Civil Aviation Authority

SAFETY NOTICE

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Carbon Monoxide Contamination Minimisation and Detection in General Aviation Aircraft

This Safety Notice contains recommendations regarding operational safety.

Recipients must ensure that this Notice is copied to all members of their staff who need to take appropriate action or who may have an interest in the information (including any 'in-house' or contracted maintenance organisations and relevant outside contractors).

Applicability:	
Aerodromes:	Not primarily affected
Air Traffic:	Not primarily affected
Airspace:	Not primarily affected
Airworthiness:	All BCAR A8-23 / A8-24 / A8-25 / A8-26, EASA Part-M/F, M/G and Part CAO/CAMO Organisations
Flight Operations:	Operators of General Aviation Aircraft
Licensed/Unlicensed Personnel:	General Aviation Pilots and Engineers

1 Introduction

1.1 This Safety Notice is published to raise awareness of the means of minimising the likelihood of carbon monoxide contamination, the hazards associated with carbon monoxide exposure and to provide guidance on the use of carbon monoxide detectors in general aviation aircraft.

1.2 The potential dangers of carbon monoxide exposure have been highlighted by the UK Air Accidents Investigations Branch (AAIB) in Special Bulletin S2/2019, concerning an accident involving a Piper Malibu. A toxicology report on the passenger identified potentially fatal levels of carbon monoxide exposure.

1.3 It is considered timely to remind aircraft owners, operators and maintainers of measures that can be taken to reduce the likelihood of critical carbon monoxide poisoning during flight.

1.4 Carbon monoxide, formed by the incomplete combustion of carbon-containing materials, is a colourless, odourless gas that can cause damage to the brain, heart and nervous system. The symptoms in you and/or your passengers of exposure include; headache, fatigue, sleepiness, breathlessness, degradation in performance. Continued exposure to elevated concentrations can cause unconsciousness and death.

1.5 The best protection against carbon monoxide (CO) poisoning is to avoid exposure. The physiological effects of CO poisoning are cumulative and take a very long time to disperse. Even a low level of CO ingestion, below the level that causes immediate physical symptoms, will cause a progressive reduction in blood oxygen levels which will reduce pilot performance and potentially cause permanent damage to the brain, heart and nervous system. It is therefore a mistake to assume that a cockpit contaminated with very low levels of CO is acceptable. Low levels of environmental CO could be considered just as dangerous as high levels, as the cumulative negative effect on human performance may not be noticed.

1.6 Preventive maintenance remains the first line of defence against CO exposure during flight. If that fails, effective alerting of its presence in the cockpit can be achieved through the use of an appropriate CO detector. This Safety Notice provides guidance on both topics.

2 Maintenance, Detection and Carbon Monoxide Presence

2.1 **Maintenance:** Exhaust system failures and/or poor sealing of the bulkhead between the engine compartment and the cabin can cause CO to enter the aircraft cockpit. Ingestion into the cabin can also occur through routes other than the firewall; there is usually a stream of exhaust gas flowing down the outside of the fuselage and poorly fitting cabin doors, access panels, wing root fairings and hatches can provide an entry path into the cabin. The extent may vary at different angles of attack. Research carried out by the FAA (see paragraph 3) unsurprisingly indicates that contamination incidents caused by leakage in exhaust system are more prevalent in the colder months and that systems with higher operating hours are more likely to be affected. Any changes to the position and configuration of the exhaust system over the life of the aircraft can notably affect the amount of CO entering the cockpit. To minimise the likelihood of carbon monoxide contamination during flight, aircraft maintainers are reminded to:

- Ensure that aircraft exhaust and associated systems are maintained in accordance with the applicable maintenance data. These can include physical inspection, physical inspection with partial dis-assembly, internal inspection, NDT and pressure testing.

- Re-familiarise themselves with the guidance in CAA Publication (CAP) 562 ‘Civil Aircraft Airworthiness Information and Procedures’ **CAAIPS Leaflet B-190** ‘CO contamination’ which provides generic expectations for maintenance-related measures to minimise the likelihood of contamination. It addresses the nature and effects of carbon monoxide, the causes of contamination, the importance of routine inspections and means of testing for contamination. In addition, **FAA AC-43-13-1B Section 3 paragraphs 8-45 to 8-52** provides valuable information on typical failures, hazards, descriptions and inspections including pressure checks, repairs and replacement recommendations.

- With due account taken of the material mentioned above, include a suitably frequent periodic inspection and test regime in each affected aircraft’s Maintenance Programme (Approved or Owner-Declared, including programmes based upon the EASA Minimum Inspection Programme), an example of which is given in **Transport Canada Airworthiness Directive CF-90-03** and its accompanying **Safety Alert document CASA 2019-07** (see para 3). UK Reg (EU) No. 1321/2014 Annex Vb (Part-ML) now includes a specific CO concentration check as part of the Minimum Inspection Programme.

- Where fitted with combustion heaters, ensure that aircraft are compliant with CAA Publication **CAP 747** ‘Mandatory Requirements for Airworthiness’ **Generic Requirement (GR) 11.** This covers servicing and overhaul requirements intended to prevent carbon monoxide contamination.

2.2 **Detection:** In addition to adopting best practice maintenance measures, consideration should also be given to the installation of a CO detector in the aircraft. There are a range of options available, with detectors falling into two categories:

- **Passive detectors** – These are the 'spot type' detectors that change colour when exposed to carbon monoxide. They are small, light, cheap (in the region of £5) and easy to fit, but they have a limited declared life, often 3 months. They therefore need to be replaced regularly for continued effectiveness. This can be facilitated by marking the expiry date on the indicator. Whilst better than no detector, the clear disadvantage of these components is that they lack attention-getting capability. Bearing in mind the nature of CO, this is not ideal.

- **Active detectors** – These provide audible, visible and/or vibration warnings when pre-determined carbon monoxide levels are exceeded (often 50ppm, although some can be self-adjusted). These detectors have the clear advantage of actively engaging the occupant's attention and are therefore far more likely to be effective than passive measures. Depending on the type, they can be either portable and 'carried on' to the aircraft or permanently 'installed' in a suitable position on the aircraft. Commercially available motorhome, caravan or boat-compatible units from a reliable source, a known manufacturer and with reasonable assurance of meeting an appropriate standard such as EN 50291-2 are available for as little as £15. Such units have a sensor life in the region of 7 years and battery lives of between 1 and 10 years. This makes them arguably at least as cost-effective as the 'spot-type' items and notably more effective at alerting. Aviation standard (e.g. approved in accordance with EASA's ETSO-2C48a) units are also available if permanent installation is preferred or required. These components often have additional functions and adhere to specific aviation-related requirements, but are more costly, typically around £200-300. Clearly, the effectiveness of these active detectors is dependent to an extent upon variables such as the trigger level for the alarm and the positioning in the aircraft. Adherence to the manufacturer's installation, usage and maintenance instructions should maximise the likelihood of effective operation.

2.2.1 Installing or Carrying a Carbon Monoxide Detector

- **Passive detectors** can simply be attached to a wall or panel in the cockpit and do not need to be professionally installed. The detector should be clearly visible to the pilot without obscuring any instruments or equipment used in flight. Positioning detectors in locations that might not reflect the typical CO concentrations in the cockpit (e.g. near fresh air vents) should be avoided.

