Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

ACCIDENT
CFM Streak Shadow, G-BVTD
Tory Island, Co. Donegal, Ireland

9 May 2016

An Roinn Iompair Turasóireachta agus Spóirt
Department of Transport, Tourism and Sport

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 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.

Extracts from this Report may be published providing that the source is acknowledged, the material is accurately reproduced and that it is not used in a derogatory or misleading context.

[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 10 May 2016, appointed Mr John Owens as the Investigator-in-Charge to carry out an Investigation into this Accident and prepare a Report.

Aircraft Type and Registration:	CFM Streak Shadow, G-BVTD	
No. and Type of Engines:	1 x Rotax 582	
Aircraft Serial Number:	PFA 206-11972	
Year of Manufacture:	1994	
Date and Time (UTC[4]):	9 May 2016 @ 17.30 hrs	
Location:	Tory Island, Co. Donegal, Ireland	
Type of Operation:	Private	
Persons on Board:	Crew - 1	Passengers - Nil
Injuries:	Crew - 1 (Minor)	Passengers - Nil
Nature of Damage:	Substantial	
Commander's Licence:	National Private Pilot's Licence (NPPL), issued by the Civil Aviation Authority (CAA) of the United Kingdom (UK)	
Commander's Age:	38 years	
Commander's Flying Experience:	111 hours, of which 17 were on type	
Notification Source:	Media report	
Information Source:	AAIU Report Form submitted by the Pilot AAIU Field Investigation	

[4] **UTC:** Co-ordinated Universal Time. All times in this report are UTC (local time minus one hour on the accident date).

SYNOPSIS

While on a private flight from Finn Valley Airfield, Co. Donegal, the microlight's engine cut out when it was over Tory Island, off the north-west coast of Donegal. The engine could not be restarted, which resulted in the Pilot, who was the sole occupant of the microlight, making a forced landing on rough ground adjacent to a roadway on the island. The microlight was substantially damaged. The Pilot sustained minor injuries. There was no fire.

NOTIFICATION

The AAIU became aware of this accident following a telephone call from a local journalist on the day after the accident. Later that day, a call was also received from the Pilot, to report the accident and to advise that the wreckage had been recovered to Finn Valley Airfield. Two Inspectors of Air Accidents inspected the aircraft wreckage at Finn Valley Airfield on 12 May 2016.

1. FACTUAL INFORMATION

1.1 History of the Flight

The microlight departed Finn Valley airfield at approximately 16.50 hrs and routed to Tory Island, which is approximately 31 nautical miles (nm) north-west of Finn Valley Airfield and approximately 6 nm off the north-west coast of Co. Donegal. The Pilot informed the Investigation that the fuel tanks were full prior to departure. The microlight climbed to 4,000 feet (ft) as it crossed Tory Sound while travelling towards the island. While over the island, it descended towards a lighthouse on the western side and completed several orbits over that part of the island at approximately 1,200 ft.

The Pilot stated that it was his intention to return to Finn Valley following the last orbit, but that as he returned to straight and level flight, the microlight's engine lost power and cut out in what he estimated was between two and three seconds. The microlight had flown for approximately 40 minutes at this stage. The Pilot said that a few minutes before the engine cut out, he had checked the fuel gauge and that it was reading "*nearly full*" and that there was no rough running before it cut out. He also said that he made three attempts to restart the engine using its pull cord, without success, and consequently looked for a suitable landing site. Noting that the general terrain was rough and consisted largely of rocky outcrops, he elected to attempt a landing on a road leading to the lighthouse. The road has a straight section measuring approximately 600 m and is on a heading of approximately 340 degrees magnetic.

The Pilot reported that he was unable to lose sufficient height to land on the road in the north-westerly direction and decided to turn the microlight to the right in order to land on the road in the opposite direction. He said that on completion of this turn, there was insufficient height to reach the road and he put the microlight down to the east of the roadway. The terrain was rough and the microlight sustained substantial damage; however, the Pilot was able to exit unaided. There was no post-impact fire. The Pilot advised the Investigation that he was wearing a life vest during the flight.

1.2 Injuries to Persons

The Pilot sustained minor injuries, which included a cut to his left arm and a bruise to his right leg.

1.3 Personnel Information

The Pilot held a NPPL with a Microlight Aeroplanes rating issued by the UK CAA, which was valid at the time of the occurrence. The Pilot's Class 2 Medical Certificate was issued by a CAA-approved Aeromedical Examiner (AME) and was also valid at the time. The Pilot's total flying experience was 111 hours, of which 17 were on type.

1.4 Meteorological Information

Met Éireann, the Irish Meteorological service, provided details of the weather conditions prevailing in the Tory Island area at the time of the occurrence. The weather was reported to be "*fine*", with clear skies over the Island. The surface temperature was reported as 20 ^{o} Celsius (C) with a dew point of 10 ^{o} C. The freezing level was stated to be 9,000 ft.

1.5 Damage to Aircraft

The microlight sustained substantial damage to its undercarriage, which separated from the fuselage, the underside of which was also damaged. The lower fuel tank (the '*slipper*' tank) had split into its constituent flat panels. The right wingtip sustained impact damage. The left wing was damaged at the wing root.

1.6 Aircraft Information

1.6.1 General

The two-seat microlight was amateur-built from a kit and was first registered in 1994 in the UK and had operated for a total time of 177 hours from the date of manufacture until the occurrence date. It was fitted with a two cylinder, two-stroke Rotax 582 engine, which powered an aft-mounted, three-bladed, ground adjustable wooden propeller, through a reduction gearbox (**Photo No. 1**). The engine was not fitted with an electric starter motor and was instead started with a pull cord. A carburettor heating system was not installed. The Pilot, who was also the Owner, sold the microlight and its engine following the accident. He advised the Investigation that the engine was successfully run at the time of sale.

UK-registered multi-seat microlights require a Permit to Fly issued by the UK CAA. The Permit to Fly requires an associated Certificate of Validity, which may be issued by approved organisations such as the British Microlight Aircraft Association (BMAA) or the UK Light Aircraft Association (LAA). The most recent Permit to Fly for G-BVTD was issued by the UK CAA on 10 March 2016. The Certificate of Validity for the Permit to Fly was issued by the UK LAA on 30 March 2016 and was valid until 29 March 2017. According to the microlight's '*Operating Limitations*' document issued by the LAA, the "*Maximum Total Weight Authorised*" of the microlight was 390 kg[5].

