The valve also had a fuel strainer and drain lever to allow fuel to be drained from each of the tanks and connecting pipes depending on tank selection.

Fuel was supplied from the tanks to the fuel injection system via an engine driven fuel pump. There was also a separate electric auxiliary booster pump providing a backup to the engine driven pump and boosting fuel pressure during periods of high fuel demand such as takeoff. The electric pump was operated from a single switch in the cockpit and had independent circuit protection.

The RSA type fuel injector system used a flow divider to proportion a constant stream of metered fuel to injection nozzles at the intake manifold port of each cylinder (Figure 7). The system used a combination of differential air pressure and differential fuel pressure to regulate and meter the fuel flow. The fuel required for the engine was metered via a venturi measuring device. This provided proportional changes to the amount of fuel according to the flow rate of air through the venturi. The fuel was then divided evenly by the flow divider and delivered to the respective intake manifolds. Fuel was sprayed onto the back of the intake valves and the resulting fuel-air mixture pulled into the cylinder when the intake valve opened.

Fuel quantity gauges for each of the four tanks were fitted to the cockpit engine instrument cluster on the lower left side of the instrument panel together with a fuel pressure gauge and a fuel flow indicator (Figure 11).

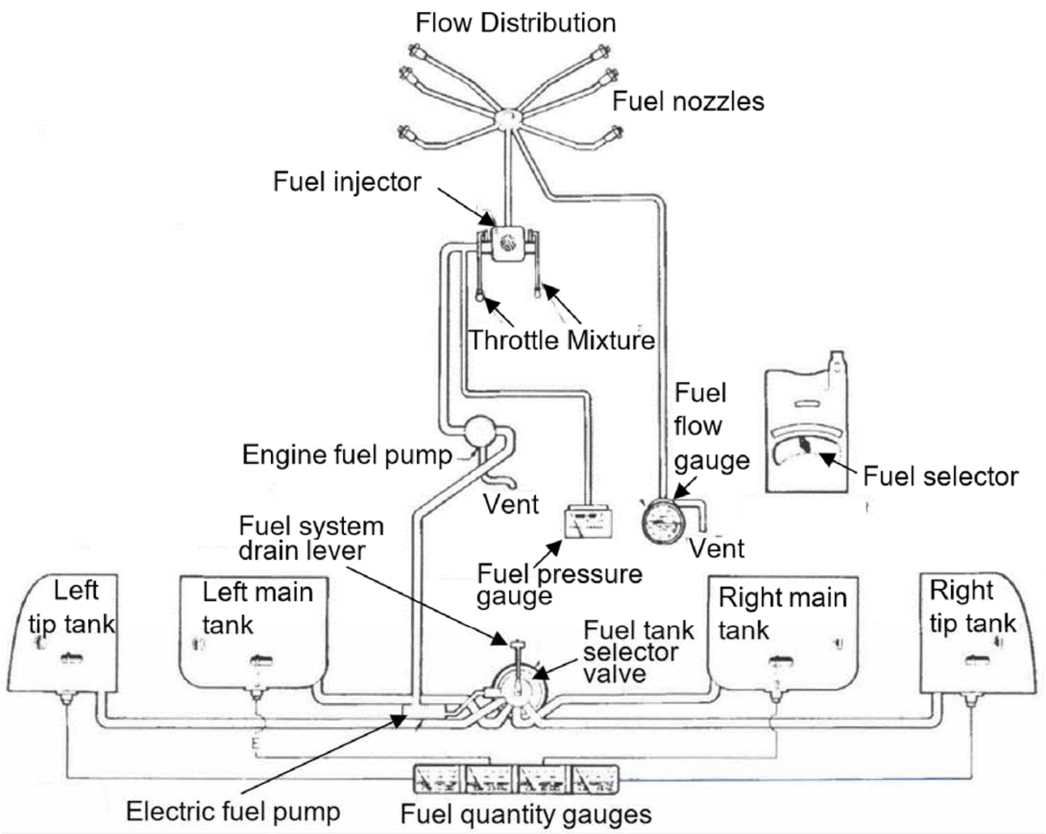

Figure 7

Fuel system diagram for G-KNOW

Information from the aircraft's Pilot Operating Handbook

Fuel system

The aircraft's *'Pilot Operating Handbook'*[7] (POH) specified the total fuel capacity as 84.0 gal US[8], including an unusable amount of 0.1 gal US[9] per tank. Each wing tip tank (tip tank) holds 17 gal US. Each main tank holds 25 gal US, or 18 gal US if fuelled to the *'FILLER NECK INDICATOR'*, also known as 'tabs'.