- **Active detectors** Most 'installed' active detector units will usually be able to be fitted to UK-registered aircraft as 'standard changes' under the provisions of **CS-STAN, CS-SC107a** (for EASA aircraft) and through **CAP 1419** (for non-EASA aircraft). This removes the need for direct EASA or CAA involvement, including avoiding the cost and time associated with applying for a formal modification. For 'carry-on' examples, no airworthiness approval is required, although it is expected that the captain will have made an assessment of the unit's suitability and condition before flight – for example, to ensure that an aural CO warning would not be so loud as to create a distraction in flight yet still be audible even when wearing noise-cancelling headsets, nor be confused with other onboard warnings

- **NOTE:** Due to the increased availability of inexpensive (commercial) active detectors, their advantages over passive detectors and the potential for an increased risk of CO contamination in an ageing fleet, the CAA intended to undertake a practical trial of such devices during the 2020 flying season covering a variety of GA types, particularly those that by dint of their age and/or configuration may be more prone to CO contamination. Due to the effect of the COVID-19 outbreak on GA flying, this has been put back to the 2021 season, or until reasonable levels of operation are able to resume. The aim of the trial is to identify whether any potential disadvantages of carrying these units may outweigh the apparent advantages. A cross-section of the UK's GA community will be invited to participate and feed back results/observations to CAA. The data received will be used as a basis for further decision-making, including potential rulemaking. Even before this trial concludes, all GA pilots should give serious consideration to the likely net safety benefits offered by [EN 50291-2 or ETSO-2C48a] CO detector carriage.

2.3**: CO Presence: If you experience symptoms or the detector alarm sounds:**

- Turn off the cabin heat supply and maximise fresh air entry into the cabin
- Keep flying the aircraft and make a radio call to alert others to your predicament
- Land as soon as possible
- Seek medical attention when on the ground
- Ensure the problem is identified and rectified before further flight

3 Recommended Reading

The following sources contain useful information concerning the nature and effects of carbon monoxide, the causes of contamination and means by which the likelihood of exposure can be reduced.

- LAA 'Light Aviation' magazine article *'**The Canary & the Silent Killer**'*, July 2017.
- FLYER article '*Top Gear; Carbon Monoxide Monitors'*; Summer 2019
- (BS) EN 50291-2; 'Electrical apparatus for the detection of carbon monoxide in domestic premises. Electrical apparatus for continuous operation in a fixed installation in recreational vehicles and similar premises including recreational craft. Additional [to EN 50291-1] 'test methods and performance requirements'.
- FAA report **DOT/FAA/AR-09/49** *'Detection and Prevention of Carbon Monoxide Exposure in General Aviation Aircraft'*, 2009.
- EASA **Safety Information Bulletins 2010-19 '**Exhaust Mufflers Inspection for piston engine Helicopters and Aeroplanes', and **2020-01** 'Carbon Monoxide (CO) Risk in Smallw Aeroplanes and Helicopters'.
- Transport Canada **Airworthiness Directive CF-90-03R2** 'Exhaust Type Cabin and Cockpit Heaters', August 1992 and associated Civil Aviation Safety Alert (CASA) 2019-07.
- EASA European Technical Standard Order **ETSO-2C48a** Carbon Monoxide Detector Instruments.

4 Queries

4.1 Any queries or requests for further guidance because of this communication should be addressed to:

GA Unit, Safety & Airspace Regulation Group,
Civil Aviation Authority,
Aviation House,
Gatwick Airport South,

West Sussex,
RH6 0YR Tel: +44 (0)1293 573988

E-mail: **GA@caa.co.uk**

5 Cancellation

5.1 This Safety Notice will remain in force until further notice.

ACCIDENT

Aircraft Type and Registration:	Scheibe Super Falke SF25E, G-KDEY
No & Type of Engines:	1 Limbach SL 1700-EA1 piston engine
Year of Manufacture:	1976 (Serial no: 4325)
Date & Time (UTC):	23 March 2020 at 1651 hrs
Location:	Aston Down Airfield, Gloucestershire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Serious) Passengers - N/A
Nature of Damage:	Destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	72 years
Commander's Flying Experience:	3,446 hours (of which 344 were on type) Last 90 days - 1 hour Last 28 days - 1 hour
Information Source:	AAIB Field Investigation

Synopsis

The pilot of G-KDEY, was flying a series of circuits and was heading towards the airfield when the aircraft struck the ground in a field west of the airfield boundary.

The investigation found that carbon monoxide had been leaking from the exhaust and is likely to have impaired or rendered the pilot unconscious before the aircraft hit the ground.

The report highlights the EASA and CAA guidance on maintenance of piston engine exhaust systems to reduce the risk of carbon monoxide poisoning and the options available in selecting carbon monoxide detectors for General Aviation aircraft. A CAA safety leaflet and EASA report also highlights the issues associated with the use of Mogas and the increased risk of carburettor icing due to the ethanol content.

History of the flight

On the day of the accident the pilot decided to go flying in order to stay current as the weather was forecast to be good. He took 20 litres of Mogas[1], in a jerry can, which he had purchased from a local petrol station on 5 February 2020 to refuel the aircraft.

Upon arrival at Aston Down airfield he met, by chance, the other member of the aircraft's syndicate and told him that he planned to do a local flight and practice some visual circuits

Footnote

[1] Mogas (Motor Gasoline) is automotive fuel suitable for use in some piston-engine aircraft.

for about an hour. They prepared the aircraft together, which included putting the Mogas into the aircraft's fuel tank. While the pilot could not recall what the fuel quantity was before the Mogas was added, the syndicate member noted that the aircraft's electric fuel gauge indicated 5 litres before the 20 litres was added. The pilot commented that 20 litres of fuel would have given about 90 minutes endurance.

Prior to departure the pilot recalled checking NOTAMs on the flight navigation software on his portable electronic device (PED) and completing the external and internal pre-flight inspection, with the syndicate member assisting. Once onboard the pilot placed the PED on the passenger's seat and started the aircraft. He remembers taking off into wind but not what runway he used or whether he used a grass or concrete runway. The syndicate member watched the takeoff at about 1530 hrs from Runway 21, a hard runway, and recalls the pilot planned to land on Runway 09.

The pilot's only recollection of the flight was leaving the circuit in a northerly direction for a period of time, but did not go so far as to lose sight of the airfield, before returning to the airfield to fly some visual circuits. At about 1635 to 1640 hrs, a witness located about 1 nm north of the airfield saw the aircraft downwind in the visual circuit and commented that there appeared nothing untoward with the aircraft. The pilot's next recollection was regaining consciousness at a very low altitude but too late to recover the aircraft before it struck the ground; he then lost consciousness.

Just before the accident another witness, located about 500 m north-north-west of the accident site, observed the aircraft on approach to Runway 09 at Aston Down airfield before she lost sight of it behind some trees. She then heard a loud bang and, assuming the aircraft had crashed, dialled the emergency services who dispatched ambulances and police to the scene. Meanwhile the witness walked for about 20 minutes toward the location of the aircraft where she found the crashed aircraft in a field with the pilot seriously injured. She made him comfortable, provided some first aid and called the emergency services with an update.