[5] Due to its wing loading/stall speed and a Maximum Take-Off Mass (MTOM) of less than 450 kg, G-BVTD was classified by the UK CAA as a microlight.

Approximately 400 Streak Shadows/Shadow variants were built. The UK CAA's '*G-INFO*' on-line search facility shows over 160 Streak Shadow/Shadow variants on the UK Register, which are overseen by either the BMAA or the LAA. The kit Manufacturer, Cook Flying Machines (CFM) and its successors have ceased trading.

Within Ireland, the National Microlight Association of Ireland (NMAI) and the Irish Microlight Association (IMA) are approved by the Irish Aviation Authority (IAA) for the inspection of microlights for the purpose of making a recommendation to the IAA for the issue or renewal of a Permit to Fly. The IAA informed the Investigation that there are four Streak Shadow/Shadow variants on the Irish Register.

Photo No. 1: G-BVTD (Source: *Microlight Owner*)

1.6.2 Fuel Tanks Fitted

G-BVTD was equipped with two inter-connected fuel tanks. One tank (the upper tank), with a capacity of five (Imperial) gallons, was fitted beneath the engine. This tank contained a filler neck to permit refuelling. The other tank, known as a '*slipper*' tank, with a capacity of seven (Imperial) gallons, was fitted below the fuselage. A fuel gauge sender unit was installed in the right hand side of the slipper tank. Each fuel tank was fitted with a drain valve and was vented through its own vent port. The Pilot informed the Investigation that the microlight had an endurance of approximately 3.5 hours with full tanks.

The fuel tanks were manufactured from flat panels of a composite material. The Manufacturer's assembly instructions for the microlight kit include the assembly process to be used for the fuel tanks. For the five gallon fuel tank, the instructions state that the flat panels are to be bonded together at their edges with a specific type of epoxy resin[6], and that after assembly, but before the top is bonded on, the interior of the tank should be coated with a thin layer of epoxy to form what is described as a "*fuel-proof lining*". A strainer (part number: F204) is listed in the parts list contained within the assembly instructions for the upper tank. This part number is also included in the complete list of all parts supplied with the microlight kit, which describes it as a "*filter*". The quantity supplied is showing as "*2*".

[6] **Epoxy resin:** An adhesive, plastic, or other material made from a class of synthetic thermosetting polymers containing epoxide groups.

The tank assembly instructions state that when the "*resin has cured, bond on F204*" and that following the installation of the top panel, a small amount of epoxy should be poured into the tank (a '*slosh*' coat). The tank should then be turned upside down to "*let the resin run around the top fuel joint*". The kit Manufacturer's Service Manual for the microlight also refers to this strainer, stating that "*a strainer is situated inside the tank over the outlet in the 5 gallon tank* [the upper tank]".

The Manufacturer's assembly instructions for the slipper tank note that "*two coats of epoxy resin*" should be applied to all internal faces, allowing 24 hours between coats. The instructions then describe how to "*bond in Fuel Filter F204*", before the slipper tank top piece is fitted. The "*filter*", which has the same part number as the upper tank strainer (F204) is included in the parts list for the slipper tank. The process of pouring in epoxy and rotating the tank to coat the top panel, as described in the assembly instructions for the upper tank, is not mentioned in the assembly instructions for the slipper tank.

The Pilot advised the Investigation that the slipper tank had developed a leak from a joint at the upper panel, which had been subsequently repaired from the outside with filling compound.

1.6.3 Fuel System Description

On the fuel system fitted to G-BVTD, fuel was gravity-fed from the upper fuel tank through an interconnecting hose to the slipper tank. It was supplied from the slipper tank through an electric fuel pump (the inlet adapter of which contained a filter), a plastic in-line fuel filter, a mechanical fuel shut-off valve, a hand-operated priming pump and a vacuum powered fuel pump, to twin carburettors fitted to the engine (**Figure No. 1**). Regarding the electric fuel pump, the Pilot informed the Investigation that he used this during take-offs, landings and when crossing water. He said that "*the pump was on when the engine stopped*".

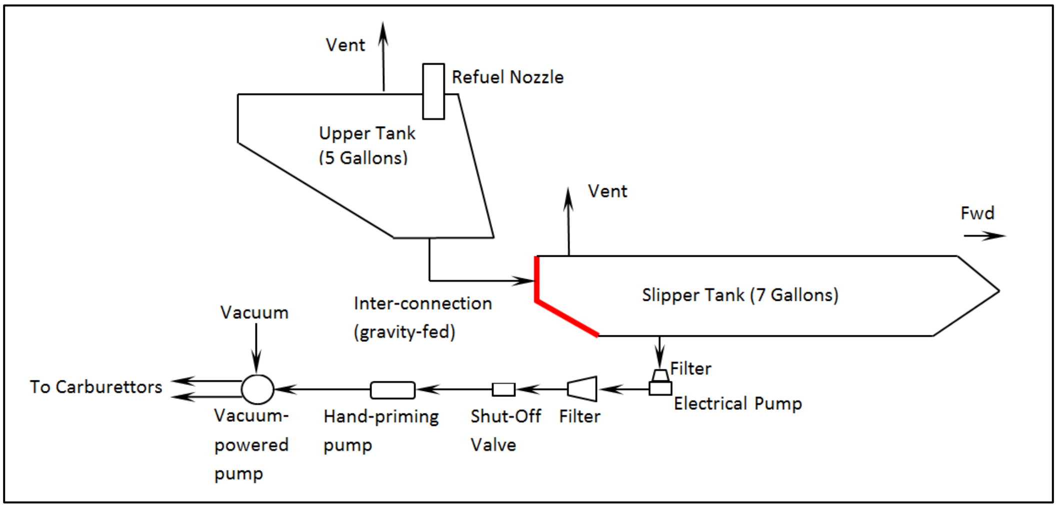

Figure No. 1: Fuel system schematic (area highlighted in red is discussed in **Section 1.8.1**)

1.7 The Use of Unleaded Automotive Petrol (Mogas) and Associated Adverse Effects

1.7.1 Fuel Used by the Owner

The Owner refuelled G-BVTD prior to the accident flight with unleaded automotive petrol, which he obtained from a local service station and to which he had added two-stroke oil. Within Europe, unleaded automotive petrol normally conforms to the EN228 standard, which permits up to 5% ethanol[7] content, by volume. When unleaded automotive petrol is used for aircraft, it is known as '*Mogas*'. This fuel type was regularly used by the Owner.

