Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

ACCIDENT
Cessna FR172K Hawk XP, EI-EZU
Near Killimordaly, Co. Galway

11 July 2020

An Roinn Iompair
Department of Transport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable and contributory causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

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[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.
[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.
[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, the Chief Inspector of Air Accidents, on 11 July 2020, appointed John Owens as the Investigator-in-Charge to carry out an Investigation into this Accident and prepare a Report.

Aircraft Type and Registration:	Cessna FR172K Hawk XP, EI-EZU	
No. and Type of Engines:	1 x Continental IO-360-KB	
Aircraft Serial Number:	FR17200597	
Year of Manufacture:	1977	
Date and Time (UTC)[4]:	11 July 2020 @ 12.02 hrs	
Location:	Near Killimordaly, Co. Galway, Ireland	
Type of Operation:	General Aviation	
Persons on Board:	Crew – 1	Passengers – 1
Injuries:	Crew – 1 (Serious)	Passengers – 1 (Serious)
Nature of Damage:	Substantial	
Commander's Licence:	Private Pilot Licence (PPL) Aeroplane (A) issued by the Irish Aviation Authority (IAA)	
Commander's Age:	65 years	
Commander's Flying Experience:	444.1 hours, all of which were on type	
Notification Source:	Shannon Air Traffic Control (ATC)	
Information Source:	AAIU Report Form submitted by the Pilot AAIU Field Investigation	

[4] **UTC**: Co-ordinated Universal Time. All times in this Report are quoted in UTC; to obtain local time, add one hour.

SYNOPSIS

The Cessna FR172K aircraft, with one Pilot and one passenger on board, was en route from Rathcoole Aerodrome, Co. Cork (EIRT) to Tibohine Airfield, Co. Roscommon. When the aircraft was north-west of Loughrea, Co. Galway, the Pilot noticed that the engine oil pressure was decreasing and that some oily smoke had emanated from the engine cowlings. This was followed by the failure of the engine. The Pilot made a MAYDAY call to Shannon Air Traffic Control (ATC), to inform them of the situation and that he was going to carry out an emergency landing. During the attempted landing in an agricultural field, the aircraft contacted the ground hard and sustained substantial damage, resulting in the serious injury of the Pilot and passenger. The Pilot and passenger were assisted from the aircraft by two passers-by. There was no fire.

NOTIFICATION

The AAIU on-call Inspector was notified of the accident by Shannon ATC at 12.17 hrs. The accident location was confirmed with An Garda Síochána, and three Inspectors of Air Accidents deployed to the scene to commence an Investigation. Following an examination of the aircraft and the accident site, the aircraft wreckage was recovered to the AAIU's wreckage examination facility at Gormanston, Co. Meath.

1. FACTUAL INFORMATION

1.1 History of the Flight

The aircraft took-off from Runway (RWY) 27 at EIRT at approximately 11.15 hrs on 11 July 2020. The purpose of the flight was to attend a '*fly-in*' at Tibohine Airfield, Co. Roscommon. The aircraft's track after take-off, which was obtained from the Pilot's portable GPS[5] navigation unit (Satnav), is shown in **Figure No. 1**. During the early part of the flight, Shannon ATC instructed the aircraft to route east of the controlled airspace surrounding Shannon Airport and the Pilot therefore turned the aircraft towards the north-east. The aircraft continued in this direction for approximately 20 minutes, before taking up a generally northerly track towards the destination airfield. At approximately 11.46 hrs, the Pilot contacted Shannon ATC to advise that the aircraft was passing Lough Derg (Co. Clare). Later, at approximately 11.58 hrs, the Pilot advised ATC that the aircraft was just passing Loughrea (Co. Galway).

Data obtained from the Satnav indicated that the aircraft's elevation and airspeed decreased at this stage. Just over one minute later, at an elevation of approximately 1,760 feet (ft), the Pilot contacted Shannon ATC, reported the aircraft registration and stated: '*MAYDAY, MAYDAY, looks like I'm having an engine failure, serious loss of oil pressure, I'm going to have to make an emergency landing'*. ATC acknowledged the transmission and advised that there was no known air traffic in the vicinity. No further transmissions from the aircraft were received by ATC, despite several attempts to contact the aircraft.

[5] **GPS:** Global Positioning System.

Figure No. 1: Aircraft track showing location of MAYDAY call and accident site

After the MAYDAY call, the aircraft descended in a north-north westerly direction for approximately 1.5 nautical miles (NM), before commencing a turn towards the west as it approached an agricultural field near Killimordaly, Co. Galway. The aircraft contacted the ground hard during the attempted forced landing. When the aircraft came to rest, it was on a magnetic heading of 114^{o} (i.e. back towards the direction it had approached from). The impact occurred approximately two minutes after the MAYDAY call was made. The aircraft sustained substantial damage in the impact sequence (**Photo No. 1**). There was no fire.

Photo No. 1: Final resting position of aircraft

A motorist passing by the field noticed the aircraft, and upon stopping his car, saw that there was movement within the aircraft. The Investigation interviewed this witness, who said that after seeing the aircraft, he got out of his car and approached the scene. He said that the injured Pilot asked him to get him (the Pilot) and the passenger out of the aircraft. The witness phoned the emergency services, and because he was beside the aircraft's right door (the passenger side), he cut the seat belt that was restraining the injured passenger, before removing and carrying the passenger towards the entrance to the field.

Another motorist arrived at the field and also went to the aircraft. The Investigation also interviewed this witness, who said that there was fuel flowing out of the aircraft, and after speaking with the Pilot, assisted him from the aircraft. Another person then assisted in bringing the Pilot further away from the aircraft.

The emergency services arrived at the scene a short time later. The passenger was taken to hospital by road ambulance. The Pilot was airlifted to hospital by an Irish Air Corps Emergency Aeromedical Service helicopter. Although there was no fire, the attending Fire Service sprayed the aircraft and the adjacent area in a blanket of fire-retardant foam as a precaution.

1.2 Interviews and Statements

1.2.1 Pilot

Due to the extent of the Pilot's injuries, the Investigation spoke briefly with the Pilot by telephone two days after the accident and again a number of days later. A detailed follow-up telephone interview was conducted with the Pilot approximately one month after the accident. Further follow-up interviews were conducted during the course of the Investigation.

The Pilot stated that during the flight he noticed that the aircraft's airspeed had dropped back to 90 kts and that this should not have occurred with the throttle setting he had. He said he noticed the oil pressure dropping and that there was a '*puff of oily smoke*' and a smell of oil. The Pilot recalled that after he noticed the oil pressure dropping, he tried to adjust the propeller setting, but that it was unresponsive. He said that the engine '*spluttered*' and he tried the throttle, but there was a '*cracking noise*'. He said he picked the landing field early and selected the flaps to 10^{o} but then retracted the flap again due to speed concerns (the flaps appear to have been subsequently deployed prior to the attempted landing – **Section 1.6** refers).

The Pilot was not sure if the engine provided any power during the descent initially, but that it did go '*silent*'. He said he did not attempt to restart the engine and focussed on getting the aircraft '*down safely*'. He said he got over the field and lined up, but that the ground seemed rough. He thought that he may have delayed the landing and looked for a smoother patch, and that he may have turned left to avoid an obstacle. The Pilot said that somehow the aircraft lost some lift, or lost momentum and he thought that it was the left wing which lost lift. He did not remember if the stall warning sounded. The Pilot said he also did not remember the actual impact but remembered '*coming to*' after the impact and that there was fuel dripping from the left wing. He said he heard a person asking if they were okay and that he asked this person to get him and his passenger out of the aircraft. The Pilot said that the passenger was removed from the aircraft first.