The pilot's next recollection was him being tended to by the witness. Police, RFFS vehicles and ambulances started arriving at the scene 37 minutes after the accident. Due to the limited access to the scene and the pilot's injuries, an air ambulance also attended. The pilot was subsequently taken to hospital in the air ambulance.

Recorded information

The pilot used a flight planning and navigation application on his PED. He stated that for this flight, he only used it to check for NOTAMs prior to the flight and that it was not used for navigation in-flight. Consequently there was no track of the flight available to download.

The aircraft was fitted with a Mode C transponder which was unserviceable for the accident flight. A review of radar recordings in the vicinity did not reveal any useful data on the aircraft's flight path.

Accident site

Figure 1

Location of the accident site on the western boundary of Aston Down airfield

The wreckage of G-KDEY stretched across two fields to the west of Aston Down airfield (Figure 1).

From the ground marks it was evident the aircraft was heading east towards the airfield at the time of the accident. The first impact marks were made by the right wing tip, which touched the ground three times before the leading edge of the wing hit a small bus parked along the treeline of the west field (Figure 2).

Figure 2

Ground impact marks, detached right wing and impact angle on the bus

Figure 3

Damage to the cabin roof and the angle sliced through the tree line

On striking the bus, the wing detached and landed by the bus, while the remainder of the fuselage and left wing glanced off a flat roofed cabin located to the left of, but in line with, the vehicle.

The fuselage bounced off the top right side corner of the building's roof and continued into the treeline. The left wing and fuselage sliced through the trees (Figure 3) before hitting the east field at a shallow angle.

The remaining wing detached and landed to the left of the aircraft's path. The fuselage continued sliding along the ground before finally stopping in a slightly right nose down attitude pointing towards the airfield (Figure 4). One of the propeller blades broke away from the hub between hitting the trees and the ground in the east field and the remains were found under the left wing.

The other propeller blade bent backwards and, although some of the blade broke away, it was still attached to the hub.

The propeller's spinner had large impact dents but there were no radial score marks to indicate the propeller was rotating under power when it hit the ground (Figure 5). The tail and fuselage behind the cockpit were largely intact, with minor damage to the leading edges of the fin and left tailplane.

The engine was still attached to the aircraft, but the engine bay and mounting frame had twisted anticlockwise and bent downwards to the left of the aircraft's centreline.

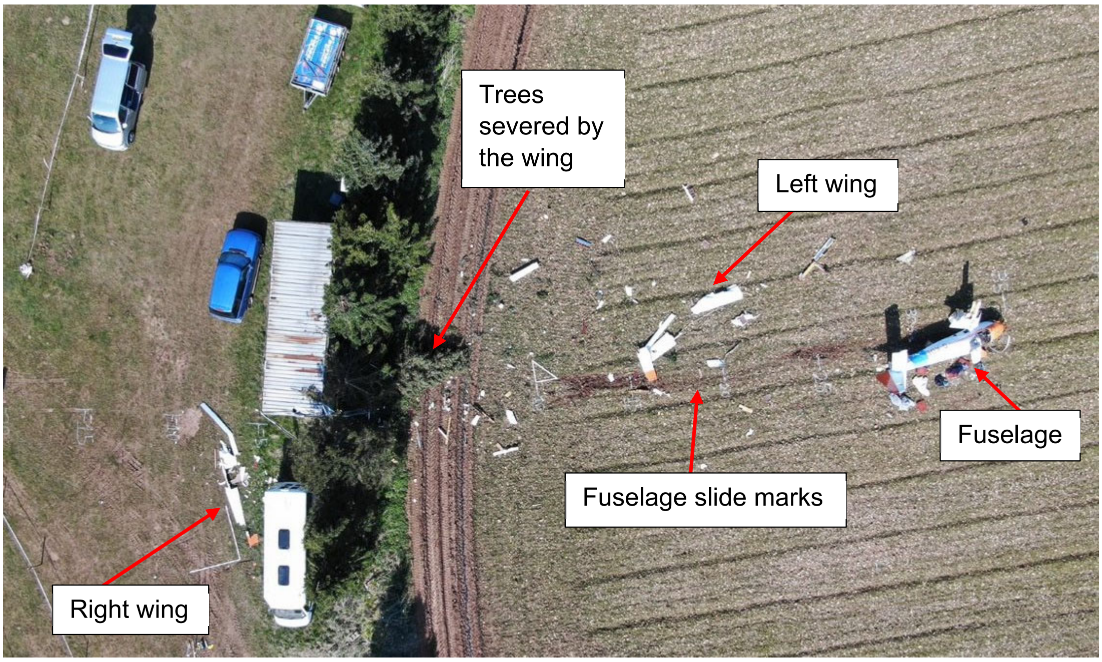

Figure 4

Overhead view of the final positions of the fuselage and wings

Figure 5

Remains of the propeller blades and the dented spinner

The fuel tank and fuel hoses behind the cockpit seats were untouched by the various impacts and the tank contained approximately 12 litres of fuel.

The wreckage was removed and transported to the AAIB's facilities for further examination.

Aircraft information

The Scheibe Super Falke SF25E is a touring motor glider designed to take off under its own power using an integrally mounted, non-retractable engine and propeller. It has a monowheel landing gear, tailwheel and fixed outriggers. The cockpit has two seats side by side and dual controls. The fuselage is constructed of tubular steel frames with a fabric covering whilst the wings are made from wooden box spars and plywood.

G-KDEY was built in 1976 and was powered by a Limbach SL 1700-EA1 four-cylinder, four-stroke, horizontally opposed, air-cooled engine. Equipped with a single magneto ignition system, single carburettor and wet sump lubrication system, the engine produced 50 kW (67 hp) at 3,600 rpm. The engine was replaced in 2009 and had operated for a total of 424 hours since installation.

The aircraft was fitted with a Hoffmann HO-V62R, twin bladed, lightweight propeller with a mechanical pitch change device. The pitch change device had three settings - takeoff, cruise and feathering.

A new BGA Airworthiness Review Certificate (ARC) was issued on 2 January 2020 following a combined annual maintenance and BGA inspection. During the annual maintenance, the propeller was removed for overhaul and the aircraft was flown twice, in February and March 2020, using a loaned propeller. The overhauled propeller was refitted on 7 March 2020 and the aircraft flew twice more without incident. The aircraft had flown a total of 1,768 hours since it was built.

Exhaust System

The exhaust consists of a silencer positioned directly under the engine and connected to each of the engine's four exhaust ports by down pipes. Exhaust gasses pass from the piston combustion chambers, through the down pipes to the silencer and are vented rearwards to atmosphere underneath the aircraft by a tail pipe. To make use of the heat from the exhaust, a heat exchanger is fitted around the silencer. Atmospheric air from the front of the engine cowling passes into the heat exchanger and is warmed by the silencer (Figure 6).

A flexible pipe from the heat exchanger is routed to the cockpit via a simple flap valve. To provide warm air, the pilot pulls the cabin heat handle in the cockpit which is attached to the valve by a Bowden cable. A second heat exchanger is fitted to the No 3 cylinder's down pipe to produce warm air for the carburettor. A flexible pipe is connected between the heat exchanger and valve attached to the carburettor to help prevent carburettor icing. The carburettor heat valve is also operated via a cockpit handle connected by a Bowden cable.