The *'FUEL SYSTEM'* section explained *'…fuel should be distributed equally between each side. The tip tanks should always be filled first, and fuel from the main tanks should be used first.'*

G-KNOW had *'Fuel quantity gauges for each of the four tanks'* and a *'fuel pressure indicator'* (Figure 9). It had an *'electric fuel pump… for use in case of failure of the engine driven pump'*.

Footnote

7 *'CHEROKEE SIX 300 INFORMATION MANUAL'*, Handbook part no. 761 632, issued 19 August 1976; therein referred to as the *'Pilot's Operating Handbook'*.
8 Different fuel capacities were specified for some aircraft with other serial numbers.
9 Around 400 ml.

Performance

Cruise performance tables gave an approximate fuel flow of 16 to 18 US gallons per hour (GPH)[10,11], when using 75% rated power setting[12]. They indicated the endurance for an aircraft fuelled to tip tanks full and main tanks 'tabs', in conditions similar to the day of the accident, could be 3 hours and 53 minutes to 4 hours and 10 minutes[13,14].

Normal procedures

The *'AIRSPEEDS FOR SAFE OPERATIONS'* section specifies the *'Landing Final Approach Speed (Flaps 40°)'* as 80 KIAS. There was no corresponding airspeed for landing with flaps up.

Emergency procedures

The *'ENGINE POWER LOSS IN FLIGHT'* emergency checklist[15] stated:

ENGINE POWER LOSS IN FLIGHT

Fuel selector . . . . switch to tank containing fuel
Electric fuel pump . . . . .ON
Mixture . . . . RICH
Alternate air . . . . OPEN
Engine gauges . . . . .check for indication of cause of power loss
If no fuel pressure is indicated, check tank selector position to be sure it is on a tank containing fuel.

When power is restored:
Alternate air . . . . CLOSED
Electric fuel pump . . . . .OFF
If power is not restored prepare for power off landing.
Trim for 87 KIAS

The corresponding amplified procedure additionally stated:

> *'Complete engine power loss is usually caused by fuel flow interruption and power will be restored shortly after fuel flow is restored. If power loss occurs at a low altitude, the first step is to prepare for an emergency landing…*

Footnote

10 Depending on use of best economy or best power settings.
11 Mixture leaned per Lycoming instructions; maximum gross weight; 2,400 rpm.
12 A power setting table provides manifold pressure values for operating at 55%, 65% or 75% rated power, using 2,100 to 2,400 rpm.
13 Depending on use of best economy or best power settings.
14 Mixture leaned per Lycoming instructions; no planned reserve; endurance includes time to climb and descend.
15 'Emergency checklist' – abbreviated in nature, containing an action sequence for critical situations. Expanded on in the corresponding 'Amplified emergency procedure'.

If time permits, turn the ignition switch to "L" then "R" then back to "BOTH." Move the throttle and mixture control levers to different settings. This may restore the power if the problem is too rich or too lean[16] *a mixture or if there is a partial fuel system restriction. Try other fuel tanks. Water in the fuel could take some time to be used up, and allowing the engine to windmill may restore power. If power loss is due to water, fuel pressure indications will be normal.*

If engine failure was caused by fuel exhaustion power will not be restored after switching fuel tanks until the empty fuel lines are filled. This may require up to ten seconds.

If power is not regained, proceed with the Power Off Landing procedure…'

The *'POWER OFF LANDING'* emergency checklist stated:

POWER OFF LANDING

Locate suitable field.
Establish spiral pattern.
1000 ft. above field at downwind position for normal landing approach.
When field can easily be reached slow to 80 KIAS for shortest landing.

Touchdowns should normally be made at lowest possible airspeed with full flaps.