The Pilot was asked about the refuelling that was carried out before the flight. He said he took a sample of fuel from both tanks and visually inspected these for water and that none was detected. The Pilot stated that he refuelled the aircraft with approximately 40 litres of Mogas (automotive gasoline) before the flight and conducted the pre-flight checks, including a test of the ignition magnetos. The Pilot said that the aircraft departed with 160 litres of fuel on board. The Pilot's logbook records that he flew the aircraft on 2 July 2020 for 30 minutes. The Pilot stated he uplifted approximately 80 litres of Mogas prior to that flight.

He thought that the aircraft may not have flown from September [2019], until the flight on 2 July 2020, but that the aircraft's engine was occasionally started. He said that prior to the 2 July flight there was very little fuel in the aircraft (approximately 30 litres). The Pilot's logbook records that three flights were conducted on 6 July 2020. The Pilot said that an uplift of fuel was not required prior to these flights. He said that the aircraft was refuelled with Mogas approximately '*fifty percent of the time*'. He also said that he always flew the aircraft with the fuel tank selector valve set to '*Both*' (**Section 1.4.1**) and that normal fuel mixture and power settings were used throughout the accident flight.

The Pilot informed the Investigation that he routinely practiced simulated engine-out landings (by reducing the engine to idle before landing) and had carried out such a landing at EIRT during one of the flights conducted on 6 July 2020. He said he was aware of the wind direction on the accident flight and this influenced the direction of the final approach to the field following the engine failure.

1.2.2 Passenger

The passenger stated that the Pilot was always very careful about checking and rechecking the aircraft before flight. The only thing that the passenger could remember about the accident itself was that the Pilot said something like the '*oil is dropping*', or the '*oil is going down'.* The passenger said that the Pilot was looking at the [oil pressure] gauge and that he made a MAYDAY call. The next thing the passenger remembered was waking up in hospital.

The passenger had taken some sight-seeing photographs during the flight, which were provided to the Investigation. One of these, with a time stamp of 11:43:41, shows a panel on the left side of the cockpit's main instrument panel, in addition to the view outside the aircraft. The panel contains several gauges, including the oil temperature, oil pressure and cylinder head temperature gauges. The Investigation provided an annotated version of the photograph to the Pilot for his opinion regarding the gauge needle positions (**Photo No. 2**). The Pilot stated that the oil temperature gauge appeared to be indicating a lower temperature than normal, whereas the oil pressure gauge appeared to be indicating close to normal. Regarding the cylinder head temperature gauge needle, the Pilot said it '*would* [normally] *be slightly to the right of vertical but not as far as it appears to be in the photo* […]'.

Photo No. 2: Cockpit panel containing cylinder head temperature and oil gauges

1.2.3 Witnesses

A person at EIRT reported that he observed the Pilot checking the engine oil level before the flight and that the Pilot ensured the passenger's seat belt was fastened.

A person working approximately 700 m to the south-east of the accident site saw the aircraft flying low overhead. He said that there was no engine noise and that the aircraft '*came down fast*'. He said he went to the accident site and when he arrived there, a '*couple of people*' were already present.

Another person, who was located approximately 1.5 km to the south-east of the accident site, saw the aircraft passing overhead and noted that there was '*no engine noise at all*'.

1.3 Injuries to Persons

The Pilot and passenger sustained multiple serious injuries in the accident.

1.4 Aircraft Information

1.4.1 General

The Cessna FR172K Hawk XP is an 8.28 m long, all-metal, high-wing aircraft, with a wingspan of 10.97 m. It is fitted with electrically operated trailing edge flaps which can be set between 0^o (full up) and 40^o (full down). Each wing is fitted with a 26 US Gallons (98 litres) fuel tank. A fuel selector valve is located in the cockpit, allowing fuel to be drawn from either wing or both.

The subject aircraft was manufactured in 1977 under licence in France by Reims Aviation S.A. It could seat four occupants – two in the cockpit and two in the rear seats. The two side-by-side cockpit seats were fitted with three-point restraint harnesses, consisting of a lap belt and a shoulder strap. The lap belts could be used independently of the shoulder straps.

The aircraft was first registered in Ireland on 22 May 2013. The aircraft's most-recent Certificate of Airworthiness was issued by the IAA on 9 September 2016. The most-recent Airworthiness Review Certificate was issued on 12 December 2019 by an IAA-approved Continuing Airworthiness Management Organisation and was valid until 11 December 2020. The aircraft was operated by a private group, of which the Pilot on the accident flight was a member.

The '*FORCED LANDINGS EMERGENCY LANDING WITHOUT ENGINE POWER*' checklist, as contained in the Pilot's Operating Handbook (POH) for the aircraft, specifies the airspeed to use as 70 kts Indicated Airspeed (IAS) for flaps up and 65 kts IAS with flaps down. The specified flap position is '*AS REQUIRED (full down recommended)*'. Regarding restraint harnesses, the checklist states: '*Seat Belts and Shoulder Harnesses - - Secure*'. The POH also tabulates the aircraft's stall speeds (IAS and Calibrated Airspeed – CAS[6]) for the aircraft at its maximum take-off/landing weight (2,550 lbs). The information contained in **Table No. 1** contains details extracted from the POH.

[6] Calibrated Airspeed (CAS): Indicated Airspeed corrected for instrument and position error.

Most Rearward Centre of Gravity				
	Bank Angle			
	0^o		30^o	
Flap Position	**IAS**	**CAS**	**IAS**	**CAS**
Up	49 kts	53 kts	53 kts	57 kts
10^o	41 kts	50 kts	44 kts	54 kts
40^o	44 kts	46 kts	47 kts	49 kts
Most Forward Centre of Gravity				
	Bank Angle			
	0^o		30^o	
Flap Position	**IAS**	**CAS**	**IAS**	**CAS**
Up	54 kts	58 kts	58 kts	60 kts
10^o	43 kts	51 kts	46 kts	55 kts
40^o	46 kts	48 kts	49 kts	52 kts

Table No. 1: Aircraft stall speeds (at 2,500 lbs)

1.4.2 Aircraft Operating History

The aircraft's logbook indicates that the aircraft operated 23 flights in 2019; the flights were conducted over 12 separate days, with the last flight being flown on 29 September 2019. The logbook records that an Annual Inspection was completed on the aircraft on 9 December 2019. It also records that a 20-minute engine run was carried out on 25 January 2020, and that a 6-Month Check and 15-minute engine run were carried out on 6 June 2020. Regarding flights operated during 2020, the logbook records that there was one on 2 July 2020 and three on 6 July 2020. The logbook also records that up until the accident flight, the aircraft had operated for a total of 2,880 hours and 40 minutes since new.

1.5 Damage to Aircraft

The aircraft was substantially damaged as a result of the impact sequence. The outer part of the left wing was bent upwards (**Photo No. 3**). This part of the wing had also sustained damage to its leading edge. In addition, there was significant creasing and bending on the left wing's upper surface at the wing root (**Photo No. 4**). It was subsequently identified that the top section of the fuel tank fitted inside the left wing was damaged, exposing the fuel to atmosphere (**Section 1.11**).

Photo No. 3: Damage to outer part of left wing

Photo No. 4: Creasing and bending on left wing's upper surface

The cabin door on the left side could not be fully opened due to the damage to its hinges, the damage to the left wing, and the orientation of the aircraft at the accident site. The right wing had minor damage to its leading edge adjacent to the wingtip; soil and grass were embedded in the damage (visible in **Photo No. 1** in **Section 1.1**). The nose landing gear had separated from its mounting points.

The engine firewall, engine mounting support structure, and forward section of the fuselage sustained significant distortion. A piece of the engine's sump had been broken; a large stone was found adjacent to the damage. Two of the propeller's three blades were broken; the other blade was undamaged (**Photo No. 5**). The propeller spinner had evidence of a significant ground impact. The aircraft's windscreen was shattered. The left main landing gear leg was displaced upwards and towards the rear of the aircraft. A piece of the wheel spat (fairing) had broken away from the left main wheel. The instrument panel had ruptured, and some instruments had become partially dislodged from the panel (**Photo No. 6**). Both control columns were broken and there was distortion of the aircraft structure in the front foot wells. The lap belt from the front right seat had been cut in two (when the passenger was being assisted from the aircraft).