Laboratory analysis of a sample of the fuel used to refuel the microlight and a sample obtained from the microlight's fuel system showed that the fuel was "*consistent with an unleaded 95 fuel being treated with an oil additive, for instance a two stroke oil*". The analysis showed that the ethanol content of both samples was similar, with an average value of 5.51%. When asked to comment on this figure, which is higher than the 5% permitted by EN228, the laboratory supervisor stated that this may have been due to evaporation of the more volatile elements prior to the samples being taken.

1.7.2 IAA and CAA Guidance Material and EASA Safety Study

Because the microlight was UK-registered, the requirements of the UK CAA applied, in conjunction with the requirements of the IAA. The UK CAA's publication '*CAP 747*' on the '*Mandatory requirements for airworthiness*' states that "*with the exception of microlights, the use of Mogas containing alcohol is generally prohibited in aircraft*".

The IAA published an '*Aviation Safety Leaflet*' (IGA 9 R1) in relation to '*Using Unleaded Petrol (Mogas) in Aircraft*'. The leaflet states that "*certain aircraft are approved to use unleaded petrol containing ethanol, but most are not*". The leaflet describes several of the adverse effects of ethanol, including damage to seals and elastomers and an increased potential for fuel system vapour lock[8]. The leaflet also warns that ethanol absorbs moisture, which increases the likelihood of carburettor icing[9] (the meteorological conditions present on the accident flight were conducive to this phenomenon). Degradation of composite fuel tanks is not specifically mentioned. The leaflet refers to IAA Aeronautical Notice A16B (dated 23 December 2010), on the '*use of motor gasoline (Mogas) in microlight aircraft*'[10]. The Aeronautical Notice permits the use of Mogas in microlights, subject to certain conditions. It also lists several "*adverse effects of using MOGAS containing alcohol* [ethanol]" and notes that "*the solvent characteristics may be unsuitable for some engine/airframe combinations. Fuel tanks, fuel lines, seals and gaskets may be adversely affected*". The notice contains a table which includes hyperlinks to several sources of information regarding the use of Mogas containing ethanol.

[7] **Ethanol:** A renewable fuel made from various plant materials. It is also known as ethyl alcohol.
[8] **Vapour Lock:** A condition of fuel starvation caused by unintended liquid fuel vaporisation, due to variations in temperature or pressure.
[9] **Carburettor icing:** This can occur in a carburettor at temperatures above freezing due to the vaporisation of fuel, combined with the expansion of the air as it flows through the carburettor (venturi effect), causing sudden cooling and ice formation. Carburettor ice can be detected by a drop in rpm in aircraft with fixed pitch propellers and a drop in manifold pressure in aircraft with constant speed propellers. It can also cause an engine to run rough. Carburettor icing is described in detail in AAIU Report No. 2014-012.
[10] The IAA also published a similar Aeronautical Notice (A16A) on the '*use of unleaded petrol (Mogas) in certain light aircraft*', which is also referred to in the IAA's Safety Leaflet IGA 9R1. The potential adverse effect of Mogas on composite fuel tanks is not specifically mentioned in this Notice.

One such source is a study carried out by the European Aviation Safety Agency (EASA) on the '*Safety Implication of Biofuels in Aviation*' (Report No. EASA.2008.C51, dated 7 July 2010). The associated report describes, *inter-alia*, the phase separation process that can occur in Mogas due to the tendency of the ethanol content to absorb water. When the absorbed water reaches a critical value and the fuel temperature is reduced, the water will separate from the fuel, taking the ethanol with it. Since the ethanol-rich water is of greater density than the base fuel, it will settle at the bottom of a fuel tank. The report states that the ethanol-water mix is *"not ignitable and would lead to an instant starvation of the engine should it be sucked in".* One of the report's conclusions was that "*safety issues do exist if ethanol admixtures*[11] *are present in gasolines used in aviation".*

1.7.3 Light Aircraft Association Leaflet

The UK's LAA, which validated the Permit to Fly for G-BVTD, produced a Technical Leaflet, TL 2.26, in July 2015, relating to the '*Procedures for use of E5 Unleaded MOGAS to EN228*'. This leaflet explains that suitable LAA aircraft were able to operate using unleaded Mogas, but that in 2010, fuel companies began to add ethanol to this fuel, and that the addition of ethanol is now mandated within Europe.

The leaflet states that the CAA, having initially prohibited the use of fuel containing ethanol in certain aircraft types, transferred the responsibility for choice of fuel and the provision of appropriate guidance to the aircraft's type design organisation, i.e. for aircraft operating on an LAA-validated Permit to Fly, to the LAA.

The leaflet notes that with appropriate measures in place, "*up to 5% ethanol in UK microlights need not prevent its use in suitable LAA aircraft/engine combinations*". However, it highlights that:

> *…where problems have occurred, it has been with chemical compatibility with composite fuel tanks, some of which have had serious leaks due to the cocktail of ethanol and petroleum dissolving the epoxy or polyester resin used in their lay-up*.

The eligibility section of the leaflet states that the use of Unleaded Mogas conforming to the EN228 is accepted on any LAA aircraft, subject to the following:

> *The airframe fuel system has been determined by the owner* [and] *verified by the inspector, as being chemically compatible with this fuel. The checks made should include a physical check of the aircraft and a review of the airframe manufacturer's recommendations plus any associated service bulletins, etc.*

The leaflet also states that:

> *Known problems exist with fuel tank chemical compatibility with ethanol in the following aircraft types:*
>
> - *Certain Jabiru aircraft per Jabiru service letter JSL7-4*
> - *Certain CFM Shadow variants*
> - *Certain MCR-01 variants*

[11] **Admixture**: Additives.