When committed to landing:

Ignition	OFF
Master switch	OFF
Fuel selector	OFF
Mixture	idle cut-off
Seat belt and harness	tight

The corresponding amplified procedure additionally stated:

'If loss of power occurs at altitude, trim the aircraft for best gliding angle (87 KIAS, Air Cond. off) and look for a suitable field. If measures taken to restore power are not effective, and if time permits, check your charts for airports in the immediate vicinity; it may be possible to land at one if you have sufficient altitude. At best gliding angle, with the engine windmilling, and the propeller control in full "DECREASE rpm," the aircraft will travel approximately 1.5 miles for each thousand feet of altitude…

When you have located a suitable field, establish a spiral pattern around this field. Try to be at 1000 feet above the field at the downwind position, to make a normal landing approach. When the field can easily be reached, slow to

Footnote

16 A pilot uses the mixture control lever fuel to adjust the air to fuel ratio, resulting in the mixture being 'rich' (relatively more fuel) or 'lean' (relatively less fuel).

80 KIAS with flaps down for the shortest landing. Excess altitude may be lost by widening your pattern, using flaps or slipping, or a combination of these.'

Aircraft examination

Examination of the cockpit at the accident site revealed the fuel selector lever was positioned between LEFT TIP (left-wing tip fuel tank), and LEFT MAIN (left main fuel tank), (Figure 8). Force was needed to move the lever to OFF, but it would not stay in position and sprang back between LEFT TIP and LEFT MAIN. From this position, moving the lever two 'clicks' to the right selected the RIGHT MAIN fuel tank and the lever remained in position. The switches on the main switch panel to the left of the cockpit and the ignition switches were set to OFF. The flap lever between the front seats was positioned in the first notch of the selection mechanism, indicating 10° flap was selected[17]. Although the flaps were selected to 10°, the flap control surfaces were in the up position (0° flap). On the engine control quadrant, the throttle lever was set just above IDLE and was bent and jammed in this position. The throttle housing was also deformed and torn. The fuel mixture lever was positioned just below RICH and the propeller lever was pushed fully forward to INCR (increase). To the right of the quadrant, the Alternate Air (Alt. Air) lever was in the CLOSED position.

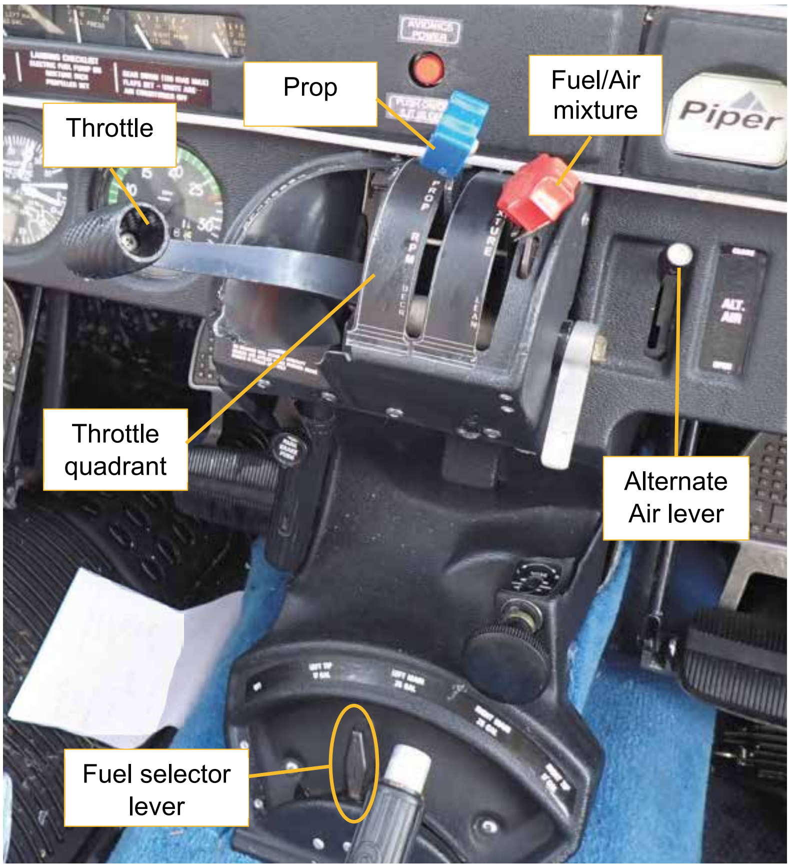

Figure 8

Fuel selector lever position, throttle quadrant and Alt. Air lever

Footnote

[17] The flap mechanism has three extended positions - 10°, 25° and 40°.

