ACCIDENT

Aircraft Type and Registration:	Auster AOP.9, G-BXON	
No & Type of Engines:	1 Bombardier Cirrus 20801 piston engine	
Year of Manufacture:	1955 (Serial no: AUS/10/60)	
Date & Time (UTC):	18 June 2017 at 1135 hrs	
Location:	Spanhoe Airfield, Northamptonshire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - 1 (Fatal)	Passengers - 1 (Serious)
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	49 years	
Commander's Flying Experience:	409 hours (of which 0.5 hours were on type) Last 90 days - 2.0 hours Last 28 days - 0.5 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The pilot was undertaking his second flight on the recently-restored vintage ex-military aircraft. Shortly after taking off from Spanhoe Airfield, the aircraft was observed to bank left into a steep descent and strike the ground to the left of the runway. The pilot was fatally injured, and the passenger sustained serious injuries. The investigation determined that the aircraft stalled at a low height, from which it did not recover before striking the ground. The investigation also identified several issues relating to the aircraft and engine performance, maintenance documentation, the Permit to Fly application process, and guidance for pilots preparing for their first flight on a new type. The Light Aircraft Association (LAA) has taken a number of safety actions. No Safety Recommendations are made.

History of the flight

G-BXON had recently been rebuilt and restored at Spanhoe Airfield. Its first Permit to Fly was issued by the Civil Aviation Authority (CAA) on 2 June 2017 and the LAA sent it to the pilot on 6 June 2017. The pilot, who was also the owner, flew the aircraft for the first time the day before the accident, accompanied by another pilot.

On the accident flight, the pilot took off from Spanhoe's Runway 27 at around 1130 hrs with a passenger. The pilot occupied the left seat, and the passenger was in the right.

A number of bystanders who were near the open entrance of a hangar watched the aircraft takeoff until it was obscured from view. Shortly after, on hearing a bang, and realising that the engine noise had ceased, they went outside to find a column of smoke rising from the field left of the departure end of the runway. One person phoned the emergency services and some of the group immediately went to the accident site, where the aircraft was found to be on fire. One of this group discharged a hand-held fire extinguisher however this had no effect due to the intensity of the fire. The pilot, who was still inside, was fatally injured. The passenger had sustained serious injuries and was found near the aircraft.

A horse rider had stopped at a position around 430 m from the end of the runway to watch the aircraft depart. She stated that the takeoff initially seemed normal but, soon after, the aircraft rocked slightly; first right then left. There was a short pause before the aircraft rolled left into a steep descent and struck the ground to the left of the runway. The engine noise sounded constant up until the impact. Figure 1 shows the location of the various witnesses.

Airfield information

Spanhoe is an unlicensed former World War II airfield in Northamptonshire, at an elevation of 340 ft amsl. It is situated 6 nm south-west of RAF Wittering, and within its Military Aerodrome Traffic Zone. It has a 700 m runway aligned 090° and 270° which is mainly concrete, and a 500 m grass runway aligned 140° and 320°.

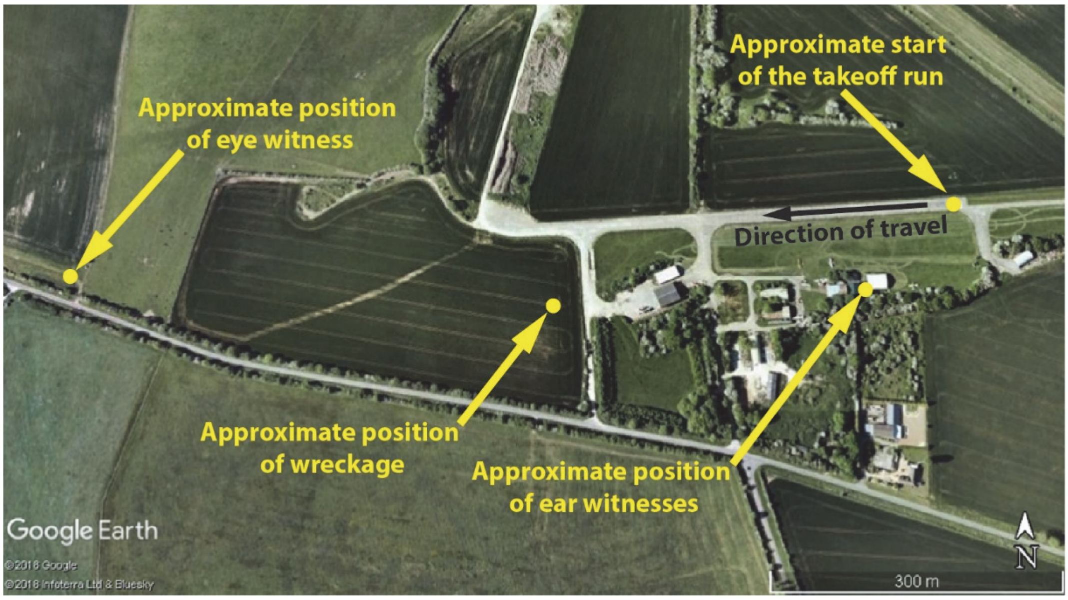

Figure 1

Spanhoe Airfield and location of witnesses

Flight on the previous day

The pilot's first flight on the aircraft departed from Spanhoe's Runway 27 at approximately 1600 hrs on 17 June 2017. He was accompanied by a pilot who had AOP.9 experience, hereinafter referred to as 'Pilot B'. The pilot acted as commander from the left seat. Pilot B occupied the right seat as a passenger, albeit acting in a supportive capacity.

Pilot B reported that takeoff flaps were used for the departure, and that the pilot accurately flew a climb speed of 60 KIAS. The pilot had asked him to monitor the takeoff engine rpm, which he recalled as being approximately 2,300 rpm. Pilot B recalled that the rate of climb (ROC) was relatively low although he was not concerned about it. The pilot raised the flaps at approximately 450 ft agl and turned left downwind. They left the circuit briefly to fly some steep turns and then landed back on Runway 27. The pilot's logbook recorded a 30 min chock-to-chock time.

Pilot B stated that he had been impressed by the pilot's professionalism during the flight. He recalled commending the pilot on his precise speed control and suggesting that he may also benefit from 'feeling' how the aircraft is performing.

Meteorology

Aftercast information provided by the Met Office indicated that, during the weekend of the accident, there was high pressure across the UK and conditions were very warm.

The weather at RAF Wittering around the time of G-BXON's first flight and the accident flight was reported as follows:

> 17 June 2017 at 1550 hrs: wind from 260° at 7 kt, visibility greater than 10 km, scattered cloud at 4200 ft, temperature 29°C and QNH 1024 hPa.
>
> 18 June 2017 at 1150 hrs: wind from 240° at 7 kt, visibility greater than 10 km, no cloud, temperature 28°C and QNH 1023 hPa.

These conditions resulted in density altitudes[1] (DA) at Spanhoe of approximately 1,930 ft and 1,840 ft[2] for the penultimate and accident flights respectively.

Recorded information

Accident flight

No recorded data was recovered from the aircraft and the aircraft was below radar coverage.

Flight on the previous day

The takeoff and landing at Spanhoe on the day before the accident were videoed by a bystander at the airfield; the recording indicated an airborne time of approximately 10 minutes. The audio and images from the takeoff video were analysed to calculate the aircraft's groundspeed and to review the climb performance, engine speed and flap settings.

The windsock was visible in the takeoff video and indicated a light, varying headwind. Based on RAF Wittering's weather report at that time, a 7 kt wind correction was added to the

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Footnote

[1] Density altitude: Pressure altitude corrected for variations from standard temperature. As density altitude increases, an aircraft's performance reduces, and vice versa.

[2] DA values throughout this report have been corrected for humidity.

aircraft's calculated groundspeed to derive its approximate true airspeed (TAS)[3]. However, there are limitations to the accuracy of the calculated groundspeed, and the derived TAS, as the wind speed correction applied for the latter was based on the reported wind conditions at an airfield 6 nm away.

The takeoff occurred at 1557 hrs. Audio analysis indicates that, as the aircraft passed the camera position during the takeoff roll, the engine speed was 2,300 rpm ±50 rpm and there was no significant variation subsequently. The video images show approximately 17° ± 2.5° of flap, consistent with a takeoff flap setting; no flap asymmetry was evident.