Photo No. 5: Damage to propeller blades and spinner

Photo No. 6: Damage to instrument panel and front foot wells

1.6 Wreckage and Impact Information

The accident site was preserved by An Garda Síochána pending the arrival of the AAIU. On arrival, the AAIU carried out a survey of the wreckage and the accident site. The field where the wreckage was located was approximately 360 m long and 190 m wide. The eastern end of the field contained rushes/coarse grass, for approximately one third the length of the field. The Investigation obtained a detailed survey of the spot heights at every 5 m of the field and the land immediately adjacent to the field, from a commercial provider. The field was at an elevation (height above mean sea level) of approximately 197 ft (60 m) at the location of the aircraft wreckage and sloped downwards towards the east. The field's elevation at its eastern perimeter was approximately 184 ft (56 m). There was a fenced-off area of land, approximately 40 m long and 20 m wide, located towards the western end of the field. This contained densely planted tall shrubs and is visible behind the aircraft in **Photo No. 1** in **Section 1.1**.

The impact site itself was compact and there was no evidence of any ground run behind the aircraft. Several areas of damage to the ground surface were evident along a line which ran from outboard and forward of the left wing tip, towards the wing root (**Photo No. 7**). A piece from a main wheel spat was present about halfway along the line of ground surface damage. Other debris from the aircraft was evident along the line of the ground surface damage.

Photo No. 7: Ground damage outboard and forward of left wing

The aircraft's trailing edge flaps appeared to be in a partially deployed state. During subsequent inspection, the flap actuator was found to be extended by approximately 70 mm. According to the aircraft manufacturer's data, this equates to a flap setting of approximately 12^{o}. The battery master switch was in the ON position. The fuel selector valve was set to '*BOTH*'. When the aircraft was lifted during recovery operations, the lower part of the fuselage was found to be wet with oil.

On a date subsequent to the accident, the Investigation conducted an aerial survey of the site using a Remotely Piloted Aircraft System (RPAS). The purpose of the RPAS flight was to replicate the aircraft's approach path to the field, based on the elevation and position data obtained from the Satnav (**Section 1.13**). Still images extracted from the RPAS video recordings at two different stages of the approach are shown in **Figure No. 2**. The left-hand image in the Figure shows the aerial view of the field looking west (as per the subject aircraft's final approach); the right-hand image in the Figure shows the view of the surface conditions at the field's eastern end when closer to the ground.

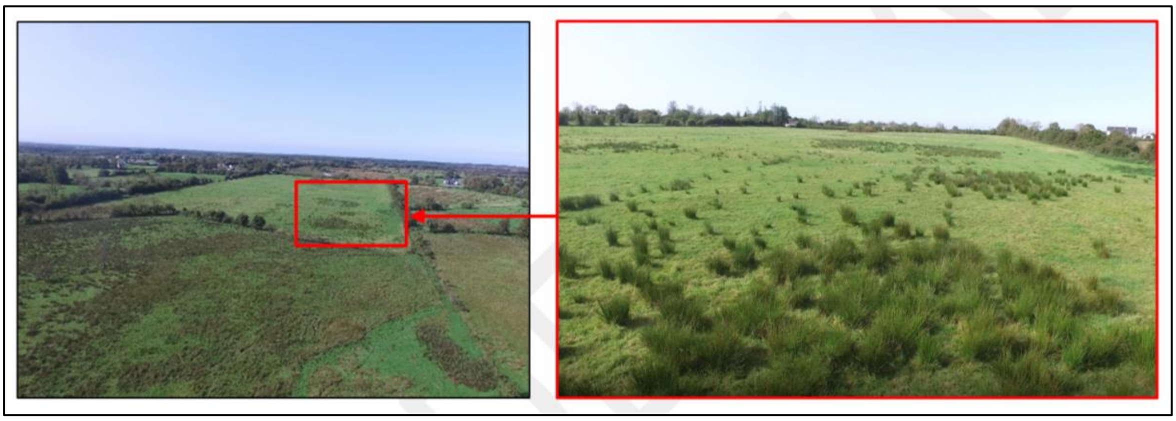


Figure No. 2: Aerial view of field as per final approach and when closer to the ground

1.7 Other Damage

There were impact marks on the field surface where the aircraft came to rest and evidence of fuel and engine oil.

1.8 Survival Aspects

The Pilot informed the Investigation that he ensured that both his and the passenger's seat belts were secured before the flight and that he also checked this before the forced landing. He said the lap belts were used but not the shoulder straps that formed part of the three-point restraint system.

1.9 Personnel Information

The Pilot held a European Union Part-FCL[7] PPL(A), which was issued by the IAA on 11 October 2016. The original date of issue of the licence was 14 October 2011. The licence contained an SEP[8] (land) Class rating that was valid until 3 September 2020.

The Pilot's Class 1/Class 2 Medical Certificate was issued on 6 December 2019. The Class 2 Medical Certificate (required for a Private Pilot Licence) was valid until 6 December 2020. The Pilot's flying experience is outlined in **Table No. 2**.

Total hours (all on type):	444.1 hours
Total on type P1:	199.2 hours
Last 90 days (all on type):	2.5 hours
Last 28 days (all on type):	2.5 hours
Last 24 hours (all on type):	0.75 hours

Table No. 2: Pilot's flying experience

1.10 Engine

1.10.1 General

The aircraft was powered by a Teledyne Continental Motors (TCM) IO-360-KB fuel-injected, air-cooled, horizontally opposed, six-cylinder engine (Serial Number 235960R). The engine cylinders are numbered as shown in **Figure No. 3**. A breather pipe is connected to the engine crankcase to permit venting of any gases that have leaked past the piston rings ('*blow-by*'). The breather pipe exits through the lower engine cowling. The engine was fitted with a three-blade MTV-12, variable pitch propeller. The propeller blades were manufactured from wood.

[7] **Part-FCL** (Flight Crew Licensing): Commission Regulation (EU) No. 1178/2011 laying down technical requirements and administrative procedures related to civil aviation aircrew pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council.
[8] **SEP**: Single Engine Piston.

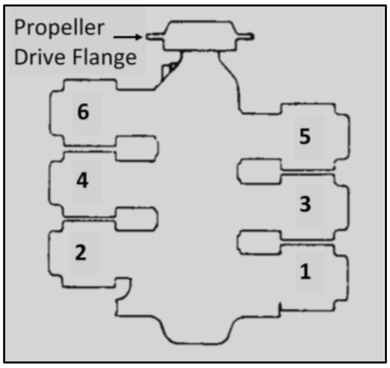


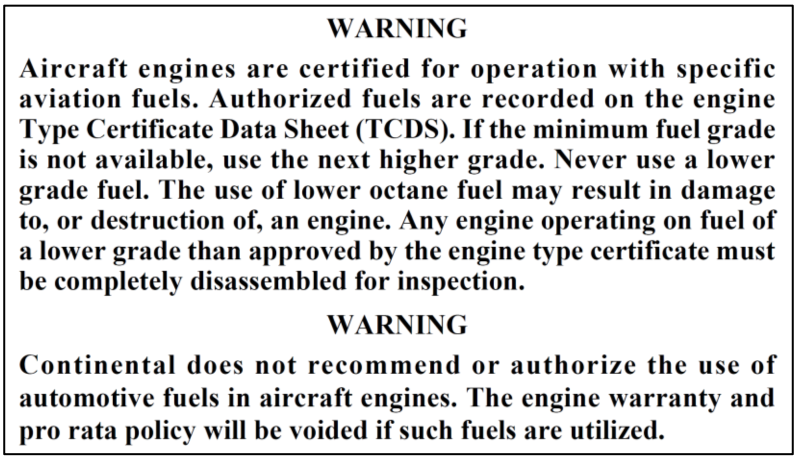
Figure No. 3: Engine cylinder numbering (viewed from above)

1.10.2 Fuel Specification

The engine Type Certificate Data Sheets, as issued by the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA), contain the list of approved fuels for the IO-360-KB engine as fitted to the aircraft; these are: [Avgas] 100, [Avgas] 100LL [Low Lead], B95/130 CIS [Russian standard], or RH95/130 [Chinese standard].