The leaflet includes a procedure for "*clearing eligible aircraft to use E5 Mogas*". The following forms part of the procedure:

> *Check the airframe fuel system is chemically compatible with unleaded Mogas containing up to 5% ethanol and record this on the checklist, verified by your LAA inspector. The checks made should include a physical check of the aircraft components (doing submersion tests where uncertain) and a review of the airframe manufacturer's recommendations plus any associated service bulletins and individual aircraft fuel system modifications*.

The LAA's Standard Modification, '*SM13312'* (Issue 1, May 2013), on the subject of Shadow '*Fuel Tank Replacement*' highlights that replacement fuel tanks manufactured from aluminium alloy are available as a replacement for the original composite fuel tanks.

1.7.4 British Microlight Aircraft Association Bulletin

The British Microlight Aircraft Association (BMAA) informed the Investigation that it does not have any Streak Shadows under its control, but that there are a number of Shadow variants "*in its fleet*". A Microlight Airworthiness Approval Note (MAAN) in relation to '*Shadow Fuel Tank Deterioration*' was published by the BMAA in March 2011 (MAAN No. 2336).

The publication states:

> *In a number of examples the tanks have developed leaks at the bonded edges. Also fragments of epoxy have been found and the strainer has become dislodged. In one known case the strainer gauze had disintegrated leading to an engine failure, due to debris entering the fuel line. Both the main and slipper tanks have been affected.*

And that:

> *It is thought that the deterioration of the tanks and strainers is partly a function of the age of the fleet but mostly the introduction of ethanol into fuel in recent years.*

A BMAA Service Bulletin (2336) appended to the MAAN provides details of an "*essential*" inspection of the fuel tanks on all Shadow variants in the "*BMAA fleet*", to be carried out at least every 50 hours or annually (whichever is sooner). The bulletin describes an inspection of the inside of the fuel tank, which should be performed through the filler neck for the upper tank and by removing the fuel tank sender unit from the slipper tank and inspecting that tank through the sender unit aperture.

Service Bulletin 2336 is listed in '*Annex A'* (*Service Bulletins and Mandatory Modifications*) of each of the UK CAA Type Approval Data Sheets (TADS) for those variants under BMAA control. According to the BMAA, compliance with the Service Bulletin is therefore "*being verified annually by a BMAA Inspector as part of the annual airworthiness review, which includes an explicit check of SB* [Service Bulletin] *compliance*".

1.7.5 Safety Study regarding Ethanol and Fibreglass Fuel Tanks

'*Boat U.S.*', an association of boat owners in the United States, commissioned a study[12] on the effects of ethanol on fibreglass[13] fuel tanks. This study found that fibreglass and epoxy resin were adversely affected by fuels containing ethanol.

1.8 Fuel System Condition

1.8.1 Visual Inspection

The slipper tank, as inspected by the Investigation, had been largely separated into its constituent flat panels (**Photo No. 2**).

Photo No. 2: Slipper tank separated into its constituent flat panels

The upper fuel tank was undamaged in the accident. A visual inspection performed through the fuel filler neck of this fuel tank indicated that there was no deterioration of the coating on the inside of the tank. However, a hemispherical plastic gauze strainer was found to be loose inside the fuel tank (**Photo No. 3**). A circular marking of similar diameter to the strainer and concentric with the fuel outlet was also visible. The Pilot told the Investigation that the strainer was in place when he refuelled the microlight prior to the accident flight.

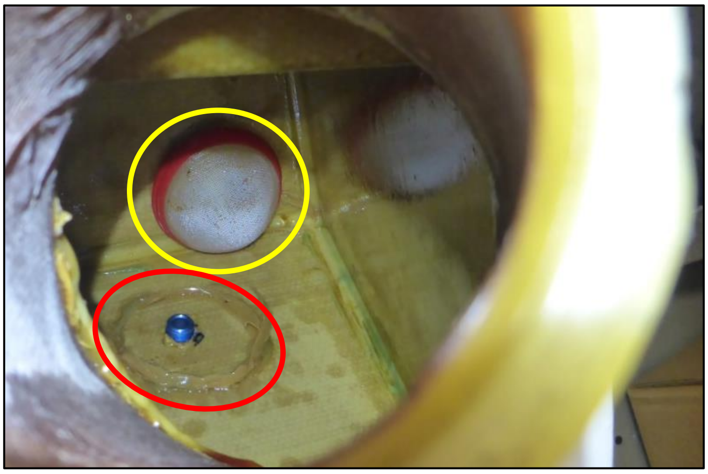

Photo No. 3: Gauze strainer loose inside the five gallon tank (circled in yellow) and circular marking surrounding the outlet (circled in red), as seen through the fuel filler neck

[12] http://www.boatus.com/seaworthy/fueltest.asp#.

[13] **Fibreglass:** A fibre-reinforced plastic composite material.

As stated earlier, a "*filter*" with the same part number as the upper tank strainer (F204) is included in the parts list in the Manufacturer's assembly instructions for the slipper tank. The assembly instructions describe how this should be bonded in place. The Pilot, who recovered the wreckage before the AAIU was informed of the event, reported that a strainer was not found at the accident site. However, on inspection of the fuel tank panels, a circular marking of similar diameter to that observed in the upper tank was evident on the inside of the fuel tank, concentric with the fuel outlet (**Photo No. 4**).

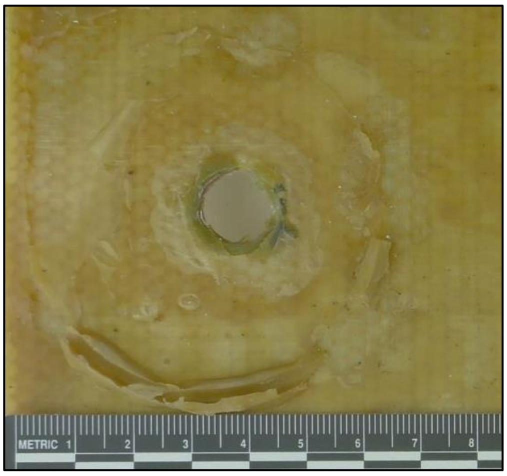

Photo No. 4: Circular marking at slipper tank outlet

The coating on the interior of the slipper tank was found to be flaking and separating from the panels of the tank, with significant deterioration of the coating on the rear panels (**Photo No. 5**). These are coloured red in **Figure No. 1** in **Section 1.6.3**. The Pilot, who was present when the Investigation examined the aircraft, observed the condition of the slipper tank and commented that he considered that fuel starvation due to a blockage caused by the flaking coating was the likely cause of the engine shutting down in flight.