As derived from the video images, the aircraft lifted off with a true airspeed of approximately 56 KTAS. It climbed away at approximately 57 to 60 KTAS, with a ROC of approximately 500 ft/min.

After the aircraft climbed through about 70 ft aal, it was no longer possible to extract useful data from the imagery. On the accident flight the following day the aircraft travelled approximately 80 m further along the runway from this point before departing from controlled flight.

Personnel information

Pilot

The pilot held an EASA Private Pilot's Licence (PPL(A)) and his logbook provided evidence that he had gained appropriate training[4] and experience in operating taildragger[5] aircraft. It showed a total of 409 flying hours, including 217 hours on taildragger aircraft. Prior to flying G-BXON on 17 June 2017, the pilot had logged two flights[6] in the preceding 90 days. He had no recorded hours on any Auster type, but a significant proportion was on other high-winged taildragger aircraft.

Spanhoe had a close-knit community and witnesses reported that the accident pilot was eager, though somewhat apprehensive, to fly his newly-restored aircraft. Anecdotal evidence indicated that he had been very focussed on G-BXON's rebuild. It was not determined to what extent he had prepared himself on the AOP.9's specific handling characteristics but another AOP.9 owner reported that the pilot had often accompanied him as a passenger in his aircraft and, on those occasions, they did talk about handling matters. That aircraft was not fitted with dual controls.

The pilot was described as being cautious and as someone who would 'fly by the numbers', tending not to deviate from target figures.

Footnote

[3] TAS is the speed of the aircraft through the air, whilst indicated airspeed (IAS) (presented on the airspeed indicator (ASI)) is a measurement of dynamic pressure entering the aircraft's pitot tube. TAS is usually higher than IAS and at low altitudes the difference is insignificant.

[4] Starting in 2003, the pilot had flown a number of hours in a Pitts S2A tailwheel aircraft with instructors, which he referred to as a '*conversion*'. There was no instructor's signature present in the pilot's logbook relating to completion of tailwheel differences training, but this may have been due to an administrative oversight.

[5] Aircraft with a tailwheel or tailskid.

[6] One of these was a Single Engine Piston (SEP) revalidation training flight involving more than one takeoff and landing.

Pilot B

Pilot B was an experienced naval and airline pilot who had owned a number of light aircraft including, previously, an AOP.9. He had 20 hours 35 minutes of flight time in the AOP.9, and his last flight in one was in G-BXON the day before the accident.

Passenger

The passenger on the accident flight was a friend of the pilot. He had automotive engine experience and had assisted with some aspects of the work on G-BXON's engine during its restoration. He was not a qualified pilot.

LAA inspector and testing pilot

The pilot had engaged the services of an LAA inspector to assist with and oversee the completion of G-BXON's rebuild, and the application for its Permit to Fly. The inspector held LAA approvals to sign off aircraft build projects, final inspections before first flight, aircraft maintenance and permit renewal recommendations. Although not required for the maintenance and inspection of LAA aircraft, he was also a Licensed Aircraft Maintenance Engineer (LAME) and owned an aircraft maintenance organisation based at Spanhoe. He also held valid EASA Part 66 and BCAR Section L licences and an ELA-1 authorisation, which allowed him to make recommendations to the CAA for issue/renewal of an aircraft Certificate of Airworthiness (CofA).

This individual was also a former flying instructor and had particular Auster expertise, having previously owned and overseen the rebuild of a number of AOP.9s. He had conducted all the test flying on G-BXON. Previously, he had performed flight testing on other aircraft under the CAA process.

First flights on type

Amongst the LAA community, a pilot's first flight on type was colloquially referred to as a 'check-out' as they would tend to be accompanied by another pilot experienced on type. However, there was no requirement for this flight to be instructional and, providing that a pilot and an aircraft were compliant with the necessary licencing and certification requirements, then a pilot new-to-type could act as commander and carry passengers.

There was an informal expectation at Spanhoe that the pilot would fly G-BXON for the first time alongside its LAA inspector and testing pilot, or another AOP.9 owner with recent experience on type. These individuals had limited availability over the accident weekend. Pilot B reported that the accident pilot approached him shortly before 1600 hrs on 17 June 2017 requesting he accompany him on his first flight.

Description of the aircraft

The Auster AOP.9 is a high-wing, strut-braced tailwheel aircraft with three seats, originally designed for military airborne reconnaissance. The fuselage is constructed of welded steel tubes covered with a doped fabric. The wings are fabric-covered, with the exception of the metallic leading edge and the tail unit is of all-metal construction.

The AOP.9 is powered by a Bombardier Cirrus 20801 inverted in-line engine, driving a two-blade, fixed-pitch metal propeller. Fuel is carried in flexible tanks located in the left and right wing roots and is gravity-fed to a collector tank. An electrically-driven fuel booster pump in the collector tank feeds fuel to two mechanical engine-driven pumps and then to a fuel injection pump, from which a metered quantity of fuel is delivered directly into the engine cylinders via fuel injection nozzles.

The flying controls[7] are conventional with control surfaces operated by push-pull rods, cables and chains. The aircraft is equipped with hydraulically-operated split flaps, actuated by a handpump and an UP/DOWN selector lever centrally mounted on the cabin roof structure. The flaps may be lowered to any intermediate position; the takeoff position is reached when the lower surface of the flap is in line with a yellow mark painted on the aileron hinge bracket.

The ailerons are linked to the flaps via a cam and cam follower, so that when the flaps are lowered, the ailerons droop up to a maximum of 10°, thereby increasing the effective flap area. At the takeoff flap position, the cam profile changes sharply, so the aileron droop does not increase with further lowering of the flaps.

The AOP.9 features a retractable pitot probe; it can be extended or retracted on the ground by withdrawing a spring-loaded locking pin on the lower wing surface. In order to lock it in either position, the locking pin must be engaged in one of the two locating holes on the underside of the probe.

The AOP.9 is not equipped with an artificial stall warning device.

Accident site and wreckage information

The accident site was located in an area of standing crop, to the left of the end of Runway 27. Examination of the ground marks and wreckage distribution indicates a dynamic impact sequence, in which the left wingtip and pitot probe made first contact with the ground, dislodging the left wingtip fairing. The aircraft then cartwheeled with the propeller and engine striking the ground, followed by the right landing gear and right wingtip. The initial impact trail was on an approximate heading of 196° and the aircraft came to rest upright on an approximate heading of 287° (Figure 2).

Several propeller strikes were evident in the crop and two distinct propeller strikes on the ground exhibited yellow paint transfer from the propeller tips (Figure 3).

An intense post-impact fire had consumed the contents of the aircraft, the cockpit controls, instrument panel and the fabric covering of the fuselage and wings.

Both wings had detached from the fuselage mounting points as a result of the impact and fire damage but remained close to the fuselage. The right elevator had separated and was found close to the main wreckage. All three aircraft doors had detached during the impact. The engine was no longer attached to its mounting points and was lying on its side.

Footnote

[7] G-BXON was fitted with dual controls, which was an optional fit on the AOP.9.