The Engine Manufacturer's IO-360 Series '*Engine Maintenance and Overhaul Manual*' contains the '*Fuel System Specifications*' and includes the same information as that listed in the Type Certificate Data Sheets. A footnote to the specifications states that the '*Engine is certified for operation with 100-LL Blue or 100 Green aviation fuel. If the minimum fuel grade is not available, use the next higher grade available; never use a lower grade fuel*'.

The Engine Manufacturer's Standard Practice Manual applicable to the engine contains the following warning in Section 7.2.2, '*Engine Fuel Requirements*' (**Figure No. 4**):



WARNING

Aircraft engines are certified for operation with specific aviation fuels. Authorized fuels are recorded on the engine Type Certificate Data Sheet (TCDS). If the minimum fuel grade is not available, use the next higher grade. Never use a lower grade fuel. The use of lower octane fuel may result in damage to, or destruction of, an engine. Any engine operating on fuel of a lower grade than approved by the engine type certificate must be completely disassembled for inspection.

WARNING

Continental does not recommend or authorize the use of automotive fuels in aircraft engines. The engine warranty and pro rata policy will be voided if such fuels are utilized.

Figure No. 4: Extract from Engine Standard Practice Manual

Similarly, an IAA Safety Leaflet (IGA 9 R2) titled '*Using Unleaded Petrol (Mogas) in Aircraft*' states that '*Using unapproved fuels in an aircraft can cause damage to aircraft, engines and their components. This may result in engine failure*. […]'. Safety Leaflet IGA 9 R2 is available on the IAA's website.

Stencilled lettering adjacent to the fuel filler cap on the upper surface of each wing of the subject aircraft highlights the fuel to use: '*AVGAS 100L*'.

1.10.3 Maintenance History

The most-recent overhaul of the engine was performed at a UK Civil Aviation Authority (CAA)-approved organisation; the associated authorised release certificate was certified on 29 July 2008. The engine logbook records that the engine had operated for a total of 259 hours and 30 minutes since '*top overhaul*'. The aircraft owner advised that the time recorded actually refers to '*time run since complete overhaul*'. The most-recent Annual Inspection was certified on 9 December 2019. The associated Certificate of Release to Service in the logbook recorded that an inspection of the engine oil filter was carried out during the Annual Inspection. No adverse findings were noted. A compression check of each engine cylinder was reported to have been carried out.

The engine logbook also records that a '*6 MONTH CHECK*' was performed on 6 June 2020. According to the aircraft owner, this includes a requirement to change the engine oil, which the owner stated was carried out at that time. Detailed maintenance records, for the individual tasks performed during the Annual Inspection and the 6 Month Check, were not available for examination by the Investigation. The retention of detailed maintenance records by aircraft owners and Continuing Airworthiness Management Organisations is subject to the requirements of Part-ML[9] (previously Part of Regulation (EU) No 1321/2014 – continuing airworthiness).

1.10.4 Engine Examination

1.10.4.1 AAIU Examination

The engine was removed from the aircraft at the accident site to facilitate aircraft recovery and was brought, with the aircraft wreckage, to the AAIU's examination facility at Gormanston, Co. Meath. A preliminary examination identified that there was a hole in the crown of the No. 1 piston, substantial abrasion to the No. 1 cylinder walls, evidence of solidified molten metal in the No. 4 cylinder, and possible piston damage and abrasion to the walls of other cylinders. There was evidence of water in the No. 5 cylinder (the aircraft had been covered in a blanket of fire-retardant foam at the accident site). The engine was shipped to the UK for dismantling and further examination by a UK CAA-approved engine overhaul organisation.

1.10.4.2 Disassembly and Examination by Approved Engine Overhaul Organisation

It was noted that the engine was very tight to turn when received at the overhaul facility. The crankshaft to camshaft timing (valve timing) was found to be correct. There was no evidence of an induction system leak; such a leak could result in lean running.

The fuel injector nozzles were removed from the engine. Each fuel injector nozzle should only be fitted to a specific cylinder, as identified by a stamped number on the nozzle assembly, which also identifies the orifice size of the nozzle. For example, the number '*210J*' identifies the size of the nozzle orifice as '*10J*' and that it should be fitted to the No. 2 cylinder. Various orifice sizes are available and according to the engine overhaul organisation, this is '[…] *to deliver more/less fuel to specific cylinders to aid in level CHT* [Cylinder Head Temperature]'.

[9] Part ML (Regulation (EU) No 1321/2014) applies to certain categories of light aircraft, including the subject aircraft type.

It was noted during engine disassembly that the fuel injector nozzles were not in their correct cylinder positions: nozzle No. 1 was found in cylinder No.2, nozzle No. 2 was found in cylinder No. 6, nozzle No. 3 was found in cylinder No. 4, nozzle No. 4 was found in cylinder No.1, nozzle No. 5 was found in cylinder No. 3 and nozzle No. 6 was found in cylinder No. 5. All removed nozzles had the same orifice size (*10J*). The nozzles were bench tested and found to be '*satisfactory overall*'.

The No. 1, No. 3 and No. 4 pistons and cylinders were found to have '*detonation/pre-ignition damage*' (**Section 1.12.2**). The damage to the No. 1 piston crown and skirt was substantial (**Photo No. 10** and **Photo No. 11**), with material missing from the edges of the piston crown and damage to the piston ring lands[10]. The No. 1 cylinder was found to be scored, with metal transfer from the piston to the cylinder wall. The piston rings were also scored and were seized in the piston ring grooves. In addition, the inlet and exhaust ports were wet with oil. There was no visible damage to the inlet and exhaust valves. The cylinder's two spark plugs could not be tested due to debris between the electrodes.

Photo No. 10: Damage to the No. 1 piston crown (ringed)

Photo No. 11*:* Damage to the No. 1 piston skirt and piston ring lands.

The findings were similar for the No. 4 piston (**Photo No. 12**) and the No. 4 cylinder. There was damage to the No. 3 piston crown (**Photo No. 13**) which was also attributed to '*detonation/pre-ignition*', although the damage was less severe. There was scoring to the cylinder walls. The inlet port was wet with oil; the exhaust port was dry. The two spark plugs from the No. 3 cylinder were tested satisfactorily.

Photo No. 12: Damage to the No. 4 piston crown (ringed)

Photo No. 13: Damage to the No. 3 piston

[10] **Piston ring lands:** The area of the piston between the piston rings.

The No. 2 piston also had damage to the crown and skirt, which the engine overhaul organisation attributed to '*debris picked up due to other failed pistons*'. The No. 2 exhaust port was wet with oil; the inlet port was dry. The cylinder wall had some scoring damage. There was no visible damage to the inlet and exhaust valves. The piston rings had scoring damage but were loose in the piston ring grooves. The two spark plugs from the No. 2 cylinder were tested satisfactorily.

There was no visible damage to the No. 5 and the No. 6 pistons; however, the No. 5 and the No. 6 cylinders had some scoring attributed to debris from other damaged pistons. The piston rings on each piston had light scoring but were loose in the piston ring grooves. There was evidence of corrosion from water ingress in the No. 5 cylinder (the aircraft had been covered in a blanket of fire-retardant foam at the accident site). No other evidence of corrosion was found. The inlet ports on the No. 5 and the No. 6 cylinders were wet with oil. The exhaust ports were dry. There was no visible damage to the inlet and exhaust valves. The spark plugs from the No. 5 cylinder displayed a weak spark when tested. This was attributed to contaminated electrodes. The spark plugs from the No. 6 cylinder were tested satisfactorily.