The front left seat was resting on the cockpit floor because the seat's lower frame assembly had collapsed during the impact. The right seat's frame was deformed, but not to the same extent as the left, and was still fixed in place. Both front seat shoulder straps inertia reels were locked with the straps almost fully extended.

Whilst both wing tip tanks were disrupted and contained no fuel, the main fuel tanks were undamaged. Approximately 8 gal US of fuel was recovered from the left main tank but only about 0.12 of a US gallon[18] was recovered from the right tank.

The damage to the propeller blades was consistent with an engine not under power when the aircraft hit the ground. The underside of the spinner was lightly scored longitudinally rather than radially, also indicating that the propeller had not been turning under power when it scraped along the ground.

Fuel System

Examination of both main fuel tanks did not reveal any signs of damage or leakage from the tanks or the connecting pipework. Examination and operation of the electric fuel pump showed that it was still functioning correctly. The engine driven fuel pump was removed, and bench tested, it also operated without fault. The engine's flow divider spring loaded valve showed no signs of obstructions or debris and the valve slid out of its housing with little resistance. Both the fuel injector servo and flow divider were sent to a certified maintenance facility for bench testing. Other than some minor calibration issues with the servo, both devices were functioning correctly. There were no signs of leakage from any of the fuel pipes between the aircraft's fuel tanks and the engine.

On accessing the fuel selector valve, a light touch of the selector rod connecting the valve to the fuel selector lever resulted in a slight displacement of the rod. The fuel selector lever operated normally afterwards, with all five selectable positions producing positive detents and the lever remaining in position when released. Subsequent examination of the fuel selector valve showed no sign of damage or obstructions and correct operation at each detent location. It is likely that the selector lever connecting rod was displaced during the accident sequence as there were no reports of fuel selection issues prior to the accident. Fuel samples from the remaining main tanks were clear, bright and showed no sign of contamination from water or debris.

Engine

Whist there were some minor faults found during the engine examination, none would have caused the engine to fail in flight or prevent the engine from restarting.

Flight control surfaces

Control surface connections were checked on site and continuity to their respective controls confirmed. The controls responded correctly to inputs from the control yoke.

Footnote

[18] Approximately 473 ml

Battery

Whilst the external surfaces of the aircraft battery showed some superficial damage, there was sufficient charge remaining to power the fuel booster pump at the site. A later recharge attempt was successful with the battery charge increased by 20%, although no further attempts were made due to the potential risk of internal damage. The battery was functioning correctly when examined.

Survivability

Injuries

The passenger sustained serious injuries to his chest, spine and skull. The pilot sustained serious and, in some cases, life changing injuries to his head, neck, spine, chest and hips.

Damage to the front seats

The front left seat's frame lower assembly had deformed and completely collapsed during the accident leaving the upper section of the seat frame resting on the cockpit floor. The lower section of the structure had broken away from the frame assembly and, although still attached to the cockpit floor, was only attached to the seat by the cables for the height adjustment mechanism (Figure 9). The assembly had failed in overload due to the vertical impact force resulting from the aircraft's high sink rate as it struck the ground.

Figure 9

Front left seat showing disrupted frame assembly

By comparison, the right seat's frame assembly although deformed, remained attached to the cockpit floor on three out of the four floor brackets (Figure 10). The seat was still elevated above the floor by the brackets but, due to the deformation of the frame assembly, not to its full extent.