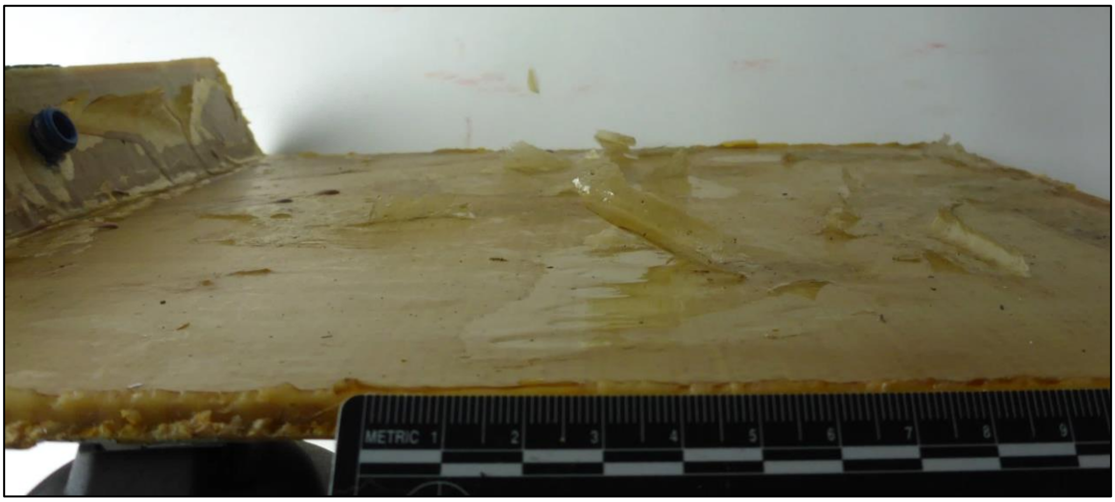

Photo No 5: Coating separating from interior of rear panel of slipper tank

No obstruction was found in the fuel supply hose from the slipper tank outlet to the pump filter. In addition, the Investigation removed the float chambers from the engine's two carburettors and noted that they were free from debris.

1.8.2 Communication with the IAA

The Investigation informed the IAA of the results of the visual inspection of the fuel tanks. The IAA advised that of the four Streak Shadow/Shadow variants on the Irish Register, only one was in use. The Investigation established that this particular aircraft was fitted with only one fuel tank, which was manufactured from aluminium alloy.

1.8.3 Fuel Pump and Fuel Filter Inspection

An information decal affixed to the microlight's 12V Fuel Pump stated that the pump was compatible with "*blended alcohol and fuel additives*". The Investigation connected the fuel pump to a 12V battery and found the pump to be operational. The inlet side of the electrical fuel pump was fitted with a screw-in fuel filter which had a metal housing. The pump filter had been connected to the flexible hose that was coming directly from the outlet of the slipper tank (see **Figure No. 1**). The Investigation unscrewed the filter from the fuel pump and cut the filter housing open to facilitate a visual inspection. No debris was evident in the exposed filter or the housing (**Photo No. 6** and **Photo No. 7**).

In addition, the plastic in-line filter downstream of the electrical pump did not appear to contain any debris.

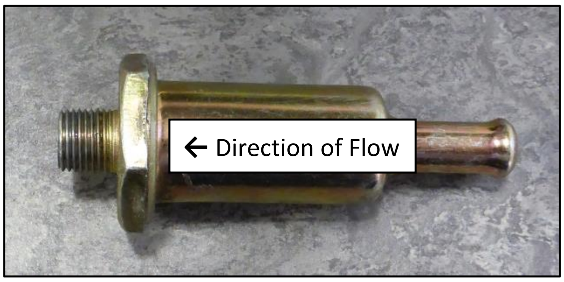

Photo No. 6: Fuel filter as removed

Photo No. 7: Fuel filter exposed and found to be free from debris

1.8.4 Laboratory Analysis of Fuel Tanks

The panels from the slipper tank were sent to a specialist laboratory for detailed analysis of the coating material and to attempt to determine the cause of the observed deterioration. As stated in **Section 1.8.1**, the coating of the upper tank appeared to be undamaged. However, this tank was also sent for analysis.

The laboratory analysis noted that:

> *There was a notable difference in the flake material and the base resin material in that the flake material on the affected part would seem to contain significantly more epoxy-groups compared to the base and control resins across the rest of the parts supplied, which all identified as phenoxy resin-based materials*[14]*.*

[14] **Phenoxy resin:** A high molecular weight thermoplastic polymer.

Samples of the coating materials were subjected to Gel Permeation Chromatography (GPC)[15] analysis which indicated that there was *"a significant quantity of non-cross-linked*[16] *material in the affected* [flaking/epoxy] *areas of resin* …".

Thermal Gravimetric Analysis (TGA)[17] was also performed. This indicated that for the flaking material, there was a "*5% less stable material early on the thermal run".* The laboratory report stated that "*this may be ingressed fuel or other lower boiling point material*".

In addition, some of the undamaged coating material was exposed to ethanol both under stress and unstressed. The report noted that in the unstressed state, there seemed to be no significant effect at room temperature. However, it was stated that under stress the material delaminated.

The laboratory report concluded, *inter-alia*, that:

> *…the epoxy and phenoxy resins are not fully chemically compatible and this would indicate that an inherent lack of adhesion between the two materials could contribute to a mechanical failure under stress…*

and that:

> *The results also indicate that exposure to ethanol will have a detrimental effect on the epoxy resin material and while not chemically changing it, there is an issue with physical stability in the exposed areas.*

1.8.5 Evidence from the Owner of a UK-Registered Starstreak Shadow

The Investigation spoke with the owner of a UK-registered Starstreak Shadow based in Ireland. This aircraft is a variant of the Streak Shadow and was previously fitted with composite fuel tanks similar to those fitted to G-BVTD.

The owner advised that he replaced the composite fuel tanks with aluminium alloy tanks. When he inspected the interior of the removed fuel tanks, he noted that the adhesive used at the internal seams of the slipper tank had degraded, which appeared to have allowed fuel into the matrix of the composite panel material, causing more widespread damage.