The timing of the magnetos was checked, and it was found that both were at 22^{o} (before top dead centre) and not 20^{o} as specified by the Engine Manufacturer. The overhaul organisation stated that such a discrepancy has been found on other engines, without any consequential detonation. It was noted that the right magneto was '*difficult to time due to material transfer on the points*'. The magnetos were bench tested. No faults were found on the left magneto. When initially tested, the right magneto did not operate until approximately 2,000 rpm[11]; when the test was repeated, it was found to operate correctly.

Other findings from the engine disassembly are documented in **Appendix A**.

The approved engine overhaul organisation summarised the findings as follows:

> '*Pre-ignition/detonation over a period, finally resulting in #1 piston and #4 piston to burn through resulting in loss of compression and causing significant metal contamination in the oil system. This metal contamination circulated through the oil galleries, and into the crankshaft, camshaft and con rod bearings causing damage/wear. Engine was very tight to turn when received and cylinder bore score marks/metal transfer on cylinder #1 and #4*'.

The Investigation provided the Engine Manufacturer with a copy of the engine teardown report. The Manufacturer agreed with the findings of the teardown inspection that '*this is a detonation/pre-ignition event*'. The Manufacturer also stated that in its experience '*engines operating on Mogas are far more likely to encounter this type of event as the detonation margin is lower than if they had used AvGas*' and that '*after a detonation event and the piston has worn all the way through, the crankcase will get pressurized and pump out all the oil within a few minutes through the breather*'.

[11] **rpm:** Revolutions per minute.

The Investigation asked the Engine Manufacturer whether it considered the incorrect magneto timing to have been a factor regarding detonation. The Engine Manufacturer stated that the 2° difference in ignition timing (22° actual vs 20° specified) would have reduced the detonation margin, but not significantly.

1.11 Fuel Analysis

The Investigation attempted to obtain a fuel sample from the aircraft at the accident site. However, due to the orientation of the aircraft, this was not possible. Several days later, on 27 July 2020, at the AAIU's wreckage examination facility, the Investigation removed a panel from the upper surface of the left wing to gain access to the left fuel tank. The fuel tank was found to have sustained a rupture to its upper surface, which exposed the contents of the tank to atmosphere, but not to a flow of free air because the tank was still within the wing structure. The Investigation obtained a sample of the fuel from the tank and sent it to a specialist laboratory for analysis.

The analysis identified that the fuel had less than 2.5 milligrams per litre (mg/l) of lead, which according to the laboratory's assessment of the results indicated that there was '*zero Avgas 100LL present*'. The ethanol content was found to be less than 0.8% volume per volume (v/v) (the detection limit). There was also free water present. The density was found to be '*very high (in the kerosene range)*'. The laboratory deemed this to be due to the '*loss of light ends*[12]*, leaving the heavier compounds, including aromatics behind*'. The distillation IBP (Initial boiling point) was 84.5°C. The laboratory noted that this is normally 20-30°C and stated that '*the whole distillation is weighted towards the heavier end of the test and confirms the other tests carried out in the loss of light ends*'.

Mogas is an unleaded fuel produced for use in automobiles, which for environmental reasons contains ethanol. Mogas sold in Ireland normally conforms to the EN228 standard and contains approximately 5% ethanol (v/v). The Investigation asked the laboratory if it was considered possible for the fuel to degrade to the extent identified during the analysis in the 16 days that the fuel tank contents were exposed to the atmosphere and for the ethanol in the fuel to have evaporated. The laboratory stated that it was possible but would probably need longer to degrade to the extent identified and that it would have had to be warmed to lose that amount of '*light ends*' and all the ethanol over a small timeframe. The laboratory also stated that it would '*expect remnants of ethanol to be detected if there was any there initially*'.

The Investigation requested the company that supplied fuel to the service station where the Pilot obtained the Mogas for the aircraft to confirm the ethanol content of the fuel supplied. The fuel company advised that the ethanol content of the fuel provided was 4.8% [v/v].

[12] **Light Ends:** The components of a mixture of hydrocarbons with a lower-boiling point, such as those evaporated or distilled off easily in comparison to the bulk of the mixture; for hydrocarbon mixtures, usually considered to be butane and lighter.

1.12 Engine Combustion Cycle and Fuel Octane Number

1.12.1 Normal Combustion

In a four-stroke reciprocating engine, such as the subject engine, normal combustion involves the progressive burning of a compressed fuel-air mixture within the cylinders. Combustion is initiated by the spark plugs located at the top of each cylinder, just before a piston reaches the end of its compression stroke (Top Dead Centre – TDC). Combustion commences and the flame front passes through the mixture evenly. The resulting combustive force is applied to the pistons in a stable manner, pushing the piston down on its power stroke.

1.12.2 Abnormal Combustion

1.12.2.1 Pre-Ignition

Pre-ignition is the ignition of the fuel-air mixture in a cylinder before it is ignited by the spark plugs. The ignition source can be a defective spark plug, carbon or lead deposits in the combustion chamber, a burned valve, or anything that could overheat and glow. When pre-ignition occurs, the combustive force acts on a piston earlier in the compression stroke than normal, resulting in increased mechanical stress on the engine, excess heat, and possible engine damage.

1.12.2.2 Detonation

Detonation is defined in the FAA’s Advisory Circular 33.47-1 (dated 27 June 1988) as ‘*the spontaneous combustion of an unburned charge* [fuel-air mixture] *which occurs ahead of the flame front after normal ignition*’ (**Figure No. 5**). The increase in pressure and temperature as a result of the normal, spark-induced combustion precipitates detonation. Both flame fronts meet, causing a rapid increase in pressure. According to a presentation produced by the FAA’s Safety Team, ‘*mild detonation may increase engine wear, though some engines can operate with mild detonation. However, severe detonation can cause engine failure in minutes*’.

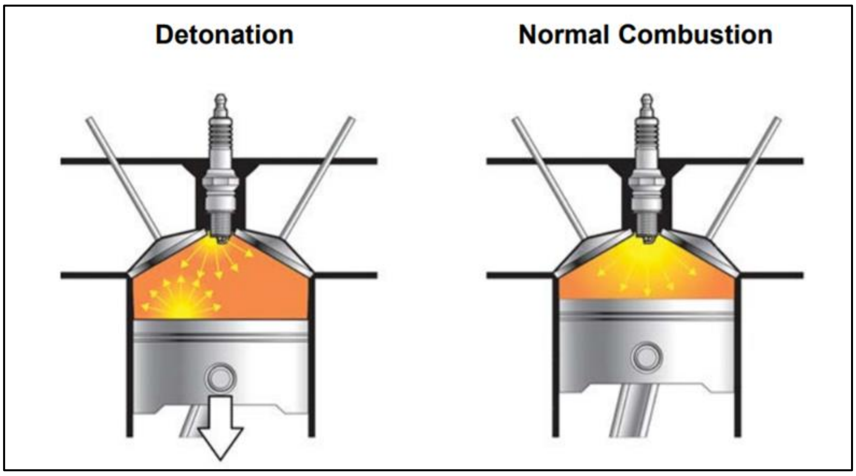


Figure No. 5: Detonation versus normal combustion (*FAA*)

A fuel's octane rating is a measure of its resistance to detonation. The rating is based on the pressure at which a fuel spontaneously combusts (auto-ignites) in a test engine. The addition of lead increases a fuel's octane rating. Mogas is unleaded, whereas Avgas contains lead. The Research Octane Number (RON) rating system is used for Mogas. However, another rating system – the Motor Octane Number (MON) – is used for Avgas and is derived from a more severe test than that used for Mogas. Avgas offers a minimum of 99.6 MON, whereas Mogas is typically only 88 MON (95 to 98 RON).