Aircraft examination

Airframe and flying controls

Continuity checks of the flying controls confirmed that they were connected and functioning correctly. Any damage found to the controls, connecting rods and cables was consistent with the various ground impacts and separation of the wings from the fuselage during the accident sequence.

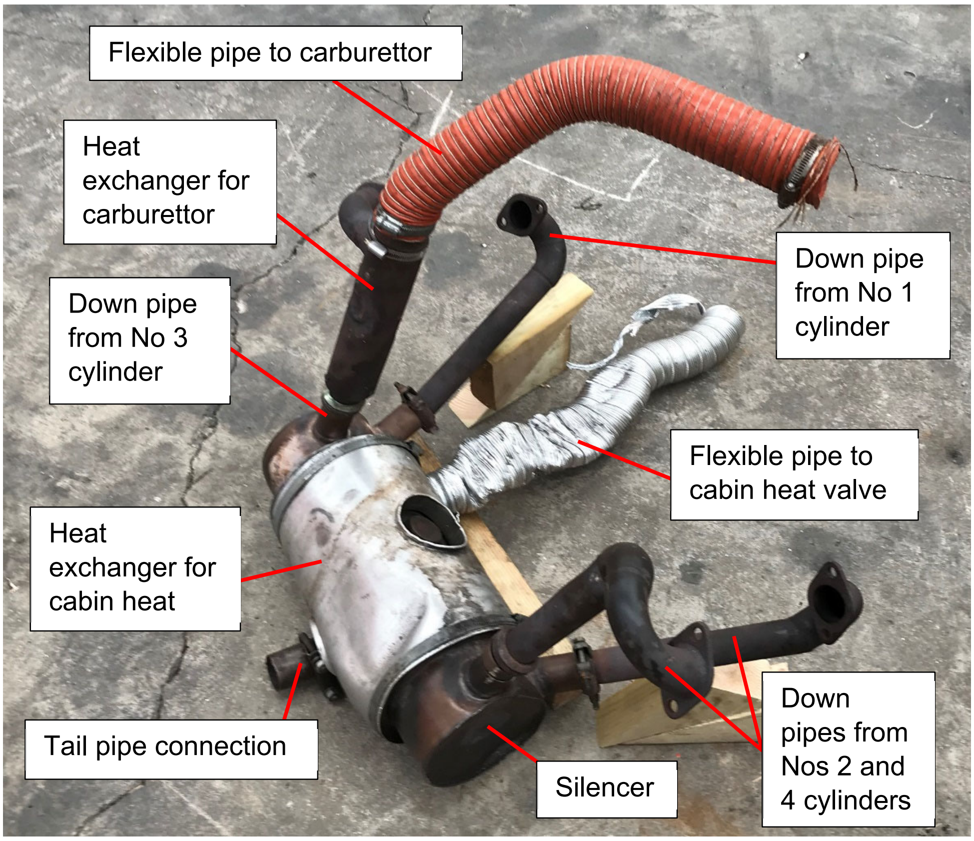

Figure 6
G-KDEY exhaust system

Aircraft examination

Airframe and flying controls

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Cockpit controls

The engine throttle handle was fully depressed and locked in place indicating full throttle was selected. The positions of the engine choke, cabin heater and carburettor heater handles showed that none of these functions were selected, although they may have been disturbed during the accident. The propeller feathering handle was pushed in and had jammed in place when the shaft bent during the accident. Whilst the fuel cock was OFF, the police accident report confirms the RFFS selected it OFF when they arrived at the scene. The magneto and battery switches were found selected ON.

Propeller

When the remainder of the propeller blades were rotated in the hub, one of the blades rotated by approximately 10° independently of the other and without engaging the pitch mechanism. Examination of the propeller by the manufacturer, Hoffmann GmbH & Co, found a number of anomalies but none of them were contributory to the accident. The examination report concluded that as far as could be ascertained from the evidence, the propeller had been fully functional. It is likely the excessive play in pitch rotation was caused by the impact with the trees or ground during the accident.

Engine

An external examination of the engine revealed the right rocker cover and securing clip had detached but were undamaged. The left rocker cover was still fitted and was also undamaged.

When the rocker valve clearances were checked against the manufacturer's recommended setting of 0.2 mm, they measured between 0.1 and 0.2 mm. Records show that they were set to 0.1 mm in December 2019.

After removing the spark plugs, visual examination revealed some build-up of carbon on their contacts. Helical coils had been fitted to the spark plug holes to prevent the steel plugs from damaging the alloy threads when inserted. On turning the propeller with the spark plugs removed, the engine crankshaft rotated without difficulty revealing that the engine had not seized.

When the cylinder heads were unbolted from the crankcase, thin layers of black combustion deposits were found covering the piston crowns, combustion chambers and valve heads. There were signs of staining between Nos 3 and 4 cylinder heads and their respective cylinders (Figure 7). Records show that cylinder pressures were only 10% below their maximum when they were tested in December 2019.

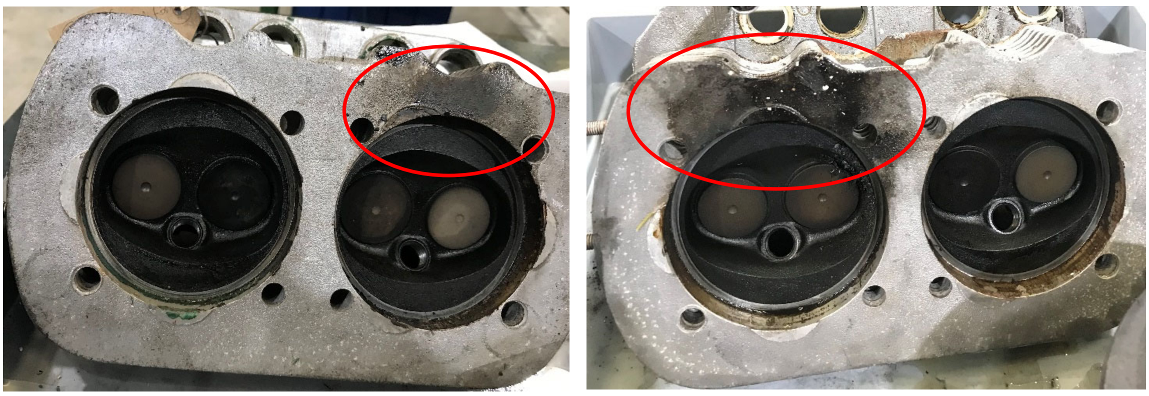

Figure 7

No 3 and 4 cylinder heads showing signs of staining

The engine manufacturer stated that the staining visible on the cylinder heads was condensation mixed with soot and may contain traces of fuel and oil. On engines that have been overheated, a slight deformation of the cylinders and cylinder heads occurs as operating time increases. For the Limbach 1700 engine, deformation only occurs at the cylinder head and the cylinders are made of grey cast iron. This means that during cold start, gases can be pushed through the seal between the cylinder and head. However, when these components are heated they become tightly sealed. The components of an air-cooled motor reach the operating temperature very quickly, so the sealing process is completed during engine warm-up.