He said that the glued seams of the main tank appeared to be sound, which he thought may have been due to the slipper tank being exposed to more continuous fuel wetting, as the main tank was usually left empty when the aircraft was on the ground.

[15] **GPC:** A type of size exclusion chromatography (SEC) that separates chemical constituents on the basis of size.
[16] **Cross-linking**: Commonly referred to as curing.
[17] **TGA:** A method of thermal analysis in which changes in physical and chemical properties of materials are measured.

2. ANALYSIS

2.1 Forced Landing

While operating at approximately 1,200 ft over Tory Island, Co, Donegal, the engine of the microlight cut out and could not be restarted. It had just flown in excess of 31 nm, including approximately 6 nm over the sea at altitudes of up to 4,000 ft. During the subsequent forced landing on rough ground adjacent to a roadway leading to the island, the microlight sustained substantial damage. However, the Pilot sustained only minor injuries and was able to exit the microlight unaided.

2.2 Fuel Tank Condition

2.2.1 AAIU Examination

During its examination of the microlight, which the owner had recovered to Finn Valley Airfield, the Investigation noted extensive deterioration of the coating on the inside of the slipper tank, with significant flaking and detachment evident. A hemispherical plastic gauze strainer was found to be loose inside the upper fuel tank. The presence of a circular witness mark of similar diameter surrounding the outlet indicates that this strainer was originally bonded to the base of the upper fuel tank at the fuel outlet. The possibility was considered that the dislodged strainer in the upper fuel tank permitted debris to block its outlet, thereby preventing fuel flow to the slipper tank, resulting in fuel starvation. However, the Pilot said that the strainer was in place when he refuelled the aircraft prior to the accident flight and the coating on the inside of the upper tank appeared to be in good condition. It is therefore likely that the strainer in the upper tank dislodged as a result of the accident.

The kit Manufacturer's assembly instructions for the slipper tank describe how a "*filter*" with the same part number (F204) as the "*strainer*" fitted to the upper tank is bonded in place. The damaged slipper tank, as inspected by the Investigation, did not contain a strainer. When asked by the Investigation if a strainer had been found at the accident site, the Pilot advised that he did not notice one. However, the circular witness mark concentric with the outlet at the base of the slipper tank indicates that a strainer, similar to that contained in the upper tank had likely been fitted.

The BMAA's Microlight Airworthiness Approval Note No 2336, regarding '*Shadow Fuel Tank Deterioration*', describes cases of leaking fuel tanks and the detachment of fragments of epoxy. Cases of strainers dislodging and/or disintegrating were also described. The possibility was considered that the strainer that appears to have been present at the outlet of the slipper tank detached at some stage prior the accident. This would allow fragments of the flaking coating to obstruct the outlet from the tank, eventually causing the engine to cut out as reported. However, this would likely result in some debris entering the fuel filter fitted on the inlet side of the electrical fuel pump, which is the first filter that fuel passes through after it leaves the slipper tank. When this filter was cut open and examined by the Investigation, it was found to be free from debris. In addition, no obstruction was found in the fuel supply hose from the slipper tank outlet to the pump filter. It is therefore probable that a strainer was present in the slipper tank until the point of impact.

The Investigation acknowledges that the surface area of a strainer is large relative to the surface area of an outlet not containing a strainer and would therefore require a significant quantity of fragments of coating material (flaking) to obstruct it. Nevertheless, the Investigation considers that the extent of the flaking evident on the inside of the slipper tank was capable of causing such an obstruction, which could have led to fuel starvation and the engine cutting out.

2.2.2 Adverse Effects of Ethanol

Mogas (unleaded automotive petrol) was regularly used by the Pilot to refuel G-BVTD. Both the CAA and the IAA permit the use of such fuel in microlights, subject to certain conditions. The EN228 standard for unleaded automotive petrol permits up to 5% ethanol content by volume. Laboratory analysis conducted on a sample of the fuel used to refuel the microlight and on a sample taken from the microlight's fuel system established that the ethanol content of the samples was similar, with an average value of approximately 5.5% by volume. This is slightly higher than the 5% specified by the EN228 standard. However, the laboratory supervisor considered that this may have been due to evaporation of the more volatile elements prior to the samples being taken.

Numerous studies and associated publications, including publications from the CAA and the IAA, have identified several adverse effects caused by the ethanol content of Mogas. Moreover, a Technical Leaflet (TL 2.26) issued by the LAA highlights the potential for ethanol-related problems regarding chemical compatibility with composite fuel tanks, some of which, the leaflet states, have had "*serious leaks due to the cocktail of ethanol and petroleum dissolving the epoxy or polyester resin used in their lay-up*". It also states that known problems exist with fuel tank compatibility in "*certain CFM Shadow variants*". The fuel leak from the slipper tank, which the Pilot reported had been repaired, was likely an indication that the interior coating of G-BVTD's slipper tank was deteriorating.

2.2.3 Laboratory Analysis of Fuel Tanks

Laboratory analysis conducted on the fuel tanks from G-BVTD identified that the deteriorated coating (flaking) observed on the inside of the slipper tank was a different type of resin (epoxy) to the coating underneath (phenoxy). The Investigation considers it unlikely that two different types of coating were used during initial assembly of the fuel tanks, as only one type of coating was present in the upper tank. It is therefore possible that a different type of resin to that used during manufacture was used at some point during the lifetime of the microlight. The analysis also identified that the flaking coating contained "*a significant quantity of non-cross-linked material*" which may have contained "*ingressed fuel*" or other lower boiling point material.

The results of the laboratory analysis indicate that the flaking observed in the slipper fuel tank was likely as a result sub-optimal adhesion between the epoxy and phenoxy material, combined with deterioration caused by the presence of ethanol in the fuel.

2.3 Other Possible Causes of Engine Cutting Out

Several other possible causes of the engine cutting out were considered, some of which are also related to the use of Mogas.

2.3.1 Fuel Quantity

The Pilot reported that the fuel tanks were full when the microlight took off from Finn Valley and that its endurance was approximately 3.5 hours. The microlight's engine cut out approximately 40 minutes into the flight and the Pilot stated that he had checked the fuel gauge a few minutes earlier and it was reading "*nearly full*". The fuel gauge sender unit is located in the slipper tank. Therefore, it is considered unlikely that the microlight ran out of fuel.