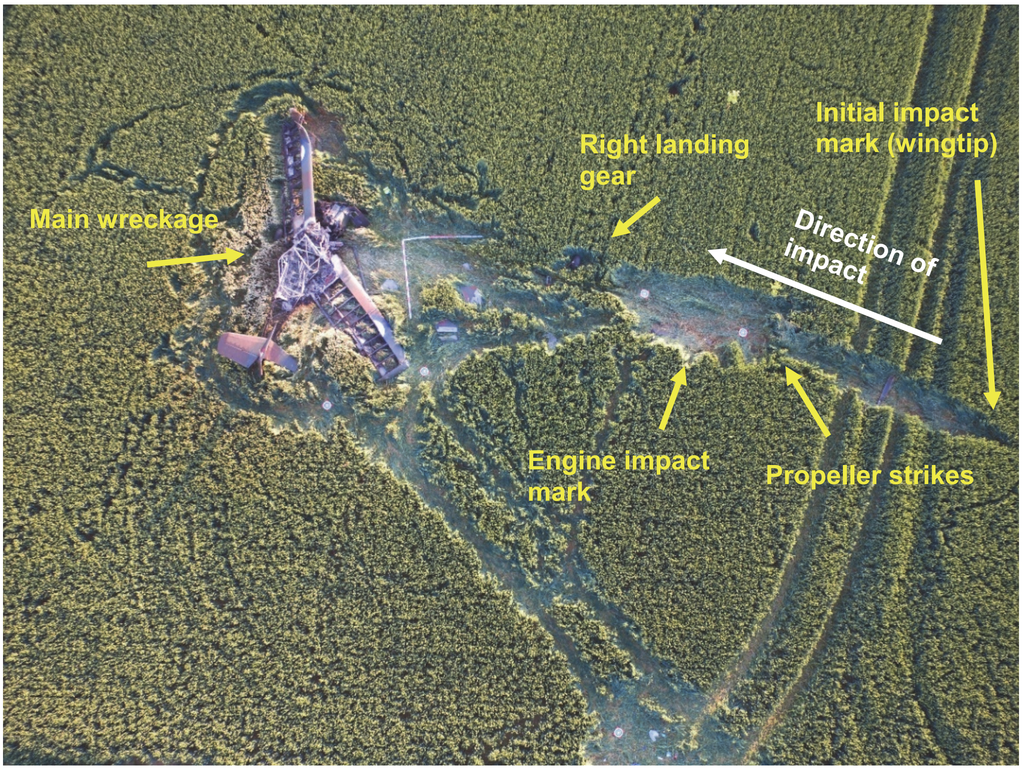

Figure 2

Aircraft wreckage and impact trail

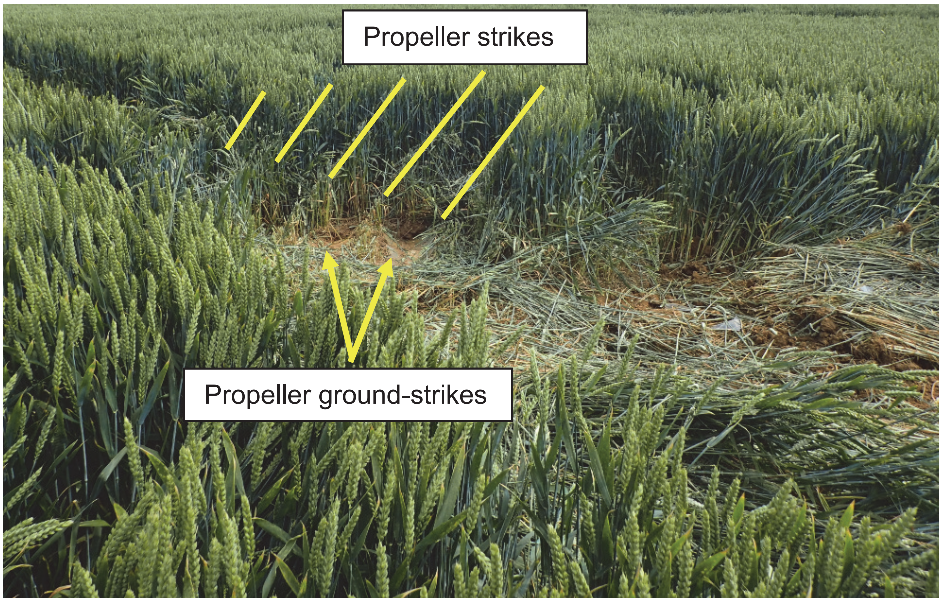

Figure 3

Propeller strikes

Detailed aircraft examination

General

The outer right wing leading edge exhibited damage consistent with striking the ground. With the exception of the metallic leading edge skin panels, all of the right wing structure inboard of the fuel tank boundary rib, including part of the flap, flap operating torque tube and aileron control run, was absent, having been consumed by the post-impact fire.

The outer left wing and wingtip displayed damage consistent with striking the ground and the wingtip rib was bent inwards by about 90°. All the wing structure in the inboard-most rib bay, including the part of the left flap surface and the inner portion of the flap operating torque tube had been consumed by the fire.

The pitot probe was filled with soil and bent upwards and outboard. It was found in a partially extended position and the locking pin was not engaged in either of the locating holes. Examination revealed that it was likely the pitot probe had been fully extended and impact forces displaced it towards the retracted position, overcoming the spring force of the locking pin. It was not possible to examine or test the remainder of the pitot/static system due to impact and fire damage.

Flying controls

The right elevator separated from the tailplane during the impact, however, all the cables and connections in the control runs for the elevator and rudder control systems remained intact. The elevator trim tab on the left elevator was found to be in the neutral position, however, the pre-impact trim setting could not be determined due to the extent of the disruption to the cockpit.

The right aileron outer attachment bolt mounted to the wingtip rib had pulled through its mounting due to impact forces, but the right aileron control circuit was otherwise intact. The left aileron outer attachment bolt had also pulled through its mounting and the cam follower for the aileron droop mechanism had dislodged from the cam due to impact forces. The left aileron control rod had separated at the joint between the rod and the forward end-fitting; the four rivets which held it in place had sheared.

The inboard end of the left flap torque tube was unrestrained, so it was not possible to make any determination of the flap position. The lower surface of the right flap was broadly aligned with the yellow indicator line on the aileron hinge bracket and witness marks indicated that it had been in the takeoff position at the time of impact.

Cockpit

The steel tubular structure of the cockpit remained largely intact, however the extensive fire damage meant that no meaningful information could be obtained from the instrument panel, instruments, flight controls or engine controls.

Each of the three aircraft seats was equipped with a four-point ‘ZA-type’ harness with a quick release fitting (QRF). It was not possible to assess the effectiveness of the restraint system on the occupied seats, as the harnesses had been entirely consumed by the post-impact fire, but three QRFs were found within the aircraft wreckage. One QRF, assumed to be that from the left seat, was fire-damaged and still had all four buckles engaged. The release mechanism appeared to function freely, however the buckles did not release, most likely due to deformation sustained in the accident. A second QRF was discoloured due to heat but appeared otherwise undamaged; one shoulder buckle remained engaged and the others were released. A third QRF was found close to the observer's seat in the back of the aircraft; the two lap buckles were engaged but, due to the extent of the fire damage, the mechanism could not be operated.

Engine examination

General

The engine and its ancillary components were examined under the supervision of the AAIB, at a specialist engine maintenance facility experienced in working on vintage piston engines.

The propeller, spinner and No.1 cylinder baffles exhibited damage consistent with striking the ground and a number of the engine accessories were broken or had been damaged in the post-impact fire. However, the engine otherwise appeared largely intact. The engine would not rotate freely until the camshaft was removed and, although not visually apparent, it was determined that impact-related distortion in the cam assembly had prevented both the camshaft and engine from turning.

No. 1, 3 and 4 cylinders exhibited poor compression, with leakage past the exhaust valves being evident. The inlet and exhaust valves were poorly seated to varying degrees on all cylinders and there were signs of blow-by and/or carbon build-up on the exhaust valves. They did not have the appearance of valves which had been recently lapped. All cylinders showed signs of glazing along with some corrosion pitting and evidence of only minimal honing. In addition, the No.1 and 2 cylinders were very oily.

The spark plugs were of varying aerospace types and the firing gaps ranged from 0.015 to 0.025 inches compared to the recommended gap of 0.012 to 0.015 inches. When tested, only three of the spark plugs exhibited a strong spark with the others exhibiting weak and/or intermittent sparks and, in one case, a spark that tracked down the insulation rather than jumping across the gap. The ignition leads had been manufactured from copper-cored automotive wire and had the appearance of having been recently replaced.

Magneto[8] timing checks revealed that the timing on the left side was slightly out, such that the voltage pulse occurred early at 48°, rather than the specified 41° ± 1°, before Top Dead Centre (TDC). The left and right contact breakers' point gaps were 0.026 inches and 0.014 inches respectively; the recommend gap is 0.009 ± 0.001 inches. The magneto was run on a test rig and sparking was evident at the contact breaker points due to the large gaps. It operated for approximately 2 hours before failing 'hot' at a temperature of 59°C. A burning smell was

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Footnote

[8] The Bombardier Cirrus 20801 is fitted with a duplex magneto which contains two separate ignition circuits within a single unit.

evident throughout the test and visual inspection showed heat degradation of the lacquer coating on the lower coils. It was not possible to determine whether this was related to the post-impact fire or whether the magneto had previously exceeded its operating temperature.

Two pieces of re-solidified molten white metal and two flakes of paint-like material, were found in the main oil filter housing. There was no evidence that this debris had come from within the engine and its origin was not determined, however, the filter had prevented it from entering the engine oil supply. It was noted that the cap nut of the oil pressure relief valve (OPRV) was unlocked with three threads visible and had not been wire-locked and there were indications of relatively recent maintenance on the valve guide and ball. The engine oil was blacker than expected, possibly as a result of the blow-by noted on the cylinders.