If exhaust gases were able to flow through the seal during high loads, there would have been an immediate melting of the affected parts at the site of the leak. Under partial load, the exhaust gases reach a temperature of 900°C and aluminum alloys melt at approximately 650°C. A leaking exhaust gas stream would act like a cutting torch and quickly burn through the cylinder head at the sealing surface.

Some minor evidence of corrosion was found on the crankshaft, but the damage was localised and not widespread. The crankshaft bearings, piston connecting rods and bearings, although worn, were still in place and rotated freely. The oil pump was visually inspected and appeared to be undamaged. There was little debris in the sump filter screen and there was oil in the sump.

Consultation with a Limbach engine specialist indicated that although the engine had been running with a rich fuel mixture, it was in good condition for its age.

Ignition System

While the ignition system was being removed from the engine, the castellated nut and washer holding the magneto's impulse coupling onto the drive shaft was found to be held on only by the last few threads of the shaft. The split-pin that should have prevented the nut and washer from unwinding was found in the engine's magneto housing with one leg bent and the other leg broken in half (Figure 8). The magneto had been overhauled in 2017.

The ignition harness, magneto and spark plugs were removed and rebuilt on a bench and their operation checked; no anomalies were found.

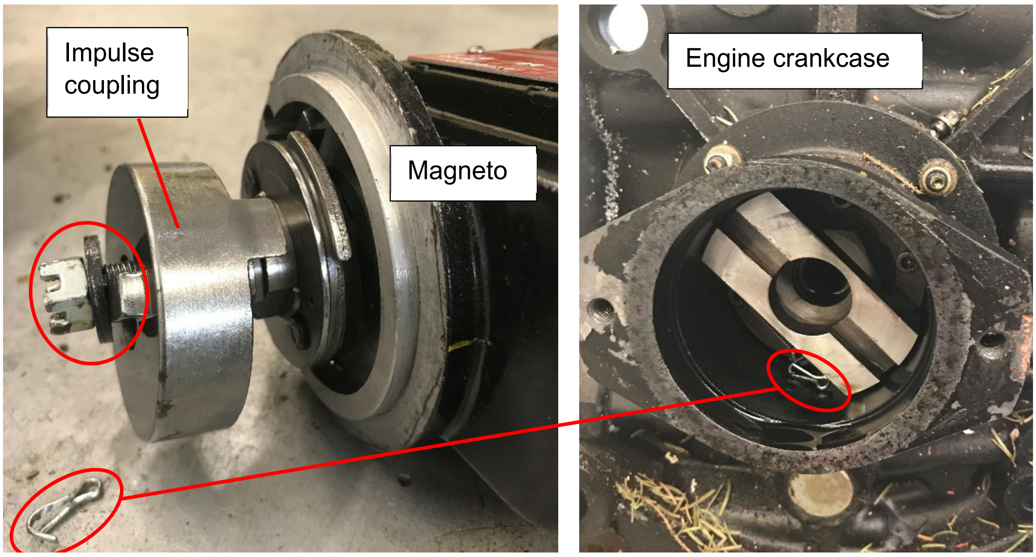

Figure 8

Magneto impulse coupling, nut, washer, split-pin and engine magneto housing

Fuel System

The fuel supply was intact between the fuel tank, fuel pump and carburettor. When inspected, the fuel lines, gascolator, fuel pump and carburettor all contained fuel.

A fuel sample was taken from the fuel tank and checked for the presence of debris, water contamination, fungal growth and clarity. No anomalies were found. Using a water extraction method[2] the sample's ethanol content was measured at approximately 3.8%, within the 5% allowable for UK E5 graded fuels.

The fuel pump was removed and its operation confirmed. The pump was dismantled for visual inspection of the filter screen, diaphragm and internal chambers and no anomalies were found.

The carburettor was also removed, dismantled and all parts visually inspected. No faults were found with any of the internal components or chambers and the fuel jets were clear of any debris.

Fuel octane rating

The Limbach L1700 engine series operating and maintenance manual[3] specifies that only Super Plus 98 fuel (according to DIN EN 228), unleaded fuels with a minimum octane rating of 98 Research Octane Number (RON) or Avgas 100LL are approved for use in this engine type. The manual cautions against the use of other fuels not approved by the manufacturer.

The use of lower octane rated fuel, such as 95 RON, in older piston engines can cause early ignition where one or more pockets of air/fuel mixture detonate outside the normal combustion front created by the spark plug and cause 'knocking.' Severe knocking can lead to catastrophic engine failure where holes are melted through the piston or cylinder head. Modern vehicle engine management systems (EMS) compensate for octane differences to avoid knocking, but older engines do not have an EMS. There was no evidence of knocking present in the pistons or combustion chambers.

Ethanol in Mogas

Mogas has a higher vapour pressure when compared to AVGAS and the addition of ethanol only increases this vapour pressure. The relatively slow fuel rate supplied to the carburettors via various pipes and pumps, which can add heat to the fuel, increases the risk of spontanous generation of vapour bubbles. High ambient temperatures and low ambient pressures further increases the risk of vapour lock. The weather conditions at the time of the accident were unlikely to have caused this problem.

Footnote

2 LAA TL2.26 '*Procedures for use of E5 unleaded Mogas to EN228*'. Available at http://www.lightaircraftassociation.co.uk/engineering/TechnicalLeaflets/Operating%20An%20Aircraft/TL%202.26%20Procedure%20for%20using%20E5%20Unleaded%20Mogas.pdf [accessed October 2020].

3 Limbach Flugmotoren '*L1700 engine for Powered Gliders and Very Light Aircraft Operating and Maintenance Manual*', edition 1 March 2016. Available at http://www.limflug.de/en/support/downloads.php?type=operatingAndMaintenanceManuals&id=L1700-all-operatingAndMaintenanceManual-en.pdf&action=download [accessed October 2020].

Ethanol has a strong affinity for water causing the fuel-ethanol-water mixture to slowly degrade rubber and plastic parts of carburettors and composite fuel tanks. Particles in the carburettor bowl can clog the jets resulting in poor engine performance. There was no evidence of particles in the carburettor, fuel tank or fuel system and the carburettor jets were clear of blockages.

Ambient temperature and humidity in combination with an ethanol fuel mixture can cause a higher enthalpy of vapourisation leading to an increased risk of carburettor icing. The combination of fuel vaporisation and pressure drop can cause a reduction in temperature of over 30°C. As the temperature falls below freezing, water vapour will form ice on the throttle valve and the internal surfaces of the venturi chamber, restricting air and fuel flow to the engine. With the aircraft engine throttle closed, during descent for example, there is a large pressure drop in the carburettor which can cause a rapid build up of ice. Because the throttle is closed, the restriction of fuel and air flow can go unnoticed. In addition, when power is removed, the exhaust temperature decreases and reduces the temperature of the warm air available from the exhaust heat exchanger for carburettor heating.

Exhaust System

Large dents were evident in the exhaust's silencer box caused by the ground impact. As the silencer is fitted below the engine, it bore some of the weight of the engine and the fuselage when it slid along the ground. The tail pipe partially fractured along a weld around the diameter of the pipe where corrosion had thinned the material. The remainder of the pipe bent around the lower structure of the engine bay and had to be cut off to allow the engine to be removed.