2.3.2 Mechanical Failure

Based on the Pilot's statement that the engine was subsequently successfully run, a mechanical failure is considered unlikely.

2.3.3 Phase Separation

The possibility of phase separation-induced fuel starvation was considered. This has the potential to result in a non-ignitable mixture of ethanol and water settling at the base of the tank and being drawn into the engine. However, as previously stated, the laboratory analysis of the fuel sample from the microlight's fuel system established that the ethanol content was similar to the ethanol content of the fuel used to refuel the microlight. This would be unlikely if some of the ethanol had separated out in the microlight's fuel tanks during the accident flight.

2.3.4 Vapour Lock

Another less desirable property of Mogas is an increased potential for fuel system vapour lock. The tendency to vapour lock is also affected by variables such as fuel temperature (which can be influenced by fuel pipe routing and heat transfer from the engine) and the ambient temperature and pressure. Therefore, the possibility of the engine cutting out due to fuel starvation arising from this phenomenon cannot be ruled out.

2.3.5 Carburettor Icing

The meteorological conditions at the time would have been conducive to the formation of carburettor icing. Furthermore, an engine operating on Mogas is more susceptible to such a phenomenon and the subject aircraft was not fitted with a carburettor heating system. Therefore, a failure due to carburettor icing was considered. The Pilot reported no engine power issues during several orbits of the lighthouse; some rough running would have been expected during these orbits if carburettor ice had been forming. Consequently, the reported sudden loss of engine power is not considered to be attributable to carburettor icing.

2.3.6 Fuel Tank Ventilation

A blocked fuel tank ventilation system could also cause an engine to cut out. However, in the case of G-BVTD, each fuel tank was independently vented and a simultaneous blocking of both vents would be unlikely.

2.4 Failure Summary

Potential causes such as insufficient fuel quantity, mechanical failure, phase separation, carburettor icing and blocked ventilation were considered. Although these cannot be completely ruled out, the Investigation deemed them to be unlikely. While vapour lock also remains a possibility, the Investigation considers that the actual physical evidence of the extensive flaking of the coating on the inside of the slipper tank, indicates that fuel starvation due to a blockage caused by this flaking was the most likely reason for the engine cutting out.

The Investigation is of the opinion that this blockage likely occurred at a gauze strainer at the slipper tank outlet. While such a strainer was not found, a "*filter*" with the same part number as the strainer (F204) described in the assembly instructions for the upper tank is also referred to in the assembly instructions and parts list for the slipper tank. This part number (quantity: 2) is also listed in the overall parts list for the microlight kit. Moreover, the following evidence suggests that it had been present before the accident:

- The flaking of the coating on the inside of the slipper tank was extensive, yet the fuel supply hose from the slipper tank outlet was unobstructed.
- The inlet filter of the electrical pump was found to be debris-free, which is the first filter that the fuel passes through after it leaves the slipper tank, and due to the flaking of the tank coating would have contained at least some debris if the strainer was not present.
- The existence of a circular witness mark, on the inside to the slipper tank concentric with the tank outlet.

Regardless of cause in this case, the Investigation considers the condition of the fuel tank coating to be a serious safety concern and consequently makes a number of Safety Recommendations in relation to composite fuel tank inspections and increasing awareness of the potential for Mogas-related degradation of composite fuel tanks and/or the coating material.

2.5 In-Service Fuel Tank Inspection

There are over 160 Streak Shadows/Shadow variants on the UK Register, which are overseen by either the BMAA or the LAA. Although some of these may have aluminium alloy fuel tanks installed, the Investigation is concerned that there may be others in operation with the original composite fuel tanks fitted, some of which may have deterioration of the internal coating similar to that found on the subject microlight. Also, when in service, the observed good condition of an upper tank on such an aircraft may give a false indication regarding the condition of the slipper tank, which is more difficult to inspect, as the fuel tank sender unit must be removed to facilitate an inspection. Furthermore, the slipper tank may be more prone to deterioration than the main tank, due to it being exposed to more continuous fuel wetting (and consequently more ethanol) when the aircraft is parked following a flight, as the main tank may well be empty at this stage. The phase separation process could, over time, also increase the potential for the slipper tank to be adversely affected. The owner of a UK-registered Starstreak Shadow noted that deterioration was limited to the slipper tank when he was replacing his microlight's composite fuel tanks with aluminium alloy tanks.

The BMAA's Service Bulletin appended to MAAN 2336 provides details of an "*essential*" inspection of the fuel tanks on all Shadow variants in the "*BMAA fleet*", to be carried out at least every 50 hours or annually (whichever is sooner). According to the BMAA, because the Service Bulletin is listed in the UK CAA TADS for the variants in their fleet, compliance with the bulletin is verified as part of the annual airworthiness review. In the case of G-BVTD, which was an LAA-administered microlight, the LAA issued the Certificate of Validity for its Permit to Fly less than two months before the accident. The Investigation considers that the performance of an inspection similar to that contained in the BMAA's Service Bulletin may have identified that the coating material in the slipper tank had deteriorated. The Investigation therefore issues the following Safety Recommendation to the LAA:

Safety Recommendation No. 1

The UK Light Aircraft Association (LAA) should consider developing fuel tank inspection instructions for Streak Shadow/Shadow variants for which it has oversight for action by its members and verify compliance with the instructions during the Permit to Fly validity certificate renewal process (**IRLD2017007**).

This Investigation and publications from the LAA and the BMAA highlight specific chemical compatibility issues with composite fuel tanks on Streak Shadow microlights and Shadow variants when Mogas containing ethanol is used. However, the LAA's Technical Leaflet TL 2.26, which highlights similar issues on other aircraft types, and other studies on the adverse effects of ethanol on composite fuel tanks, indicate that the problem is more widespread. Consequently, the Investigation makes the following Safety Recommendation to the LAA:

Safety Recommendation No. 2

The UK Light Aircraft Association (LAA) should consider developing fuel tank inspection instructions for aircraft for which it has oversight that are fitted with composite fuel tanks, for action by its members and verify compliance with the instructions during the Permit to Fly validity certificate renewal process (**IRLD2017008**).