Figure 10

Front right seat showing compressed and partially disrupted frame assembly

Inertia reel, three-point harnesses

Both front seat three-point inertia reel harnesses were locked in place. Once the belts were slackened and pushed back into the reel, they unlocked and rewound slightly back onto their reels. Visual inspection of the shoulder harness webbing connected to their respective release buckles revealed signs of stretching and damage to the stitching commensurate with the effect of the impact forces on the occupants. Post-accident inspection of both shoulder harnesses revealed similar lengths of the belts were extended from their reels to the belt buckle and similar damage to their stitched ends fitted to the belt buckles.

Arrangements for using the aircraft

The aircraft's owner kept G-KNOW at Lydd and allowed a small number of other pilots to fly it, including the accident pilot. The other pilots would inform the owner, then arrange to use the aircraft directly with the airport. Each pilot would refuel it afterwards, to tip tanks full and main tanks tabs.

G-KNOW was last flown prior to the day of the accident on 1 February 2022 by the accident pilot. He performed three touch and go's, and a landing, and refuelled the aircraft according to the normal agreement.

Personnel

The pilot started flying in 1995 and had owned a number of aircraft. That included a PA-32R-301T Saratoga on which he had logged 140 hours. His logbook showed he had regularly flown with passengers, often landing away at other airfields.

The pilot's logbook and G-KNOW's technical log indicated he first flew that aircraft in August 2020. Almost all his logged flights since then were in G-KNOW, totalling around 40 hours. These were mainly single flights out of Lydd of 0.5 to 2.0 hours. Three return trips to other airfields – Goodwood, Lee-on-Solent and Duxford – were recorded, and the pilot said he had flown the accident route before. On the Lee-on-Solent and Goodwood trips, the pilot had logged the outbound flight, but not the return.

The passenger described himself as an aviation enthusiast. He did not hold a pilot's licence.

One of the other pilots who flew G-KNOW worked as a contract pilot and flight instructor – herein he is referred to as 'Pilot B'. He reported having around 60 to 70 hours in G-KNOW and had instructed the aircraft owner and accident pilot in that, and other, aircraft.

Additional aircraft operating information

Information relating to the pilot

The pilot indicated, for trips like the accident one, he would depart with the aircraft fuelled to "tabs"[19], so he could fly there and back with generous reserves. He would select the fullest tank for takeoff[20] and switch tanks in response to the fuel alarm. He said he normally used a 75% rated cruise power setting and would begin leaning the mixture in stages when approaching cruise altitude.

The Saratoga aircraft the pilot previously owned had two interconnected fuel tanks in each wing. The fuel selector had three positions, one corresponding to each inboard wing tank and an OFF position.

Information from other G-KNOW pilots

Pilot B considered the Cherokee Six to consume comparatively more fuel than other aircraft he flew, and the mixture should be leaned effectively. He described the fuel alarm audio alert as "intrusive". He said he used the EMU's fuel information with caution because he could not be sure of its accuracy. Its quantity reading relied on being updated by pilots. Both the aircraft owner and Pilot B reported expecting a fuel flow of around 17 GPH[21] when operating G-KNOW, which could normally be leaned to around 16 GPH. The aircraft owner indicated he would identify where on a route he anticipated switching to tip tanks.

Pilot B commented the aircraft's glide performance was less than other types he flew and could be noticeably improved by setting the propeller control to 'full decrease'[22,23].

Footnote

19 Main fuel tanks filled to tabs and wing tip tanks full.
20 The POH's *'BEFORE TAKEOFF'* checklist included moving the *'Fuel selector'* to the *'proper tank'*.
21 The owner said he would expect 18 GPH fuel flow for cruise altitudes at or below 1,500 ft.
22 The propeller control lever is used to adjust propeller RPM to high ('INCR') to low ('DECR').
23 POH glide performance tables assume the use of 'full decrease'.