On dismantling the remaining exhaust system, the down pipes from No 1 and 2 cylinders were easily removed by hand from the silencer despite their securing clamps and sealing rings remaining in place. Visual examination revealed the ends of both pipes had corroded and fractured completely around their diameter. The detached ends of the pipes were still fitted in the silencer. The jagged edge of No 1 cylinder's down pipe had bent inwards as the pipe was pushed further into the silencer during the accident (Figure 9). The two exhaust down pipes from No 3 and 4 cylinders were removed and visually inspected but only minor surface corrosion was evident.

Forensic analysis found that although the exhaust down pipe from No 2 cylinder was corroded and the wall thickness had reduced, it had fractured during ground impact. The down pipe from No 1 cylinder was severely corroded and forensic analysis found that it had already failed some time before the accident. Both the pipe and its sealing ring showed traces of exhaust gas leakage. The evidence was very difficult to detect visually with the exhaust still fitted to the engine and in the engine bay. The signs of leakage were not easily descernable even with the system dismantled and required forensic examination to confirm that leaks had occured.

Figure 9

No 1 and 2 cylinders' exhaust down pipes and silencer pipes showing failures

Whilst the partial failure of the exhaust tail pipe at the weld was due to ground impact, there was evidence that gas leakage had also occurred at the connection of the tail pipe to the silencer. The tail pipe had three, 3 cm cuts along the length of the pipe from the end to enable it to expand to fit over the silencer connection. A clamp was placed over the cut end of the pipe to secure it in place. As the pipe had not been fully pushed over the connection, the cuts were not completely blanked by the silencer pipe, which allowed gas to escape when the engine was running (Figure 10). The aircraft manufacturer stated that the tail pipe fitted was not an approved design.

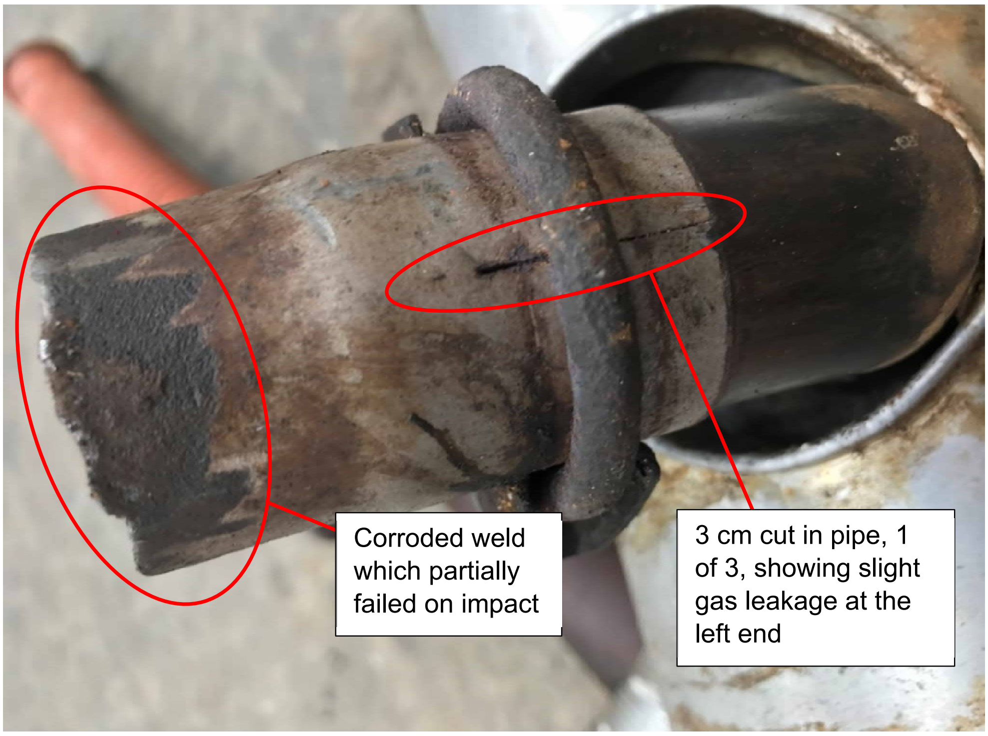

Figure 10

Partially fractured tail pipe attached to the silencer

EASA Safety Information Bulletin 2010-19[4] (EASA SIB 2010-19) was issued following reports of numerous events resulting from failed exhaust system components on piston engine aircraft and helicopters. In most cases, the causes of the events were CO poisoning, partial or complete loss of engine power, fire or a combination of these. Standard maintenance manuals or procedures do not always contain adequate inspection procedures for exhaust systems. The bulletin stresses the importance of properly inspecting and maintaining exhaust system components to reduce the hazards associated with their failure.

Engine bay firewall

During engine removal, it was evident that the seals and grommets used in the engine firewall to protect the cockpit from engine bay gasses had deteriorated and perished. It was likely that gasses in the engine compartment could flow into the cockpit through the firewall (Figure 11).

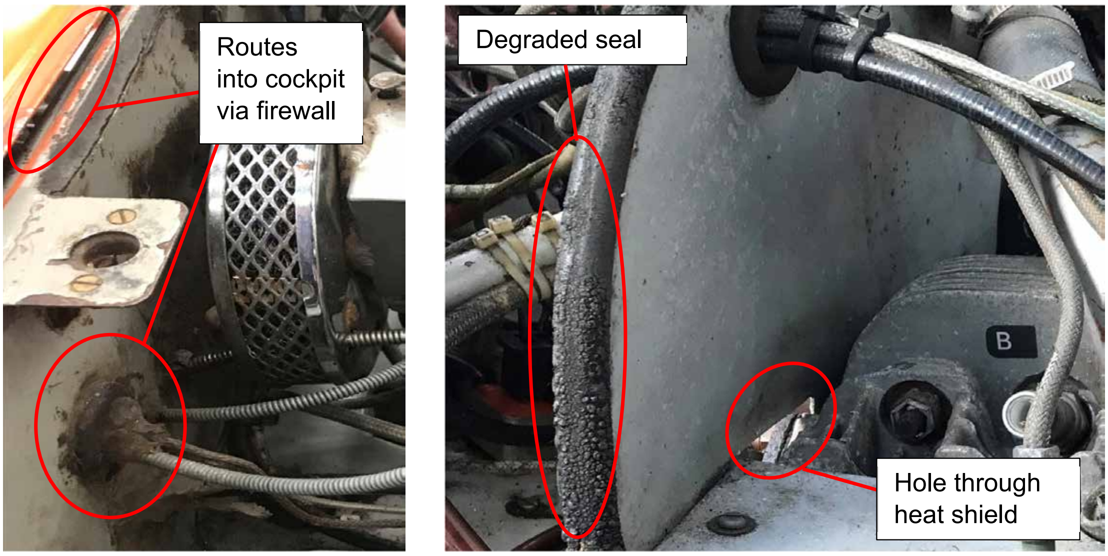

Figure 11

Exhaust gas routes into the cockpit through bulkheads and firewalls

Survivability

The pilot used a four-point harness which was found to be in good condition with no cuts or degradation of the fabric. The seat buckle was undamaged. The four parts of the harness remained in place with no disruption or bending of the anchor points.

The tubular frame structure of the fuselage intruded into the cockpit space on the right side where it had been damaged when the right wing detached or the fuselage hit the ground. The right seat was displaced to the left, partly over the edge of the right seat.