Mechanical fuel pumps

There was no fuel present in either of the mechanical fuel pumps, the interconnecting pipe, nor the fuel line to the fuel injection pump. Although externally heat damaged, the fuel pumps and pipes were intact so there was no evidence that fuel could have leaked out since the accident but the possibility that the fuel evaporated in the post-impact fire could not be ruled out. The securing wing nuts on the fuel pump bowls were not wire-locked.

When run on a fuel test rig neither pump was able to develop or maintain suction pressure to deliver fuel, even when manually primed. It was therefore not possible to conduct a delivery flow rate test on the pumps. Additionally, in certain conditions, fuel was observed to leak from the pump body and the fuel drain, which indicated that fuel was leaking past the internal diaphragm. In an attempt to determine how the pumps would perform on-aircraft, the installed aircraft condition was simulated by providing gravity-fed fuel to the pumps from an external source mounted above the test rig. In this condition, the head of fuel created sufficient pressure to allow fuel to pass through the pumps. A rudimentary flow rate check was conducted at a test rig operating speed of 800 rpm[9]. After taking into account the contribution from the gravity-fed fuel, the delivery rate for each pump solely due to pump action was determined to be approximately 21% of the expected delivery rate at this operating speed.

Disassembly revealed that on both pumps the clamping nut at the base of the central spindle was loose, resulting in the internal diaphragm not being adequately clamped. Additionally, the diaphragms did not have the appearance of having been professionally fitted and cut to size, exhibiting stretching and creasing, elongated bolt holes and a crudely-cut central hole (Figure 4). Oil had leaked to the fuel side of the diaphragm, indicating that the diaphragm did not form an effective seal between the fuel and oil (atmospheric) side of the pump. One effect of this is that fuel could escape through the centre of the diaphragm into the oil side of the pump and exit a fuel drain in the upper part of the pump body; this would result in reduced suction.

Footnote

[9] The fuel flow test described in the *'Amal Operation, maintenance and overhaul instructions for Fuel Pump type 240/8'* has four test points at various test rig operating speeds; 800 rpm is the third test point.

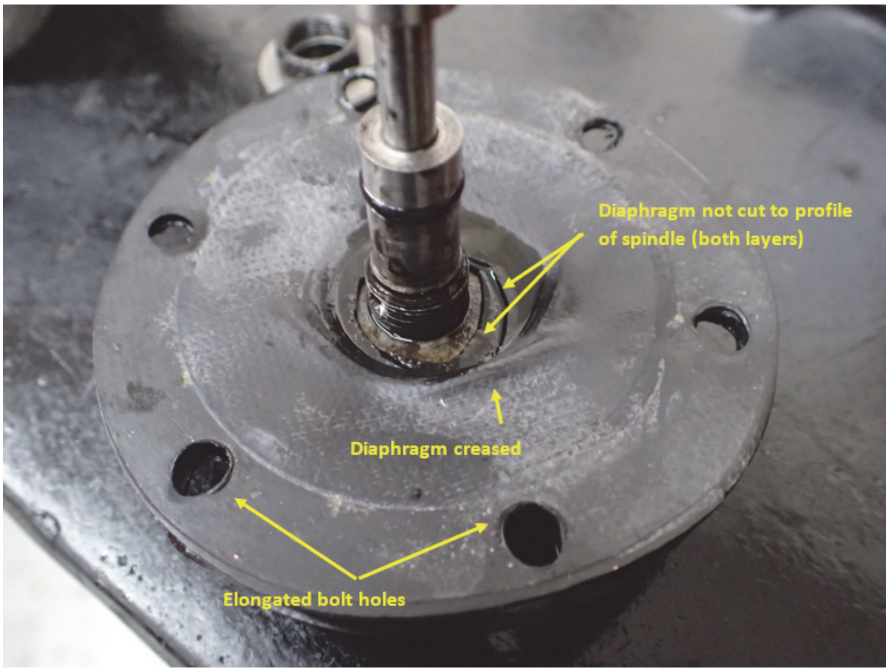

Figure 4

View showing oil side of diaphragm from right mechanical fuel pump

Fuel injection pump

The fuel injection pump was intact and did not display any obvious impact damage. No fuel was present in the pump, but a small amount of residual fuel was found in the No. 4 fuel injection line and was retained for further analysis.

The timing of the fuel injection system is normally set to coincide approximately with the induction period of the engine. A fuel injection pump timing check was performed and fuel delivery to the No.1 cylinder commenced at 130° before TDC and stopped at 27° before TDC; the engine manual indicated that fuel delivery should commence at 27° before TDC.

The fuel injection pump and nozzles were removed from the engine and tested on a fuel test rig using shop fuel lines. Leaks were observed on the No. 2 and 4 fuel injection nozzles. The part of both nozzles which mates with the fitting on the fuel injection line exhibited an uneven surface, with burrs, such as if they had been damaged by a spanner. This may have made it difficult to achieve an effective seal between the nozzles and fuel fittings on the aircraft. Additionally, two of the six clamping screws on the No. 2 nozzle were loose, causing fuel to leak from the injector body. These anomalies were rectified to allow testing of the injection pump.

The pump operated normally when tested but the fuel flow was out of calibration because the mixture strength was running lean. The adjuster nut on the pump, which allows mixture strength to be altered, did not have an index mark, so it was not possible to determine if/how it had been previously adjusted. However, the end cap on the adjuster nut had modern wire locking, which indicated that it may have been disturbed at some point.

Aileron control rods

Left aileron control rod

The heads of the failed rivets in the left aileron control rod forward end-fitting were not found. However, the rivet tails remained within the end-fitting and were subjected to metallurgical examination. The top rivet tail came loose during removal of the control rod from the aircraft and is shown separately in Figure 5.