The presence of ethanol in Mogas increases the fuel's ability to absorb water. Once the water remains dissolved, it is not detectable by visual inspection. However, if the water content exceeds a critical threshold, or if the temperature of the fuel is lowered, a non-reversible[13] phenomenon known as '*Phase Separation*' can occur, whereby the ethanol present in the fuel attaches itself to the water molecules and sinks to the bottom of the tank, resulting in two layers within the fuel tank – a gasoline only layer at the top and an ethanol-water mixture at the bottom. The ethanol-depleted gasoline layer will have a lower octane number and will be less-resistant to detonation.

Detonation can also occur if parts of the combustion chamber are hotter than normal. Excessive heat can be caused by issues such as improper cooling, high compression from excessive combustion chamber deposits, lean mixture, or advanced timing. Detonation causes a temperature increase, which tends to lead to further detonation. If detonation damage is limited to one cylinder, it is likely the result of a problem specific to that cylinder, such as a defective fuel injector, whereas detonation caused by the fuel itself is more likely to affect several cylinders, since the contributing factor is present in all cylinders.

As shown in **Figure No. 5**, detonation occurs ahead of the normal (spark-induced) flame front and usually initiates at the extremities of the combustion chamber. It can cause rapidly rising temperatures at the piston edges, which, along with the piston ring lands, can be damaged as a result. Once this occurs, the damaged piston edge is exposed to severe heat and pressure which can cause a hole to be burned through the edge of the piston. Once the integrity of the piston is compromised, pressure from compression and combustion will cause the pressure within the crankcase to increase and could result in the engine's lubricating oil being ejected through the engine breather.

1.13 Recorded Data

The aircraft was not fitted with a Cockpit Voice Recorder (CVR) or a Flight Data Recorder (FDR), nor was it required to be. However, the Pilot was using a Garmin GPSMAP 296 satellite navigation unit (Satnav) to assist with en route navigation. This unit is capable of recording time-stamped flight track, ground speed, and elevation data. The elevation (altitude) data is GPS-derived (triangulated from several GPS satellites and referenced to mean sea level). The unit is not crash-protected but was undamaged in the impact sequence, and the data from the accident flight was successfully downloaded by the Investigation. The times recorded by the Satnav were local (UTC +1) and have been adjusted to UTC by the Investigation.

[13] Without chemical treatment.

The Satnav recorded elevations of between 273 ft and 275 ft when the aircraft was travelling on RWY 27 at EIRT before taking off on the occurrence flight. The Investigation obtained a detailed survey of the spot heights of the Runway from a commercial provider. These recorded runway elevations of between 268 ft and 269 ft at the same data points. The Satnav data indicates that the aircraft took-off at time 11:15:00 and climbed to a recorded elevation of 2,437 ft at time 11:19:12, before the recorded elevation reduced to 1,994 ft at time 11:21:38. The recorded en route elevation varied between 1,557 ft and 2,375 ft.

At time 11:58:12, the Satnav recorded an aircraft elevation of 2,008 ft (two seconds earlier, the Pilot informed Shannon ATC that the aircraft was '*just past Loughrea*'). The Pilot's next transmission to Shannon ATC was the MAYDAY call, which was made at time 11:59:23. The elevation recorded by the Satnav at time 11:59:30 was 1,759 ft.

According to the Satnav, in the final stages of the flight, the aircraft approached the field from the east (**Figure No. 6**). The Pilot informed the Investigation that this was because he was aware of the wind direction. At time 12:01:20, the Satnav recorded that the aircraft was approximately 200 m from the eastern perimeter of the field and was at an elevation of 310 ft (94 m) (**Point A**, **Figure No. 6**). The ground speed recorded was 71 kts (the ground elevation at this location was approximately 173 ft).

The next data point recorded (**Point B**, **Figure No. 6**) was at time 12:01:29, when the aircraft was above the field and had travelled over approximately one third of the length of the field; the Satnav recorded the aircraft's elevation at this point as 202 ft (62 m) and the ground speed as 58 kts (the ground elevation at this location was 190 ft). The next data point recorded (**Point C**, **Figure No. 6**) was at time 12:01:33 and was approximately 120 m from the previous data point, when according to the data, the aircraft had turned to the left by approximately 5^{o}; an aircraft elevation of approximately 248 ft (76 m) and a ground speed of 36 kts were recorded at this point (the ground elevation at this point was 193 ft).

The final data point recorded (**Point D**, **Figure No. 6**) was at time 12:01:38. It was approximately 90 m from the previous data point and 40^{o} to the left (south-west) of it. The Satnav recorded the aircraft's elevation at this point as 220 ft. The field elevation at this location is 197 ft (60 m). The aircraft wreckage came to rest approximately 10 m to the south-west of the final point recorded.

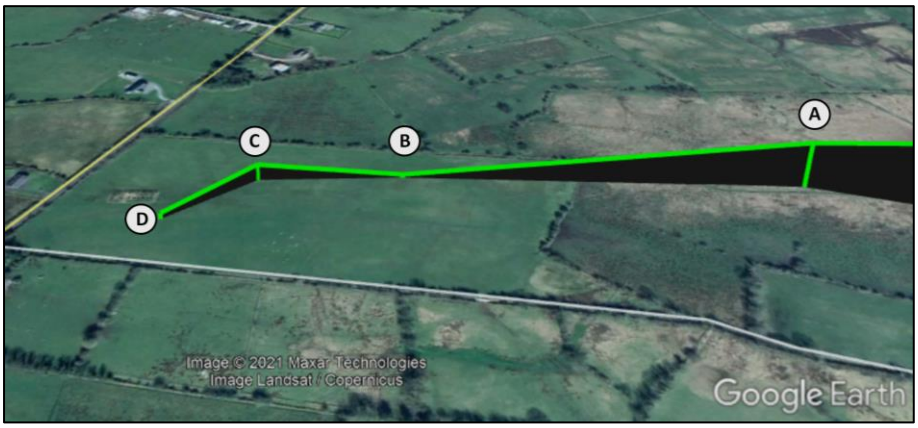


Figure No. 6: Final stages of flight as recorded by on board Satnav unit

1.14 Meteorological Information

The Aviation Service Division of *Met Éireann*[14] provided the Investigation with the following aftercast for Killimordaly, Co. Galway (**Table No. 3**):

Meteorological Situation:	An anticyclone of 1029 hPa [hectoPascals] is centred close to the southwest coast giving a light to moderate variable airflow across Ireland.
Surface Wind: **Wind at 2,000 feet (ft)** **Between Surface and 300 ft:**	West to south-west, 3-7 KT [Knots]. South to south-west 5-10 KT. Varying between south-east and west, 3-7 KT.
Visibility:	40+ km [kilometres].
Weather:	Dry and mostly cloudy, isolated sunny spells.
Cloud:	Few (1-2/8th oktas[15]) cumulus with bases between 3,000-4,000ft and a broken (5-7/8th oktas) stratocumulus layer with the base at 4,000-5,000ft.
Surface Temperature/Dew Point:	16/8 degrees Celsius.
Mean Sea Level (MSL) Pressure:	1028 hPa.
Freezing Level:	11,000 feet.

Table No. 3: Meteorological conditions for Killimordaly

2. ANALYSIS

2.1 Accident Sequence

Following the failure of the aircraft's engine, the Pilot selected an agricultural field located to the north-west of the aircraft's location, and due to the wind conditions lined up in a westerly direction for a final approach to the field. According to Satnav data, the aircraft was at an elevation of 310 ft and a ground speed of 71 kts when it was approximately 200 m from the eastern perimeter of the field. The ground elevation at this location was approximately 173 ft. The Satnav recorded elevations of between 273 ft and 275 ft when the aircraft was travelling on RWY 27 at EIRT before taking off on the occurrence flight. Survey data obtained from a commercial provider recorded elevations of between 268 ft and 269 ft at the same points on RWY 27. Therefore, the Investigation considers the Satnav elevation data to be reasonably accurate.