Footnote

[4] https://ad.easa.europa.eu/blob/SIB_201019_Exhaust_Muffler_Inspection.pdf/SIB_2010-19_1 [accessed 2 October 2020]

Meteorology

The Met Office provided an aftercast for the period of the flight. It stated that there was high pressure over the area leading to fine settled conditions. Visibilities remained above 10 km with no cloud reported below 5,000 ft amsl with light south-easterly winds throughout the period. The syndicate member estimated that the wind was from 120° at 20 kt gusting to 30 kt.

Observations at Gloucestershire Airport, approximately 11 nm north of the accident site, at the time of the accident indicated that the wind was from 140° at 5 kt. The visibility was in excess of 10 km, the temperature was 13°C and the dew point -1°C. The atmospheric pressure was 1024 hPa. When plotted on the CAA's carburettor icing chart they indicate that there was a likelihood of serious icing with descent power (Figure 12).

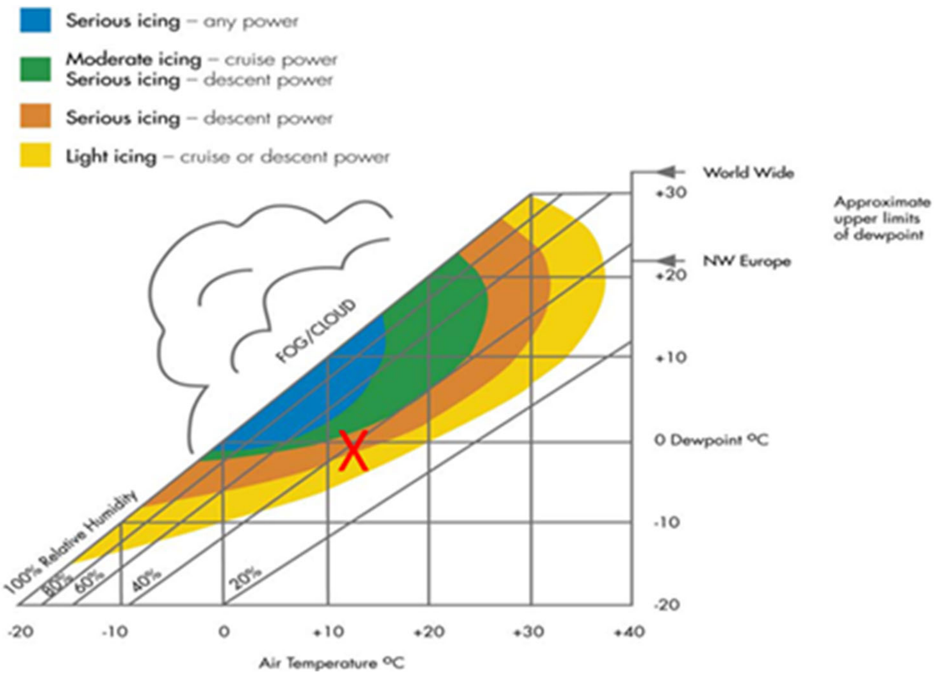

Figure 12
Carburettor Icing Chart

Symptoms of CO poisoning

The symptoms of CO poisoning are not always obvious, particularly during exposure to low-level concentrations. A tension-type headache is the most common symptom of mild CO poisoning. Other symptoms include, dizziness, feeling and being sick, tiredness and confusion, stomach pain, shortness of breath and difficulty breathing.

The symptoms of exposure to low levels of CO can be similar to those of food poisoning and flu but, unlike flu, CO poisoning does not cause a high temperature.

The longer CO is inhaled, the worse the symptoms will be, including loss of balance, vision, memory and, eventually, loss of consciousness.

Medical

The pilot suffered serious injuries in the accident including a trauma to his head. While in hospital he was not tested for carbon monoxide (CO) poisoning.

He had no underlying medical issues that would have contributed to a possible incapacitation.

CO detection

A CO spot detector was fitted to the centre of G-KDEY's instrument panel to warn the pilot if CO entered the cockpit. The detector's tan coloured spot turns black in the presence of CO. It was purchased from a non-aviation specific store in February 2020. The detector was removed and placed in front of a petrol mower exhaust to check its operation. The spot had to be held directly in the exhaust flow for 4 to 5 minutes before it started to discolour and approximately 7 minutes to turn it black (Figure 13). After an hour in fresh air, the spot reverted to its original colour.

Figure 13

Spot detector colour change when exposed to CO

Research into exhaust system failures and analysis of different CO detectors was commissioned by the FAA and a report, DOT/FAA/AR-09/49[5], was published in 2009. It expands the information contained in the EASA SIB 2010-19 and contains an evaluation of the three most common commercially available CO detector types: biometric, semiconductor and electrochemical. It concluded that electrochemical sensors appeared to be the most suitable for a General Aviation (GA) environment as they were relatively accurate with a quick response time, were inherently immune to false alarms and had low power consumption.

The AAIB investigation of the accident involving Piper PA-46-310P Malibu, N264DB, on 21 January 2019 found that the pilot was probably affected by CO poisoning[6]. As a result, the AAIB made Safety Recommendations to the EASA, FAA and CAA recommending that they require piston engine aircraft to have an active CO detector fitted. In response to

Footnote

[5] US Department of Transportation *Detection and Prevention of Carbon Monoxide Exposure in General Aviation Aircraft,* October 2009. Available at http://www.tc.faa.gov/its/worldpac/techrpt/ar0949.pdf [accessed October 2020].

[6] AAIB Aircraft Accident Report AAR1/2020, Piper PA-46-310P Malibu, N264DB, 21 January 2019, 13 March 2020. Available at https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-1-2020-piper-pa-46-310p-malibu-n264db-21-january-2019 [accessed November 2020].

these recommendations, CAA Safety Notice SN-2020/003[7], published on 2 March 2020, considered measures to minimise the likelihood of CO contamination and the hazards of CO exposure, and provided guidance on the use of CO detectors in GA aircraft. The safety notice highlighted spot detectors' '*lack of attention-getting capability*'. Active detectors have the advantage of '*actively engaging the occupant's attention*' and can be set to detect low CO saturation levels of 35 parts per million (ppm) or above. The EASA, the FAA and the CAA are currently reviewing the regulatory requirements for the carriage of CO detectors.

Additionally, the Australian Transport Safety Bureau (ATSB) investigation of the accident involving a de Havilland Canada DHC-2 Beaver floatplane, VH-NOO, on 31 December 2017, also found that the pilot and some passengers were also probably affected by CO poisoning[8]. As a result The ATSB have recommended that the Civil Aviation Safety Authority of Australia takes further safety action to enable it to consider mandating the carriage of CO detectors in piston-engine aircraft, particularly passenger-carrying operations.

Pilot's comments

The pilot was interviewed by the AAIB six weeks after the accident, but did not recal detail of the accident flight.

He stated that he was aware of the possibility of carburettor icing and added that he used carburettor heat habitually throughout a flight, including during the final approach.

The pilot added that, given the conditions on the day, he was unlikely to have used the cabin heater. Also, as he mainly flew gliders, he probably would not have checked the aircraft's CO detector in flight. The syndicate member commented that he had not noticed the CO spot detector change colour before.