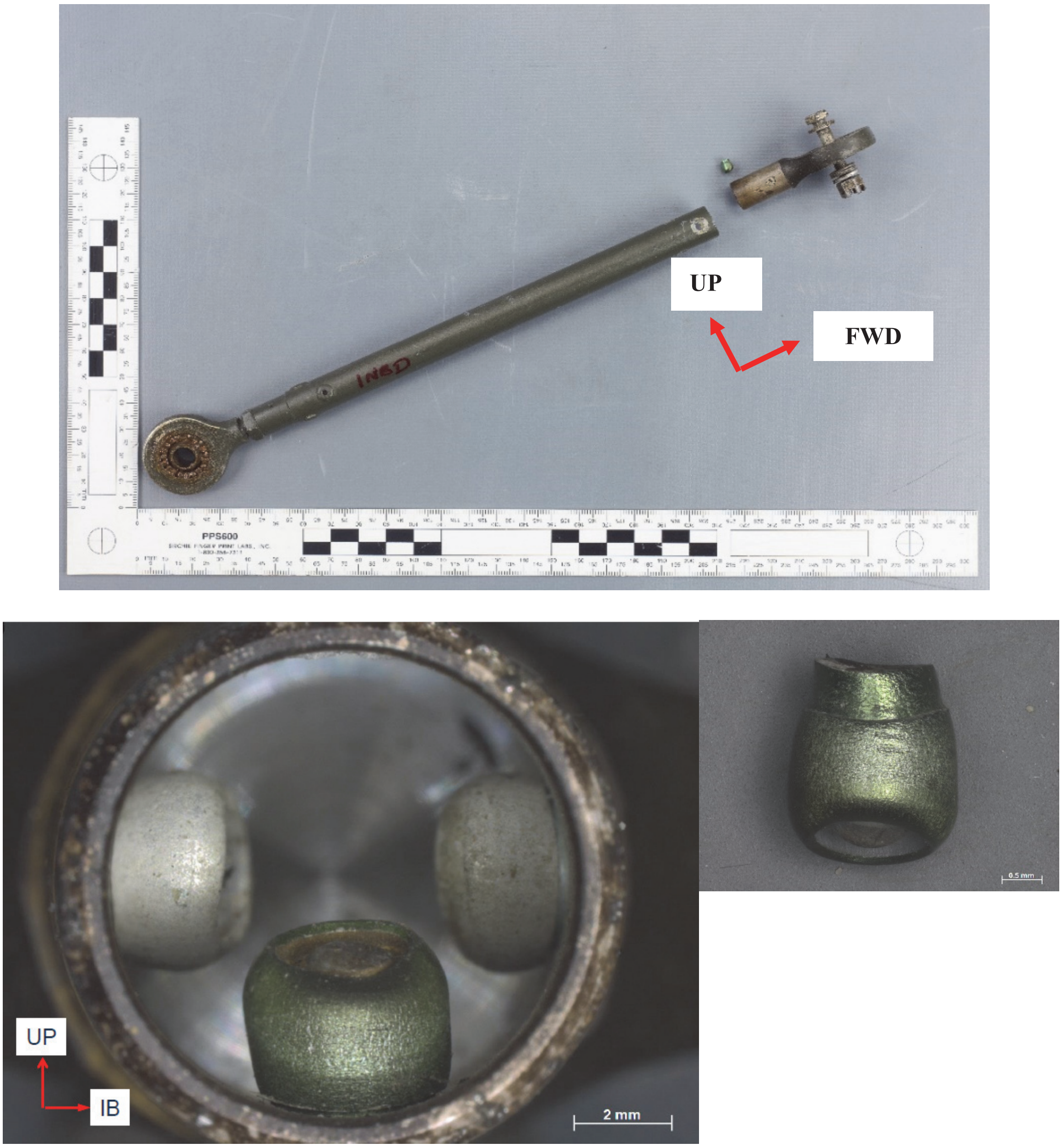

Figure 5

Left aileron control rod (top) and end-fitting attachment rivets (bottom)

The rivets were identified as ⅛ inch diameter break-stem, pop-type blind rivets[10]. The inboard and outboard rivet tails were grey and were filled with corrosion product and paint. Conversely, the top and bottom rivet tails were green, and only the head of the mandrel was observed in the hollow centre.

Metallurgical examination showed that the fracture surfaces of all four rivets exhibited differing amounts of mechanical damage, caused by contact between the opposing fracture surfaces during detachment of the end-fitting. The remaining surface detail showed that all four rivets had failed as a result of ductile overload in shear, indicating that they were carrying load at the time of failure. The outboard rivet also exhibited three distinct patches of intergranular fracture (shown in purple in Figure 6), which indicated the presence of pre-existing intergranular cracking prior to the shear overload failure. The precise extent of the intergranular fracture could not be determined due to the mechanical damage, but the areas in which it was observed indicated that it may have extended across one third of the surface area.

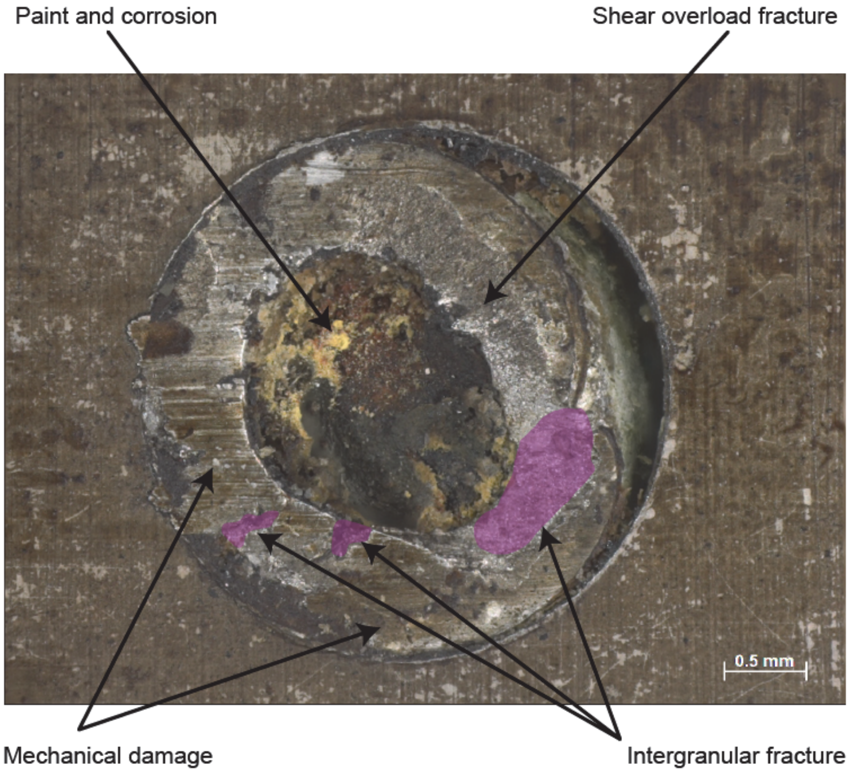

Figure 6

Fracture surface of outboard rivet showing areas of intergranular corrosion

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Footnote

[10] Blind pop rivets are installed by pulling a mandrel through from the head side. When a tight joint has formed, the mandrel breaks at a pre-determined position on the stem, hence they are referred to as break-stem rivets. The head of the mandrel remains in the centre of the hollow rivet but does not provide any support to the joint in shear.

Intergranular corrosion and stress corrosion cracking[11] was also observed on the internal surfaces of the inboard and outboard rivets. Although no intergranular fracture was evident on the fracture surface of the inboard rivet, the mechanical damage may have destroyed any pre-existing cracking that was present.

Energy Dispersive X-ray (EDX) analysis determined that all four rivets were manufactured from an aluminium-magnesium alloy consistent with 5056 Grade, which is commonly used for rivets. Micro-hardness tests indicated that the hardness range of the rivets was closer to the annealed condition than the fully hard condition[12].

All four rivets on the aft fitting of the control rod were green and manufactured from the same material as those on the forward fitting.

Right aileron control rod

A comparative examination of the right aileron control rod identified that all eight end-fitting attachment rivets were grey in colour. It was noted that the inboard rivet on the aft end-fitting had failed. The rivet tail was filled with corrosion product and the rivet head was absent. The remaining rivets were intact, and there was no evidence that the joint had distorted under shear loading. Detailed examination showed that the fracture surface of the failed rivet was entirely comprised of intergranular failure. The absence of any ductile shear overload features indicated that this rivet was not carrying any load at the time of failure. The remaining rivets in the right aileron control rod were not examined.

Aileron control rod drawings and material properties

The AOP.9 spares manual[13] indicates that, following a modification, there are two standards of aileron control rod, for which there are separate drawing numbers. No part number was marked on the failed aileron control rod from G-BXON, so it was not possible to identify whether it was of a pre or post-modification design. The original pre-modification drawing was not located, however, the AOP.9 Type Record document made reference to the pre-modification drawing and indicated that the original rivets were AGS 2048-420 ⅛ inch pop rivets. The data sheet for AGS 2048-420 rivets indicated that they are green in colour and made from BS L.58[14] aluminium alloy which is equivalent to 5056 Grade.

Footnote

[11] Stress corrosion cracking can occur when susceptible metals or alloys are subject to a continuing tensile stress above a threshold level in a corrosive environment. Initiation normally occurs when the protective surface finish has been compromised allowing corrosion to start. In the case of the rivets, the residual stresses from the rivet forming process may be sufficient, in combination with a corrosive environment, to provide the conditions for stress corrosion cracking.

[12] Typical hardness values for 5056 Grade aluminium are 74 HV in the annealed condition and 123 HV in the fully hard condition. The hardness results obtained indicated that there had probably been some strain hardening of the rivets close to the fracture surface, due to deformation caused by the installation process. In each case the lowest hardness value for each rivet was measured close to the fracture surface and ranged from 85 HV to 93 HV. The rivets were therefore closer to the annealed condition.

[13] Air Publication 2440 H Volume 3, Part 1 *'Auster Mk.9 (AOP) Aircraft Schedule of Spare Parts',* first issued December 1954, amended June 1962.

[14] The BS L.58 specification *'Wire for solid, cold-forged rivets of aluminium – 5% magnesium alloy'* has since been superseded by BS 3L.58, but the material properties remain the same.

A copy of the post-modification drawing[15] was provided to the investigation and specified the use of ⅛ inch diameter Chobert snap-head rivets[16] and sealing pins[17]. The change to Chobert rivets did not appear to be directly related to the modification but had been added to the drawing at a subsequent revision.

The Chobert rivets have an ultimate shear strength of 240 – 260 MPa, dependent upon the sealing pin material. By comparison, 5056 Grade aluminium alloy in the annealed condition, from which G-BXON's rivets were manufactured, typically has an ultimate shear strength of 179 MPa, with a minimum shear strength of approximately 159 MPa.