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[14] **Met Éireann:** The Irish meteorological service

[15] **Oktas:** An estimate of cloud coverage in the sky on a scale from 0 to 8; completely clear sky is described as 0 oktas, while completely overcast sky is described as 8 oktas.

The Satnav data indicates that when the aircraft had flown over one third of the field's length, it had descended to an elevation of 202 ft (the survey data field elevation at this point is 190 ft), before the aircraft climbed to an elevation of 248 ft. The Pilot recalled that he may have delayed the landing and looked for a smoother patch of ground. Any increase in altitude without any means of increasing power, would result in a reduction in airspeed; the Satnav data indicates that the ground speed reduced from 58 kts to 36 kts during this period.

The Pilot also said he thought that that he may have turned left to avoid an obstacle. There was a fenced-off area of land, located towards the western end of the field, which contained densely planted tall shrubs. This area would have been in front of the aircraft following the delayed touchdown and may have necessitated such a turn. An examination of the aircraft wreckage identified that the flaps were likely extended to 12^{o}. According to the POH, the aircraft's stall speed (at maximum take-off/landing weight), with 10^{o} flap selected and zero degrees angle of bank is 41-43 kts IAS, depending on the position of the aircraft's centre of gravity. This increases to 44-46 kts IAS at 30^{o} angle of bank. The weather report indicated that the surface wind was west to south-west, at 3-7 kts; this would likely have resulted in the aircraft's airspeed being greater than its ground speed in the final moments, and the 36 kts ground speed indicated by the Satnav was likely close to the aircraft's stall speed. Any increase in bank angle would have resulted in an increased stall speed, i.e. the aircraft would have had to fly at a greater airspeed than the increased stall speed to avoid stalling. Therefore, it is probable that a stall occurred, leading to a rapid loss of any remaining height above the ground.

The severity of the damage to the left wing, the left main landing gear and the front section of the aircraft indicates that these areas made hard contact with the ground. This suggests that the left wing stalled first and therefore dropped, which is consistent with the Pilot's recollection of the final moments of the flight. The aircraft wreckage was pointing back in the direction of the aircraft's approach to the field. The orientation of the wreckage, the nature of the ground damage adjacent to the left wing, and the apparent lack of any ground run behind the aircraft, also indicates that the aircraft struck the ground in a left-wing-down attitude and that it likely pivoted about the left wing tip after impact.

The soil and grass embedded in the leading edge of the right wing adjacent to the wingtip and the minor nature of the damage to that wing tip, suggests that it only made brief contact with the ground after most of the impact energy had been absorbed and before the aircraft reached its final resting position.

The final elevation recorded by the Satnav was 220 ft, whereas the actual elevation of the field at the location of the aircraft wreckage was 197 ft. Also, the aircraft wreckage was located approximately 10 m to the south-west of the final point recorded. The Satnav calculates elevation and position by triangulation which relies on the unit receiving signals from several satellites and this may not have been possible in the final moments due to the aircraft's unusual attitude at that stage.

2.2 Engine Failure

2.2.1 General

Records indicate that the aircraft did not fly from September 2019 until July 2020, although the logbook records that an engine run was carried out in January 2020 and another in June. The Investigation therefore considered the possibility that the lack of operation adversely affected the condition of the engine. However, apart from the No. 5 cylinder, which had evidence of corrosion due to water ingress, no other corrosion of the engine components was found. It would not have been possible for water to be present in the No. 5 cylinder during engine operation. Therefore, the Investigation attributed the water ingress to the fact that the aircraft had been covered in a blanket of fire-retardant foam at the accident site and considers that corrosion was not a factor in the engine failure.

Detonation occurs ahead of the normal flame front and usually initiates at the extremities of the combustion chamber. It can cause rapidly rising temperatures at the piston edges, which, in conjunction with the piston ring lands, can be damaged as a result. When the engine was disassembled it was found that several of the engine's pistons had sustained damage, which included damage to the edges of the piston crowns and large areas of material missing. The damage found is therefore consistent with detonation.

The fact that several of the pistons sustained damage suggests a cause common to all cylinders. The fuel used affects all cylinders. A fuel's octane rating is a measure of its resistance to detonation; fuels with a lower octane rating are more susceptible to detonation. The aircraft was routinely operated on Mogas, which has a lower octane rating than Avgas – the fuel approved for use in the aircraft.

Engine disassembly found that the ignition timing was set to 22^{o} before TDC and not 20^{o} as specified by the Engine Manufacturer, i.e. the ignition timing was advanced by 2^{o}. This can contribute to detonation. According to the Engine Manufacturer, a 2^{o} difference in ignition timing, which would also have affected all cylinders, would have reduced the detonation margin, but not significantly. Furthermore, the engine overhaul organisation found such a timing discrepancy on other engines with no consequential detonation.

Engine Disassembly also found that the fuel nozzles were not in their correct cylinder positions according to the numbers stamped on the nozzles. However, in this case, all fuel nozzles had the same orifice size and therefore the incorrect positioning would likely have had no adverse effect on engine operation. The Investigation therefore considers that the detonation-induced damage was primarily due to the continued use of Mogas, while the advanced ignition timing may have exacerbated its tendency to detonate.

The engine is not type-certificated to operate on Mogas and its use is not approved by the Engine Manufacturer. The Engine Manufacturer warns of the risk of using automotive fuels in its Standard Practice Manual, as does the IAA's Safety Leaflet on '*Using Unleaded Petrol (Mogas) in Aircraft*'. Therefore, no Safety Recommendation is made in this regard.

2.2.2 Fuel Analysis

The laboratory analysis of the fuel obtained from the fuel tank in the left wing identified very low levels of ethanol and also a loss of the fuel's '*light ends*'. Mogas sold in Ireland normally conforms to the EN228 standard, which permits up to 5% ethanol content. The Investigation requested the company that supplied fuel to the service station where the Pilot obtained the Mogas from to confirm the ethanol content of the fuel supplied. The fuel company advised that the ethanol content of the fuel provided was 4.8% [v/v]. The Pilot said he uplifted 40 litres of Mogas into the aircraft before the flight and a further 80 litres nine days earlier (on 2 July 2020) and that there was a total of approximately 30 litres of fuel in the aircraft before that.

Records indicate that the aircraft had not flown from September 2019 until July 2020. Notwithstanding that any fuel remaining in the fuel tank for such an extended time period would likely lose some '*light ends*' and ethanol, recent uplifts of 120 litres of fuel should have resulted in higher levels being detected during analysis. The fuel sample analysed was taken from the fuel tank in the left wing, which had sustained a rupture to its upper surface and exposed the contents of the tank to atmosphere for 16 days before the sample was taken. However, the tank was still contained within the wing structure and therefore was not exposed to a flow of free air. The laboratory, in effect, deemed it unlikely that this exposure would have resulted in the loss of such an amount of '*light ends*' and ethanol.

Laboratory analysis also detected the presence of free water in the fuel sample analysed. Ethanol in Mogas increases the fuel's ability to absorb water. If the water content of Mogas exceeds a critical threshold, or if the temperature of the fuel reduces, as could occur during flight, Phase Separation can occur and result in water/ethanol separating from the fuel, with the remaining ethanol-depleted fuel being less-resistant to detonation. The presence of free water, and the low level of ethanol identified during the analysis is consistent with Phase Separation, and therefore it could have been a factor on the occurrence flight. Condensation occurring in the aircraft's fuel tanks during the extended period of inactivity could result in free water forming in the fuel tanks. Any free water present in the tank could also adversely affect fuel added during refuelling. However, the Pilot said that no water was detected in the fuel samples taken from the aircraft's fuel tanks before the flight. Although dissolved water would not be obvious during visual inspection, the reported normal appearance would suggest that no free water was present in the samples taken by the Pilot and it is possible that the water detected during laboratory analysis was due to the water content of the fire-retardant foam used at the accident site.

These factors render the results of the fuel analysis inconclusive. However, any loss of the fuel's '*light ends*' or ethanol depletion could have contributed to increased combustion temperatures and detonation.