The Investigation notes the detailed fuel tank inspection instructions contained in the BMAA's Service Bulletin (2336) which should be effective in identifying fuel tank degradation on Shadow variants in the "*BMAA fleet*". However, to address the concerns that issues in relation to chemical compatibility with composite fuel tanks and Mogas containing ethanol may be more widespread, the Investigation makes the following Safety Recommendation to the BMAA.

Safety Recommendation No. 3

The British Microlight Aircraft Association (BMAA) should consider developing fuel tank inspection instructions for aircraft for which it has oversight that are fitted with composite fuel tanks, for action by its members and verify compliance with the instructions during the Permit to Fly validity certificate renewal process (**IRLD2017009**).

The IAA's Aviation Safety Leaflet IGA 9 R1 on '*Using Unleaded Petrol (Mogas) in Aircraft*', Aeronautical Notice A16B on the '*use of motor gasoline (Mogas) in microlight aircraft,* and A16A ('*the use of unleaded petrol (Mogas) in certain light aircraft*') describe several of the adverse effects of ethanol. While Aeronautical Notice A16B refers to fuel tanks, stating that they may be adversely affected, potential degradation of composite fuel tanks is not specifically mentioned in Safety Leaflet IGA 9 R1 or Aeronautical Notice A16A. According to the IAA, there are four Streak Shadow microlights on the Irish register, but that only one was in use which, the Investigation established, was fitted with an aluminium alloy fuel tank. Nevertheless, to highlight the potential for Mogas-related fuel tank deterioration on other aircraft types fitted with composite fuel tanks, the following Safety Recommendation is made to the IAA:

Safety Recommendation No. 4

The Irish Aviation Authority (IAA) should revise its publications (Safety Leaflet IGA 9 R1 and Aeronautical Notice A16A) relating to the use of unleaded petrol (Mogas) in aircraft to specifically highlight the potential for Mogas to cause degradation of composite fuel tanks and/or their internal coating materials (**IRLD2017010**).

To highlight the subject accident to Streak Shadow and Shadow variant owners in other States, a copy of this Report will be provided to the following organisations:

- The European Microlight Federation, through EASA.
- The United States Ultralight Association, through the National Transportation Safety Board (NTSB).
- Recreational Aviation Australia, through the Australian Transport Safety Bureau (ATSB).

3. CONCLUSIONS

3.1 Findings

1. The Permit to Fly for the microlight was valid.
2. The Pilot's Licence and Medical Certificate were valid.
3. The microlight's engine cut out when the microlight was over Tory Island, having just flown over the sea for approximately 6 nm. The engine could not be restarted, resulting in the Pilot performing a forced landing on the island.
4. The microlight sustained substantial damage due to the forced landing, resulting in the Pilot sustaining minor injuries.
5. The AAIU was unaware of the accident until the microlight had been recovered to Finn Valley Airfield and therefore was unable to examine the wreckage at the accident site.

6. Unleaded automotive petrol (Mogas) was used to refuel the microlight before the accident flight.

7. Mogas was regularly used to refuel G-BVTD. Its use is permitted by the IAA and the UK CAA, subject to certain conditions.

8. Laboratory analysis conducted on a sample of the fuel used to refuel the microlight and on a sample taken from the microlight's fuel system, established that the fuel contained approximately 5.5% of ethanol by volume. EN228 specifies a maximum ethanol content of 5% by volume. The laboratory supervisor stated that the increase may have been due to evaporation of the more volatile elements prior to the samples being taken.

9. Several studies and associated publications have identified several adverse effects caused by the ethanol content of Mogas.

10. The coating on the inside of the lower (slipper) fuel tank was found to be deteriorated, with substantial flaking evident.

11. Laboratory analysis of the fuel tanks identified two types of coating on the inside of the slipper tank, an epoxy resin and a phenoxy resin and that the flaking observed was likely due to sub-optimal adhesion between the epoxy and phenoxy material, combined with deterioration caused by the presence of ethanol in the fuel.

12. Laboratory analysis of the fuel tanks identified that the coating on the inside of the upper tank was phenoxy resin-based.

13. Potential causes such as insufficient fuel quantity, mechanical failure, phase separation, carburettor icing and blocked ventilation were considered. Although these cannot be completely ruled out, the Investigation deemed them to be unlikely.

14. While vapour lock also remains a possibility, the Investigation considers that the actual physical evidence of the extensive flaking of the coating on the inside of the slipper tank, indicates that fuel starvation due to a blockage caused by this flaking was the most likely reason for the engine cutting out.

3.2 Probable Cause

A forced landing on rough terrain following an un-commanded in-flight engine shutdown due to fuel starvation.

3.3 Contributory Cause(s)

1. Blocked fuel flow from the slipper tank due to fragments of detached fuel tank coating material.

2. Sub-optimal adhesion between the two materials used to coat the inside of the slipper tank.

3. The adverse effects of ethanol on composite fuel tanks and their coating materials.

4. SAFETY RECOMMENDATIONS

	It is Recommended that:	Recommendation Ref.
1.	The UK Light Aircraft Association (LAA) should consider developing fuel tank inspection instructions for Streak Shadow/Shadow variants for which it has oversight for action by its members and verify compliance with the instructions during the Permit to Fly validity certificate renewal process.	IRLD2017007
2.	The UK Light Aircraft Association (LAA) should consider developing fuel tank inspection instructions for aircraft for which it has oversight that are fitted with composite fuel tanks, for action by its members and verify compliance with the instructions during the Permit to Fly validity certificate renewal process.	IRLD2017008
3.	The British Microlight Aircraft Association (BMAA) should consider developing fuel tank inspection instructions for aircraft for which it has oversight that are fitted with composite fuel tanks, for action by its members and verify compliance with the instructions during the Permit to Fly validity certificate renewal process.	IRLD2017009
4.	The Irish Aviation Authority (IAA) should revise its publications (Safety Leaflet IGA 9 R1 and Aeronautical Notice A16A) relating to the use of unleaded petrol (Mogas) in aircraft to specifically highlight the potential for Mogas to cause degradation of composite fuel tanks and/or their internal coating materials.	IRLD2017010

View Safety Recommendations for Report 2017-009

- 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.

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