Cockpit fuel information

Figure 11

G-KNOW analogue fuel information[24]

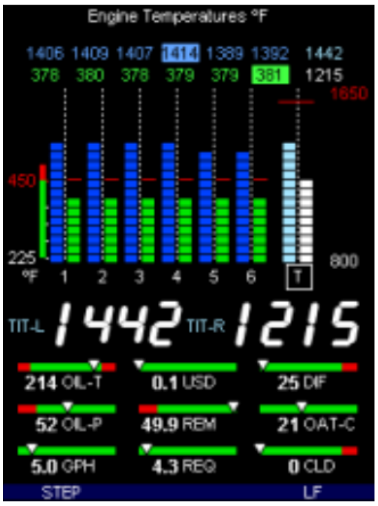

Figure 12

Typical display configuration of the EMU[25]

Fuel planning guidance

The CAA's *'Safety Sense Leaflet 1E Good Airmanship'*[26] contains the following guidance:

> *'13 <u>FUEL PLANNING</u>*
>
> *a) Always plan to land by the time the tanks are down to the greater of ¼ tank or 45 minutes' cruise flight, but don't rely solely on gauge(s) which may be unreliable. Remember, head-winds may be stronger than forecast and frequent use of carb heat will reduce range.*
>
> *b) Understand the operation and limitations of the fuel system, gauges, pumps, mixture control, unusable fuel etc. and remember to lean the mixture if it is permitted.*

Footnote

24 Photograph taken some weeks after the accident.
25 From the unit's *'Pilot's Guide'.*
26 SafetySense Leaflet 01 (caa.co.uk) [accessed 16 August 2022].

c) Don't assume you can achieve the Handbook/Manual fuel consumption. As a rule of thumb, due to service and wear, expect to use 20% more fuel than the 'book' figures.'

The CAA's *'Skyway Code'*[27] stated *'You must ensure sufficient fuel, oil, coolant or ballast (depending on the type of aircraft) is carried for the intended flight and a safe margin for contingencies…'*. The minimum day time VFR fuel reserve for an aircraft like G-KNOW[28] is 30 minutes.

It advised:

'You should have a good working knowledge of your aircraft's fuel burn at different power settings. Leaning is also an important element of engine and fuel management. You should be familiar with the procedure for your aircraft's engine.

- *Fuel burn and range figures can be found in the AFM[29]*
- *The amount of fuel reserve carried should be proportionate to the nature of the intended flight...*
- *On a longer flight or if fuel reserves may be marginal, you should pay much more attention…[30]*
- *Fuel gauges in most GA aircraft are not sufficiently reliable for the purposes of flight planning or pre-flight checking… However in flight, low fuel gauge readings should never be ignored.'*

The Aircraft Owners and Pilots Association (AOPA) produced a *'Safety spotlight'* article on *'Fuel Management'*[31]. It included the following advice:

'Know the fuel system of the airplane you fly. Some systems are quite simple, while others may be complex and include auxiliary and aftermarket tip tanks with electrical boost and transfer pumps. Pilots have made forced landings with fuel still available because they did not understand the system or operate it properly…

To maintain lateral balance in airplanes that cannot simultaneously feed fuel from both wings, try to keep tanks as equal as possible (within reason)… Many pilots mount a timer in plain view to remind them to switch tanks…

Determine available fuel in hours and minutes instead of gallons and pounds…

Recalculate range and endurance hourly to maintain adequate fuel reserves.'

Footnote

27 CAP1535S Skyway Code Version 3.pdf (caa.co.uk) [accessed 16 August 2022].
28 Part-21 under Part-NCO.
29 Aircraft flight manual.
30 Listed factors relating to fuel burn, cruise altitude and TAS, winds and diversion options.
31 Fuel Management - AOPA [accessed 16 August 2022].

Startle

A SKYbrary article on *'Startle effect'*[32] stated:

> *'Startle has been found to impair information processing performance on mundane tasks, such as continuous solving of basic arithmetic problems, for 30 to 60 seconds after the event occurrence. The duration of the performance degradation increases as the task becomes more complex. Thus, the startle effect disrupts cognitive processing and can negatively influence an individual's decision making and problem solving abilities.'*

CAP 737 stated the following in its section on *'Surprise and startle'*:

> *'…the fight or flight[33] response is accompanied by an urge to be engaged in the active solution… the brain wants to quickly establish a very basic mental model then drop any assessment process in order to concentrate all attention to the response. But if resources are not given to assessment and problem solving then the person cannot decide the best response… This situation would be best described as a vicious circle… the brain favours sources of information that require the minimum of processing. This means simple 'real-world' cues or conditioned cues and responses.*
>
> *…reduced fear of situations can happen… for example becoming more confident in one's ability to cope with emergencies, more familiar with an aircraft type or more familiar with unusual situations or upsets.'*

Analysis

Engine and fuel system

During aircraft examination there was no evidence of pre-existing faults with the engine and fuel system which would have caused the engine to stop in flight.