Aerodynamic flight loads for the AOP.9 aileron were calculated[18] by the AAIB. Based on the rivets used in G-BXON and using the minimum allowable shear strength for 5056 Grade, the ultimate shear strength of the rivets was calculated to be sufficient to sustain the maximum flight loads which could be expected in the aileron control rod, even if two of the rivets had completely failed.

The AOP.9 Type Record document included a '*Strength summary of aileron control circuit*' which indicated that the critical design load case for the rivets was the 'pilot effort' case; this refers to the maximum control stick loads that could be applied by a pilot on the aileron control circuit, for example, if trying to overcome a jammed aileron. For this load case, the load in each rivet was quoted as 194.25 lbs and the allowable load as 195 lbs, giving a reserve factor of 1.004.

Fuel sample analysis

The fuel sample retained from the fuel injection line and another sample taken from the jerry cans used to fuel G-BXON, were tested to determine whether they conformed to the industry standard fuel specification for Avgas 100LL[19].

The jerry can sample did not meet the specification for vapour pressure, indicating that it was contaminated with a more volatile fuel, most likely automotive gasoline. Further testing indicated that the sample was broadly consistent with Avgas 100LL and that the level of contamination was small.

The fuel injection line sample contained some particulate contamination and was green in appearance. Avgas 100LL typically has a blue tint. There was insufficient fuel to complete the full specification test, but analysis by other techniques indicated that, although similar to the jerry can sample, the fuel from the injection line had some volatile components

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Footnote

[15] Originally issued in July 1957, and subsequently revised in August 1957 and September 1962.

[16] Chobert rivets are installed using a reusable steel mandrel which is pulled through the rivet towards the head. The installed rivet is hollow, although the use of a sealing pin effectively makes the rivet solid, increasing its shear strength and sealing the internal structure of the assembly from the environment.

[17] The sealing pins can be manufactured from either L64 or DTD 423 grade aluminium alloy, which is equivalent to a modern 2014 T4 or 2014 T6 respectively.

[18] Using the criteria described in 14 CFR FAR 23 Appendix A *'Simplified design load criteria of for conventional single-engine airplane of 6,000 pounds or less maximum weight'.*

[19] Defence Standard 91-90/4 for Aviation Gasoline, produced by the UK MOD Aviation Fuels Committee and endorsed by the CAA.

missing. This sample also contained some phthalate esters[20] and other unidentified components.

Medical and pathological information

The pilot held a Class 2 medical certificate, valid until 22 July 2018, and records from his doctor indicated that he was in good health. A post-mortem of the pilot found no evidence of disease or toxicology that could have contributed to the event and concluded that the cause of death was burns sustained in the post-impact fire. The only injury not related to the effects of fire was a pelvic fracture and associated hip dislocation. The post-mortem report suggested that this could provide an explanation as to why the pilot was unable to extricate himself from the aircraft following the collision. However, the report also indicated that there was '*no macroscopically apparent soot staining*' in the pilot's airways and that the only '*slightly raised level*' of Carboxyhaemoglobin[21] in the pilot's blood '*supports that he died relatively quickly*' after the fire started.

The passenger suffered multiple impact injuries and burns to his left arm and leg. Following the accident, he was found about 21 m away from the aircraft wreckage. He later commented that, despite some vague flashbacks, he could not reliably recall anything between taxiing out to the runway and being found in the field afterwards.

Both occupants were wearing normal clothing which would not have offered protection against the post-impact fire.

LAA published guidance

Permit to Fly

Aircraft that do not meet the certification standards required to hold a CofA may operate in the UK under a national Permit to Fly[22,23] issued by the CAA. For aircraft operated under the LAA system, the CAA delegates responsibility to the LAA to oversee the airworthiness requirements and make recommendations for the issue of a Permit to Fly. The LAA, as the responsible sporting body, supports amateur build and restoration projects and maintenance of aircraft by its members, under the supervision of a suitably-approved LAA inspector. The LAA system places the responsibility for the airworthiness of the aircraft on the owner of the aircraft. On the Permit to Fly application form, an owner is required to sign the following declaration:

> *'I undertake to keep the aircraft in an airworthy condition and to operate it within the limitations of the Permit to Fly.'*

Footnote

[20] Phthalate esters, typically plasticisers, are substances added to plastics to increase their flexibility, transparency, durability and longevity. These are common contaminants found in Avgas, as they can be extracted from polymeric materials that are in contact with fuel, such as fuel hoses or plastic storage containers.

[21] Carboxyhaemoglobin is formed when carbon monoxide, a common product of combustion, is inhaled.

[22] Aircraft in this category are typically amateur-built, vintage, ex-military, microlights or gyroplanes without a valid Type Certificate.

[23] The Permit to Fly airworthiness regime allows aircraft to be built and/or maintained by an owner rather than a certified manufacturer or an approved maintenance organisation.

LAA Technical Leaflet TL 2.01 *'A guide to LAA aircraft ownership'*, dated 31 March 2014, provides a general summary of the responsibilities of owning, operating and maintaining a Permit to Fly aircraft. In the section titled *'Maintain the aircraft in an airworthy condition'* it states:

> *'The Permit to Fly requires that an aircraft be maintained in an airworthy condition…. LAA encourages owners to engage themselves fully with the maintenance of the aircraft, but alternatively this can be carried out on a commercial basis either using paid individuals or a maintenance organisation. Either way, by their very nature, Permit to Fly aircraft are somewhat unique and less well supported in airworthiness terms than their CofA cousins and need a greater degree of owner engagement, technical appreciation and vigilance to achieve an equivalent level of safety.'*

And*:*

> *'Note that if an LAA inspector carries out maintenance on behalf of an owner, he or she can do so but whether they are remunerated or not, this is not carried out under the LAA inspector's remit. The LAA inspector's remit only covers the inspection and certification role.'*

Rebuild and restoration of LAA aircraft

LAA Technical Leaflet TL 2.21 *'Rebuilding an aircraft under the LAA system'*, dated 3 January 2013, provides guidance for those undertaking an aircraft rebuild or restoration. It states:

> *'Between you and your inspector, you will need to write up worksheets describing the rebuild, to be signed up by your inspector as you go along. A copy of the worksheets are* [sic] *to be submitted on completion of the rebuild.'*

TL 2.21 describes the final inspection required upon completion of the rebuild and the process of applying to LAA Engineering for approval for flight testing. It states:

> *'When the rebuild of the aircraft is complete, a final inspection must be carried out. Normally this takes the form of an annual check as listed in the LAMS* [Light Aircraft Maintenance Schedule] *schedule or the LAA generic maintenance schedule (see TL 2.19). In addition, a symmetry check and in-depth rigging check is carried out and all systems calibrated and tested fuel flows checked and engine ground run.'*

And:

> *'A minimum period of five hours flying followed by a formal flight test is required before a full Permit to Fly can be issued.'*

LAA test flying

Testing pilots

LAA aircraft require test flying to qualify for initial issue of a Permit to Fly, and thereafter for renewal of a Permit to Fly. LAA Technical Leaflet TL 1.19, *'Initial test flying of LAA aircraft'*, dated 1 January 2008, is aimed at both owners and testing pilots, and outlines some of the safety and logistical considerations for the test flying process. It states:

> *'The choice of pilots for carrying out test flying is another issue where owners put forward their suggestion and LAA Engineering have to vet the proposal, based on the previous flying experience of the person put forward, currency on aeroplanes of the type concerned, or at least, similar or related types… The whole point of the test period is to get the aeroplane fine-tuned so it will handle properly in normal use later on.'*

The LAA produced a checklist[24] for testing pilots entitled *'LAA self-briefing tool for use pre first flight of newly completed aircraft'*. It includes items such as reading the relevant operating manual; awareness of the operating limitations; and awareness of special issues for the type, for example, handling issues. The tool also contains a prompt to consider applying '…*operating limitations over the standard ones eg reduced envelopes.*' At the time of this accident, no equivalent self-briefing tool existed for owners preparing for their first flight on type.

Testing pilots are not necessarily affiliated with the LAA, nor are there specific qualifications required.

Flight test schedule (FTS)

TL 1.19 also describes the LAA FTS, stating:

> *'The test form… looks for much more detailed evidence of satisfactory engine cooling and mixture settings than previously, calling for a five minute climb with readings taken every minute, and a more thorough investigation of the stall characteristics and speeds in each configuration.'*

The FTS form provides fields for testing pilots to record their observed values from a flight but, for a number of test items, there are no fields to record the expected values. These are further discussed in subsequent sections of this report.