2.2.3 Failure Sequence

An increase in engine temperature due to detonation would lead to further detonation. Notwithstanding that the oil temperature gauge appeared to be indicating a lower temperature than normal and the oil pressure gauge appeared to be indicating close to normal in a photograph taken by the passenger during the flight, the cylinder head temperature gauge appeared to be recording an elevated temperature and may have been providing an indication of abnormal engine operation at that stage.

The nature of the piston damage that occurred would cause the pressure in the crankcase to increase and possibly result in engine lubricating oil being discharged through the engine breather. It is likely that this occurred in this case, as the lower part of the fuselage was found to be wet with oil when the aircraft was lifted during recovery operations. Several of the exhaust valves were also found to be wet with oil during engine disassembly. Any increase in crankcase pressure, combined with the nature of the damage to the pistons could result in engine oil being lost through the exhaust valves. This could explain the appearance of what the Pilot described as '*oily smoke*' during the engine failure sequence. The Pilot also reported a loss of oil pressure before the engine failed. A continuing loss of oil would result in the oil pressure reducing and further damage to the engine. Metal particles and debris were found in the lubricating system, which could have obstructed and contaminated the oil supply required for effective lubrication and likely resulted in further engine damage.

The engine was found to be stiff to rotate prior to disassembly. It is likely that rotation would have been even more difficult when the engine was hot and internal clearances were reduced. The loss of airspeed observed by the Pilot prior to the loss of oil pressure was likely due to the engine beginning to fail. The damage quickly reached a level whereby engine operation was no longer possible.

2.3 Human Factors

Simulated engine failures (by reducing the engine to idle power) and preparing for forced landings are usually practised during flight training. In this case, the Pilot routinely practised these and had carried out such a landing at EIRT a few days before the accident. However, when an actual engine failure occurs in flight, it is likely to be the first time that a pilot has to deal with the situation for real. When an engine fails at low altitude, a pilot has limited time during which to select a suitable field for landing, and without engine power, corrections to an aircraft's glide path are more difficult. In this case, the Pilot selected a suitable field in terms of size and orientation, and was also able to transmit a MAYDAY call to ATC to advise them of the situation. Such a call could have proved vital in assisting the emergency services in locating the aircraft after the accident had it not been quickly noticed by passers-by.

The actual surface conditions of a chosen field and the presence of obstacles may only become clear when nearing the ground. In this case, the surface at the eastern end of the chosen field contained rushes/coarse grass, and although it was likely adequate for a forced landing, the Pilot thought that he may have delayed the landing to reach what he considered to be better surface conditions. However, unlike when landing on a runway at an airfield, references on which to judge an aircraft's height above the ground are limited and the upward-sloping nature of the field may have resulted in an inadvertent climb. Without engine power, airspeed was lost, and it is likely that a stall occurred during a turn to avoid the fenced-off area at the field's western end.

2.4 Survivability

There was no ground roll to absorb any impact energy before the aircraft came to rest. However, energy was absorbed by the left wing and left main landing gear and when the aircraft pivoted about the left wing. This likely minimised the damage to the cockpit area. The Pilot ensured that both his and the passenger's lap belts were fastened before the flight and again before the forced landing. However, the shoulder harnesses were not used and the lap belts would only have provided limited protection in such an impact. The Investigation notes that the '*FORCED LANDINGS EMERGENCY LANDING WITHOUT ENGINE POWER*' checklist as contained in the POH for the aircraft requires the '*Seat Belts and Shoulder Harnesses'* to be secure. This occurrence serves to highlight the importance of using all safety restraints as fitted to the aircraft.

3. CONCLUSIONS

3.1 Findings

1. The Certificate of Airworthiness and the Airworthiness Review Certificate for the aircraft were valid.

2. An Annual Inspection and a 6 Month Check were performed on the aircraft on 9 December 2019 and 6 June 2020 respectively. The detailed records, for the Annual Inspection and the 6 Month Check, were not available for inspection.

3. The Pilot's licence, ratings, and medical certificate were valid.

4. The aircraft's engine failed in flight, necessitating a forced landing in an agricultural field.

5. The aircraft's airspeed reduced in the final moments of the landing attempt due to an increase in the aircraft's altitude.

6. A stall and a left wing drop likely occurred when the airspeed reduced.

7. The left wing and left main landing gear impacted the ground first and the aircraft likely pivoted about the left wing after the initial impact.

8. The shoulder restraint straps, which formed part of the three-point restraint system, were not used on the accident flight.

9. Engine examination identified piston damage consistent with detonation.

10. The aircraft was routinely operated on automotive gasoline (Mogas), which was not approved for use and is less resistant to detonation than the approved fuel (Avgas).

11. The ignition timing was advanced by 2^o (before Top Dead Centre).

3.2 Probable Cause

Loss of control due to stall and wing drop of the left wing at a low height during a forced landing following a detonation-induced engine failure.

3.3 Contributory Cause(s)

1. Loss of airspeed during the final moments of the landing.

2. The aircraft was routinely operated on automotive gasoline (Mogas), which was not approved for use and is less resistant to detonation than the approved fuel (Avgas).

4. SAFETY RECOMMENDATIONS

This Report does not sustain any Safety Recommendations.

Appendix A: Further details noted during engine disassembly and examination

Pistons and Con-Rods

All six pistons were found to have '*the same part numbers and are correct for this engine type application*'. The big-end bearings were found to be '*scored* [and] *impregnated with metal as a result of metal FOD*[16] *from pistons*'. The small-end bushings were '*all free on the piston* [gudgeon] *pin*' and the bushings were '*free of damage/scoring*'. The crankshaft bearing journals had '*light score marks from main and big-end bearing metal contamination*'.

Intake and Exhaust Valves/Valve Seats

The workshop noted that '*no excessive visual damage was observed to the inlet/exhaust valve faces or valve seats*' and that the '*valve springs/keys* [were] *found satisfactory and valves* [were] *free in the valve guides*'.

Crankshaft

The crankshaft journals were found with light score marks from main and big end metal contamination.

Crankcase

All six crankcase mounted piston cooling jets '*appeared satisfactory and were open and free of FOD/blockage*'.

The main bearings were found to be '*scored* [and] *impregnated with metal as a result of metal FOD from pistons*'.

There were metal particles found in the oil feed for the camshaft journals.

It was also noted that the crankcase halves '*appear to have been assembled with correct silk thread and sealant application*'.

Fuel System

The fuel flow divider was bench tested and was found to meet the test criteria. No leaks were detected.

The fuel pump was bench tested. The Idle Cut Off function[17] was found to be satisfactory. No external leaks were detected. The fuel flow was found slightly rich on low setting and slightly lean on the mid/high setting. The engine overhaul organisation noted that '*this is not abnormal as these flow specifications are for individual fuel pump calibration*' and that the settings are '*re-adjusted on the wing for specific engine aircraft set up*'. No leaks were detected under pressure test and the fuel pump was found to function satisfactorily overall.

[16] **FOD:** Foreign Object Debris/Damage.

[17] **Idle Cut-Off function:** There is a test at the end of the flow test to ensure that the pump pressure drops below 3psi, to allow the spring in the manifold valve to close and provide a positive shut-off of fuel so the engine will shut down.

The fuel control unit was bench tested. The fuel flow was '*found to be very slightly on the rich side at the high end*'. It was pressure tested and no leaks were found. It was also noted that there was smooth movement of the throttle and controls and that the unit function satisfactorily overall.

There was no evidence of blockages in the fuel lines. (This would rule out lean running due to lack of fuel).

Oil System

Debris attributed to be from the damaged pistons was found at the oil pressure relief valve and in the oil filter. The oil pump had a 'worn, textured finish' but there was no significant damage/scoring identified. The crankcase-mounted fitting for the supply to the oil pressure gauge was free of obstruction.

- END -

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

Produced by the Air Accident Investigation Unit

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