The pilot was also aware of the increased possibility of fuel vapour lock when using Mogas, but had never experienced it. He was not aware of any flight manual limitations on types of fuel that may make the engine susceptible to vapour lock. He has always used Mogas, sourced from a local automotive fuel garage, in the aircraft. There was no Avgas 100LL available at Aston Down airfield.

Analysis

The flight

The aircraft was observed by a witness while downwind in the visual circuit, about 10-15 minutes before the accident, and appeared to be operating normally. This was likely to have been a circuit prior to the one in which the accident happened.

Footnote

7 Safety Notice SN-2020/003 – '*Carbon Monoxide Contamination & Detection in General Aviation Aircraft*', published by the CAA. Available at https://publicapps.caa.co.uk/modalapplication.aspx?catid=1&pagetype=65&appid=11&mode=detail&id=9442 [Accessed December 2020].

8 ATSB Investigation number AO-2017-118, de Havilland Canada DHC-2 Beaver aircraft, VH-NOO, 31 December 2017. Available at https://www.atsb.gov.au/publications/investigation_reports/2017/aair/ao-2017-118/ [accessed February 2021].

The pilot stated that he remembered regaining consciousness just before impact. While it is not known if or when he became incapacitated it was probably only for a short time. Had he become incapacitated on the downwind leg the aircraft would have continued downwind before either he regained consciousness, or it descended and struck. Had he become incapacitated during the turn onto the final approach the aircraft is likely to have continued turning and descending before either he regained consciousness or it struck the ground.

Engine power

Examination of the engine, the propeller and the spinner indicated that the engine was not producing power when the aircraft struck the ground. However, the remains of branches were lodged in the engine bay and propeller from the trees that were damaged in the tree line between the east and west fields. It is likely the engine stopped when the propeller sliced through the trees, causing one blade to separate near the root and land in the east field, while the other was bent backwards but remained attached to the hub.

Magneto coupling

The magneto impulse coupling securing-nut and washer were found partially unwound but still on the shaft, and the split pin not fitted. It is likely the nut and washer would have unwound completely in time, although the magneto's impulse coupling would not have disconnected from the magneto. This did not contribute to the accident.

Engine condition

Despite the anomalies found with the engine, there was no evidence of a mechanical failure of the engine immediately before the accident.

Avgas, Mogas and carburettor icing

Avgas 100LL, the most commonly used aviation fuel for piston engines, has an octane rating of 100 and contains no added ethanol, making it suitable for the Limbach L1700 engine. However, Avgas costs more and its lead additive has an adverse environmental impact, and the aviation industry is working to phase it out. There are unleaded versions of Avgas 100LL, such as UL94, but they are not direct replacements. Some have a lower octane rating making them suitable only for lower octane-rated engines. To date, a direct replacement has not been approved for all aviation piston engines and Avgas 100LL continues to be used.

As Mogas is a popular choice for GA users due to its lower cost and wide availability, several engines have been designed to use this fuel and some older engines have been successfully converted. For some of those approved and converted to use Mogas, manufacturers such as Limbach will state the grade of fuel that should be used – for example 98 RON – in order to maintain the engine's performance and prevent damage.

The use of Mogas can cause a number of issues including increased risk of vapour lock and clogging of fuel filters with particles. One of the main issues highlighted by EASA report EASA.2008.C51, '*Safety implication of Biofuels in aviation',* published by EASA[9] is '*carburettor icing due to raised enthalpy of evaporation for ethanol-admixed gasolines if there is no additional heat input into the intake air'*. Safety Sense Leaflet 14 – '*Piston engine icing'* published by the CAA[10] also discusses the problem of carburettor icing, explains how to recognise the symptoms and provides procedural advice to pilots on how to avoid the problem.

There are plans to increase the ethanol content of UK Mogas up to 10% (E10) for environmental reasons in 2021. The EASA.2008.C51 report highlights that fuel related problems in aviation piston engines are likely to increase with the planned introduction of E10 fuels, particularly for older engine types.

The pilot stated that he was aware of carburettor icing. He added that he used carburettor heat habitually throughout a flight, including during the final approach. The carburettor heat control handle was found in the off position during the aircraft examination, although it is possible it moved during the accident sequence.

Increased levels of ethanol in Mogas increases the risk of carburettor icing. Given the weather conditions on the day, partial or complete engine failure due to carburettor icing could not be ruled out.

Carbon monoxide

There were no reported underlying medical issues that may have caused the pilot to become incapacitated and he has no memory of the flight until moments before the accident. The results of forensic examination showed that it is highly likely CO was present in the engine bay during the flight. CO could have leaked into the cockpit via the degraded firewall seals and grommets. Although leakage may have been minimal, the effects of CO are cumulative and would have built up over the duration of the flight. The pilot and the BGA inspector commented that the canopy was not sealed and leaked fresh air into the cockpit from around it's structure reducing the risk of CO poisoning.

The pressure test results from the annual maintenance in December 2019 were well within the 33% pressure reduction limit in the Limbach L1700 engine operating and maintenance manual and would not have given cause for concern.

Even if the colour of the CO detector spot attached to the instrument panel had changed, the pilot may not have noticed unless he specifically looked at the spot. By that time, he would already be suffering the effects of CO poisoning. At the low saturation levels (<50 ppm) stated in DOT/FAA/AR-09/49, the spot may not have changed colour at all or changed so slowly that it would be barely noticeable. Concentrations would have to rise significantly above low levels before a colour change would be noticed and it is likely the

Footnote

9 https://www.easa.europa.eu/sites/default/files/dfu/Final_Report_EASA.2008-6-light.pdf [accessed November 2020].

10 http://publicapps.caa.co.uk/docs/33/20130121SSL14.pdf [accessed December 2020].

pilot would already be impaired. Once the activated spot detector was exposed to fresh air, it returned to its original colour and erased any record of the presence of CO in the cockpit.

CAA SN-2020/003 provides an overview of both passive and active CO detectors. The notice highlights the advantages of carrying an active detector which is designed to provide visible and audible warnings at specific CO thresholds (often 50 ppm) giving the pilot time to respond.

The inspecting BGA engineer observed that following this accident he did not consider "dark spot" detectors to be an adequate means of alerting pilots to the presence of hazardous CO levels.

Survivability

The rigid structure of the fuselage, the integrity of the pilot's four-point seat harness and the shallow angle the aircraft struck the ground probably enabled the pilot to survive this accident.

Conclusion

The investigation found evidence of exhaust system gas leakage in the engine bay and pathways by which the gas could have reached the cockpit. EASA SIB 2010-19 emphasises the need to carry out detailed inspections and maintenance of the exhaust system of piston engine powered aeroplanes.

The available evidence is consistent with the pilot having suffered CO poisoning and being incapacitated before the accident occurred. Although he reported regaining consciousness, it was not in time to prevent the accident.

The issues associated with the use of Mogas and the impact of ethanol content in fuel on carburettor icing are highlighted in CAA Safety Sense Leaflet 14 and EASA report EASA.2008.C51. The increasing popularity of Mogas, it's low price, reduced environmental impact and the future increase in ethanol content makes incidents of carburettor icing more likely. Partial or complete engine failure due to carburettor icing could not be ruled out as a contributary factor in the accident.

Published: 18 March 2021.