The LAA's Technical Leaflet TL3.22 *'Flight Test Reports'*, dated January 2014, asks testing pilots to supply the completed FTS to the aircraft owner, who should then send a copy to LAA Engineering together with any other requested information. Due to the informal nature of their role, testing pilots are not expected to brief owners on their aircraft's FTS. However, the LAA subsequently commented that because a testing pilot is normally an

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Footnote

[24] http://www.lightaircraftassociation.co.uk/engineering/flight%20test%20self-brief.pdf [accessed 20 August 2018].

experienced enthusiast, nominated by an owner, then the two would normally take a keen interest in discussing the FTS, albeit informally.

Flying guidance for aircraft owners

There is no published LAA guidance for owners regarding the content or duration of their first flight on type, or on choosing an accompanying pilot. While the LAA is not responsible for pilot licensing or training, it does offer an optional Pilot Coaching Scheme which is designed to train LAA members in their aircraft and promote good standards of flying and airmanship. Following completion of an aircraft's test flying, TL 1.19 advises:

> *'…before flying the aircraft yourself, please remember that the LAA Pilot Coaching Scheme is there to get you up to speed with flying the aircraft and get the most out of it.'*

Furthermore, the LAA leaflet *'Ready to fly? - Pilot Coaching Scheme'* which was available at the time of the accident stated[25]:

> *'Statistics show that 20% of all homebuilt accidents happen during the first two flights and are usually caused by pilot error. The same is true of the first flight of any unfamiliar aircraft, whether it is homebuilt, vintage or microlight.*
>
> *The Pilot Coaching Scheme is here to provide tuition in the skills of learning to fly a new type of aircraft…*
>
> *Do not under-estimate the challenge which some of the types on the LAA register may represent…*
>
> *Look closely in the mirror, and ask yourself if you have sufficient experience to ensure that you can safely operate your new aircraft without any coaching…*
>
> *All coaches are current CAA and JAR-FCL certified Class Rating Instructors or Flight Instructors. They're also your trainer, confidante and mentor throughout the process of you learning to fly your aircraft.*
>
> *There is no reason to go through the process of learning to fly a new type alone or with a bunch of friends helping you guess how to do it.'*

It was not determined if G-BXON's pilot was aware of the LAA's Pilot Coaching Scheme. However, the LAA subsequently reported that the pilot had been sent a copy of TL 1.19. The LAA also commented that a survey in 2016 indicated that 95.8% of its members were aware of the pilot coaching scheme.

Footnote

[25] The LAA subsequently updated this leaflet and removed reference to the accident statistics, having advised that these were based on data from the USA rather than the UK.

G-BXON rebuild and restoration

Background information

G-BXON was constructed in 1955 by Auster Aircraft Ltd and was operated by the Army Air Corps until 1965, after which it fell into disuse. In 1997, the aircraft was purchased and placed on the UK civil register, with the intention of rebuilding it. However, before completion, one of the owners and a previous LAA inspector overseeing the rebuild, passed away and the aircraft was sold.

The accident pilot purchased G-BXON in March 2016 as a part-complete restoration project. The work already undertaken by the previous owners included structural work and complete fabric recovering and painting of the airframe and wings, and overhaul of the propeller. The engine was installed but had been inhibited. No worksheets were provided with the aircraft, so there was no record of the maintenance tasks which had been completed by the previous owners, and only limited historic technical records were provided.

Rebuild and Permit to Fly application process

The pilot decided to base G-BXON at Spanhoe Airfield, where he engaged an LAA inspector to assist with and oversee the completion of the rebuild. In May 2016 he notified LAA Engineering of his restoration project and the LAA confirmed that G-BXON was eligible to be restored and flown on an LAA Permit to Fly. The accompanying documentation indicated that the aircraft had last flown in August 1965, had accumulated 2,524 flight hours and its engine had accrued 252 operating hours since last overhaul.[26] The LAA requested that, upon completion of the rebuild, the pilot submit, among other items, worksheets detailing each stage of the strip down, inspection and rebuild, as well as final inspection checks, range of movements, duplicate inspections, engine ground runs etc. Also requested were details of any modifications, substitute materials and replacement parts, and copies of logbook certificates relating to engine rebuild, propeller overhaul, instrument calibration etc.

Over the following months the pilot undertook maintenance restoration tasks on the aircraft with the assistance of the LAA inspector, friends, and other aircraft owners based at Spanhoe. This included fitting the wings, conducting a 'top-end' overhaul of the engine and replacement of various engine and fuel system components.

In September 2016, the LAA inspector submitted, on behalf of the pilot, an application to the LAA for a Permit to Fly. It was accompanied by supporting worksheets listing 45 separate maintenance tasks, a list of modifications embodied on G-BXON and a '*Rebuild Final Inspection & Declaration of Design'*. All these documents were signed by the LAA inspector and dated 16 September 2016.

Between October 2016 and March 2017, in a series of email exchanges, the LAA requested the LAA inspector to clarify which of the maintenance tasks had been undertaken by the

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Footnote

[26] No historic airframe or engine logbooks were found for G-BXON and therefore the original source for this information was not established.

previous owners/inspector and to state clearly that he had re-inspected and certified those tasks. It also requested that he provide the results of fuel flow tests and engine ground runs, and properly documented duplicate inspections, which had not been noted on the original worksheets.

On 10 April 2017, the LAA inspector submitted a single supplementary worksheet to the LAA to address this request. This worksheet identified which of the tasks on the initial worksheets had been undertaken by the previous owners/inspector and were subsequently re-certified by him. It also included a statement that all remaining tasks had been carried out under his supervision.

Flight testing and permit issue

On 26 April 2017, following receipt of this information, the LAA issued a *'Certificate of clearance'* for flight testing to the pilot and LAA inspector/testing pilot. The accompanying correspondence stated:

> *'No particular number of hours or landings is required, just as long as it takes to re-establish reliable use, fix any defects, trim to fly in balance and wings level, and then complete the flight test schedule.'*

Between 28 April 2017 and 10 May 2017, the testing pilot undertook three flights in G-BXON totalling 1 hour 10 minutes flight time. He reported that the aircraft had performed well on the first flight and required no defect rectification, so he flew again the next day. On 11 May 2017, he conducted a 40-minute formal flight test (the section *'G-BXON flight test'* later in this report covers this aspect in more detail), after which the completed FTS was sent to the LAA along with a copy of G-BXON's logbook page showing a total of 1 hour 50 minutes flight time. The testing pilot conducted a further flight lasting 20 minutes on 14 May 2017 with the accident pilot as a passenger.

G-BXON's Permit to Fly was issued by the CAA on 2 June 2017 and this was sent to the pilot by the LAA, together with the Certificate of Validity and Operating Limitations on 6 June 2017.

Engine maintenance

Some of the other Spanhoe-based aircraft owners who had assisted the pilot in restoring G-BXON reported that it had been a challenging and lengthy process to return the engine to proper working order. A friend with automotive engine experience had assisted the pilot in stripping the engine and cleaning engine inhibiting oil from 'top-end' components, which included honing the cylinders and cleaning and lapping the valves. Separately, it was reported that the magneto was also replaced.

It was reported that by August 2016 the engine was running but misfiring, did not operate consistently across the full rpm range and the oil pressure readings were fluctuating. Between August 2016 and January 2017, a number of problems were experienced with the fuel injection pump. The quill drive within the pump snapped a number of times, necessitating replacement of the quill drive and, on at least one occasion, the fuel injection pump itself. The oil hoses to the fuel injection pump and the fuel injection nozzles were also replaced. The problem was subsequently determined to be related to a high oil pressure feed to the injection pump, caused by a seized OPRV. This was subsequently adjusted.

Further engine issues experienced were reported to have included ignition problems and a persistent misfire on the No.4 cylinder. Work to address these included replacement of the right ignition lead in March 2017 and cleaning/replacement of the spark plugs. By the end of March 2017, the engine was reported to have been running well and the aircraft was successfully taxied for the first time on 9 April 2017.

Anecdotal information from witnesses suggested that G-BXON's engine had been developing approximately 2,200 to 2,300 rpm at takeoff setting. The pilot was reportedly not satisfied with this and had discussed the engine performance with another AOP.9 owner, by way of comparison.