Fuel selection

There was no evidence of fuel leakage from the right main fuel tank. As only 0.12 US gallons of fuel was recovered from the right main fuel tank, and it had an unusable fuel volume of 0.1 US gallons, the tank was effectively empty when examined. There was sufficient fuel in the left main tank to continue powered flight and there was anecdotal evidence from the rescue services at the accident site that both tip tanks contained fuel prior to the impact. The most probable cause of the loss of engine power was fuel starvation as a result of continued use of fuel from the right main fuel tank.

Accident dynamics

The ground impact on the front left nose of the aircraft was sufficient to bend the nose and engine upwards and overload the left pilot's seat's support structure. The aircraft's impact

Footnote

32 Startle Effect | SKYbrary Aviation Safety [accessed 10 February 2023].
33 Innate, 'alarm' reaction to a threat – often coincides with startle effect.

dynamics show that it had a high sink rate and left-wing low attitude when it struck the ground creating vertical forces on the left seat that were much greater than the right seat. This is why the pilot received more significant injuries than the passenger.

Fuel planning and management

General information

The pilot mainly could not recall the day of the accident. The HEMS pilot's description of moving the fuel selector lever after the accident suggested the right main tank, which was empty of useable fuel, was selected when the engine stopped.

The evidence suggested the pilot followed the normal procedure of using fuel from the main tanks first. Assuming the tip tanks were full when the engine stopped, the resulting main tank quantities and recorded data indicate 28 gal US was consumed, at a rate of 15.1 GPH, during both flights. That rate, being slightly lower than that suggested by other pilots and relevant performance tables, indicated the pilot was leaning the mixture effectively.

Endurance

Consistent with advice to consider fuel in 'time' as well as quantity, relevant performance tables suggested G-KNOW's outbound departure fuel equated to around four hours' endurance, with thirty minutes of that constituting the required daytime minimum reserve. Recorded data indicated the aircraft's engine had been running for 1 hour and 51 minutes across the two flights when it stopped, with more than half its initial departure fuel still on board.

The pilot indicated he tended to fly familiar routes, well within the range of the aircraft fuelled to 'tabs'. The investigation did not establish what, if any, additional pre-flight fuel planning he undertook. Estimating an engine running time of around 2 hours and 30 minutes for both flights, sufficient total fuel was onboard to complete them while preserving a substantial margin over, not just the required reserve, but also the *'45 minutes' cruise flight'* suggested in CAA guidance.

The estimated fuel burn of 15.1 GPH indicated G-KNOW's actual endurance was around 40 minutes higher than the planning figure. Though CAA guidance recommends expecting to use 20% more than POH figures.

In-flight fuel management

The POH and other guidance recommended keeping the fuel as equal as possible between sides. Recorded data and fuel quantities found in G-KNOW's main tanks after the accident indicated there was a fuel imbalance equating to around 32 minutes flying time when the engine stopped, theoretically enough time for two fuel alarms. While the passenger described the pilot inspecting G-KNOW's fuel and operating the fuel selector lever, the investigation did not establish how the pilot managed fuel across the flights and how that imbalance developed.

The pilot said he normally switched fuel tanks in response to the fuel alarm, the audio for which was found after the accident to be OFF. While the screen message would still have presented, the absence of that "intrusive" sound indicates why the otherwise observant passenger did not notice any alarms, and probably reduced the pilot's fuel awareness. The engine stopped around 19 minutes into the return flight. Given the pilot normally took off using the fuller fuel tank, he possibly switched to the emptier one shortly before the engine stopped, in response to the first fuel screen message.

The investigation did not establish whether the pilot updated the EMU fuel quantity, and consequently how accurate it was. That total quantity does not account for separate tanks. Therefore, while cockpit gauges can be imprecise, they pictorially represent individual tank quantities and should be continuously observed, particularly when switching tanks and when fuel becomes low in a tank.

Under the same circumstances, an aircraft with two fuel feeds like the Saratoga could probably have completed both flights, even with the right side selected for the remainder of the return leg. The Cherokee's fuel system – having four, independent, manually selected fuel tanks – may require particular understanding and disciplined management, for example, in relation to fuel burn awareness and balancing. Endurance and reserves could be considered for each tank, as well as overall, perhaps applying the CAA's minimum quarter tank landing fuel guidance. EMU information and GPS fuel alarms are useful back-up tools which can be checked against fuel gauges, and inflight endurance calculations using timers mounted in plain view.

Events after the engine stopped

Track

Recorded data and weather reports were consistent with the pilot's suggestion that he turned the aircraft right to face into wind, and to avoid a built-up area. While there were hills on the right, the fields may have appeared more suitable than those on the left. It is possible the undulation of the terrain was not immediately obvious at the height the aircraft was flying.

The passenger's description of the pilot's actions, and the aircraft's final turn representing a decision between "bad options", indicate – to the extent the terrain would have allowed – a pattern was not established around a chosen field.

Descent and airspeed

Relevant emergency procedures specified trimming for the best gliding angle speed of 87 KIAS and preparing for an emergency landing. G-KNOW's airspeed initially reduced to around 83 KIAS. It fluctuated and continued reducing to a minimum of 67 KIAS, around 30 seconds before it struck the ground. Notwithstanding the effects of the wind, which was light, flying at speeds other than 87 KIAS meant G-KNOW travelled 0.1 nm less than that suggested by the POH. Selecting the propeller lever to FULL DECREASE improves glide performance.

The power off landing procedure specified a landing speed of 80 KIAS, with flaps down. Therefore, G-KNOW's landing speed of 67 KIAS, with flaps up, was substantially slower than what would be the relevant speed. The resulting 650 ft/min descent rate combined with rising ground contributed to the "hard" nature of the touchdown.

Emergency checklists

Notwithstanding any unrecorded cockpit selections which may have occurred immediately after the accident, the positions of the fuel selector lever, electric fuel pump switch, mixture control lever, alternate air control, and ignition switch, indicated the engine power loss in flight and power off landing checklists were not performed. However, consistent with the power off landing procedure, the master switch appeared to have been switched off.

Startle

Relevant emergency procedures recommended first attempting to restore fuel flow – which can take 10 seconds – and or preparing for an emergency landing. The passenger's description of the pilot focussing on a 'real-world' active solution of re-starting the engine, suggested the pilot was experiencing 'fight or flight'. No faults were found supporting the pilot's recollection of a battery problem.

Regularly self-briefing emergency procedures reduces the mental processing required by them, allowing the actions to become *'conditioned'* responses. The act of performing a learned procedure can help a startled pilot rebuild situation awareness.

Threat and error management

Threat and error management (TEM) involves pilots thinking ahead to identify threats and specifying actions to prevent or deal with any resulting errors – thus raising situation awareness and reducing the potential effects of startle. Examples in the context of this accident could include identifying significant characteristics of a new aircraft type; considering the ramifications of four separate fuel tanks; regularly self-briefing engine failure procedures; and managing potential distractions related to carrying passengers and locating landmarks.

A pilot more used to flying the outbound leg of a trip might identify fuel management on the return leg as a 'threat' – when tank quantities may be lower. That might involve determining where, geographically, they expect to switch to tip tanks.

Safety promotion

In response to this accident, the CAA said it intends to include fuel management awareness in its general aviation safety promotional activities before summer 2023.

Conclusion

The aircraft's engine stopped because the fuel tank being used ran out of useable fuel. There was sufficient fuel in the remaining three tanks to complete the flight. Relevant emergency checklists were not carried out and the aircraft struck hilly ground.

Proper fuel management, especially on aircraft with multiple fuel tanks, and regularly self-briefing emergency procedures in a threat and error management context could reduce the risk of, or consequences of, engine stoppage due to fuel starvation.

In response to this accident, the CAA intends to include fuel management awareness in its current safety promotional activities.

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