It was reported that the pilot had fitted new longer ignition leads on the day before the accident, in preparation for installing automotive spark plugs[27].

In a text message exchange following the pilot's first flight on the day preceding the accident, the other AOP.9 owner asked if the loom [ignition lead] had worked. The pilot's response indicated that the engine had operated much better with more power, that there had been no misfiring in flight and that the magneto drop check after landing was okay.

Documentation

Maintenance tasks undertaken during G-BXON's restoration were documented on a standard LAA worksheet template, which contained fields for recording up to seven maintenance tasks. Against each task there were columns for the engineer/pilot and LAA inspector signatures. The worksheet template also contained a Permit Maintenance Release to be signed by the inspector which stated:

> *'The work recorded above has been completed to my satisfaction and in that respect the aircraft is considered fit for flight.'*

The worksheets submitted to the LAA in support of G-BXON's Permit to Fly application contained a brief outline of the maintenance tasks performed during rebuild. The tasks were not individually dated but had been collectively grouped together and retrospectively documented and dated 16 September 2016.

The original worksheets submitted in September 2016 described a number of engine-related maintenance tasks including overhaul and reinstallation of the mechanical and fuel injection pumps, engine top overhaul and reassembly, check of fuel flow to the injector pump and

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Footnote

[27] The pilot had contacted the LAA to enquire about the possibility of applying for a modification to convert to automotive spark plugs, due to the difficulty in obtaining the correct aerospace spark plugs for G-BXON's engine. However, he had not made the application before the accident occurred.

engine ground runs. The results of the fuel flow checks[28] and engine ground runs[29] were not originally recorded but were subsequently included on the single supplementary worksheet dated 10 April 2017.

Other tasks documented on the original worksheets included connection and testing of the pitot/static system, calibration and fitment of the altimeter and ASI, and propeller overhaul by a specialist overhaul company. The results of the ASI and altimeter calibration were not recorded.

All of the worksheets had been completed by the LAA inspector. He signed his initials against each task in the *'Inspector'* column and signed the Permit Maintenance Release statement at the bottom of each worksheet. The pilot's signature only appeared in the *'Engineer'* column against one task on the 10 April 2017 worksheet; this related to the duplicate inspection of the flight and engine controls, which required two signatures.

The *'Rebuild final Inspection and declaration of design'* form submitted with the worksheets described the extent of the work performed on the engine as *'Top overhaul. Fuel pumps overhauled. Injectors tested. Injector pump overhauled.'* The LAA inspector had signed both the fields for the *'builder'* and the *'inspector'*.

The engine-related work undertaken between September 2016 and April 2017 did not appear to have been recorded on worksheets.

The LAA inspector was vague in his recollections of exactly what work had been undertaken on G-BXON and when. He commented that he looked after many aircraft and could not recall the details of work done on each of them and that he did not keep copies of worksheets or separate records. He also advised that, while he might inspect individual maintenance tasks on different days, his preferred approach was to sign them off all together. Furthermore, he stated that he is only able to verify the condition of an aircraft at the time of his inspection, and that owners may change something subsequently.

Other than the worksheets submitted to the LAA in support of the Permit to Fly application, no other technical records were found which related to G-BXON's rebuild.

No receipts were found among the pilot's documentation, so it was not possible to determine the provenance of replacement parts used during the rebuild. An invoice from the maintenance organisation dated 22 February 2017 referenced installation of a new radio and wiring, investigating an engine problem, timing and installing a new fuel pump.

Footnote

[28] Noted on the worksheet as 32 gallons per hour under gravity and 58 gallons per hour with both mechanical fuel pumps operating, but it was not determined how these flow rates were measured. The AOP.9 maintenance manual calls for minimum flow rates to the mechanical fuel pumps under gravity, with the booster pump off and on, of 23 and 50 gallons per hour respectively. It also specifies a minimum flow rate between the mechanical fuel pumps and the fuel injector pump of 2.5 pints per minute (18.75 gallons per hour), This corresponds to the maximum expected fuel delivery rate described in the *'Amal Operation, maintenance and overhaul instructions for Fuel Pump type 240/8'*.

[29] The [maximum] static rpm was noted as 2,200 rpm.

G-BXON's logbook[30] did not contain any summary of the maintenance work carried out during the rebuild or cross-reference to the worksheets. The flights conducted between 28 April and 11 May 2017 were recorded, together with the flight conducted by the pilot on the day prior to the accident. The flight on 14 May 2017 was not recorded in the logbook.

Weight and balance

The AOP.9 Pilot's Notes[31] specifies two maximum weights. The normal maximum weight of 2,350 lb applies to all forms of flying. The overload maximum weight of 2,550 lb limits the aircraft to gentle manoeuvres only.

From information provided by witnesses, G-BXON's weight for the accident flight was calculated to be around 2,258 lbs and the CG was within specified limits.

Aircraft operating information

Pilot's Notes guidance

The Auster AOP.9 Pilot's Notes explains how to depart using takeoff flap as follows:

> *'…lower the flaps to take-off and open up to full throttle against the brakes… At full load the aircraft can be pulled off at approximately 45 knots. To clear obstacles climb at 50 knots, which will give the steepest angle of climb though not necessarily the greatest rate of climb. When clear of obstacles increase speed to 55 knots and raise the flap in stages by manipulating the selector lever… The speed should be allowed to increase slowly to 65 knots (normal climbing speed) and the last few degrees of flap pumped up with the hand pump.'*

It details the AOP.9's zero flap climb performance as follows:

> *'Climb at full throttle and 65 knots… The initial rate of climb is about 800 feet per minute…*

The '*Stalling'* section states:

> *'There is no warning of the stall in any configuration. Pilots should bear this in mind when manoeuvring near the ground at low airspeed… Shortly before the stall is reached the aircraft wallows slightly and then, at the stall, the nose will drop probably accompanied by either wing… Recovery is immediate on releasing the backward pressure on the control column, the height loss being about 200 feet. If the control column is held back after the aircraft has stalled, a spiral or spin may develop.'*

Footnote

[30] The initial entry in G-BXON's logbook of total flight time carried forward had been mistakenly entered as 252 hours. This figure was in fact the operating hours of the engine since overhaul. The total flight time carried forward was 2,524 hours.

[31] The Pilot's Notes document was produced under direction of the Air Ministry as the operating manual for the AOP.9.

Pilot interviews – AOP.9 handling characteristics

The AAIB interviewed a number of AOP.9 instructors and display pilots (military and non-military), and civilian AOP.9 owners.

The AOP.9 was widely described as an operationally challenging aircraft which should especially be flown by 'feel'. One pilot commented that many of its handling peculiarities are not included in the original Pilot's Notes, and that there had been no formal mechanism in the military for subsequently documenting them. Consequently, pilots have tended to share them anecdotally.

It was also mentioned that achieving the correct angle of attack[32] (AOA) during takeoff is important in the AOP.9. If a pilot under-rotates[33] the aircraft, its mainwheels might dig in to soft ground, thus inhibiting acceleration. Conversely, with over-rotation[34], the aircraft can 'stagnate', and the airspeed may not increase until the AOA is reduced.

The AOP.9 was viewed in general as a low-performing aircraft type. Some pilots explained that, if the aircraft does not initially climb well during takeoff on a hot day, they might choose to lower the nose so that the airspeed can increase whilst still in ground effect[35].

Most pilots expressed a preference for flying faster than the published speeds and one highlighted the potential for stalling the AOP.9 during takeoff, particularly due to the absence of any stall warning. One pilot stated that he would climb at an airspeed well above 60 KIAS when departing using takeoff flaps on a hot day.

The AOP.9's stalling characteristics were widely discussed. One pilot stated that, when flight testing an AOP.9, he accepts a maximum deviation of 3 or 4 KIAS from the published stall speeds. A main concern was the aircraft's tendency to drop a wing during the stall. If a pilot reacts to this using opposite aileron, a spin may develop. Aileron droop and high engine power settings exacerbate the wing drop.

CAA advice on stall and spin awareness

The CAA's '*Handling Sense Leaflet 2: Stall/Spin Awareness*' states:

> *'At least one of the symptoms of the fully developed stall MUST happen before the aeroplane can spin… these are: wing drop (undemanded roll), nose drop, inability to maintain level flight, and buffet. It is clearly inappropriate to wait for this confirmation before recovery.*
>
> *What signs will be evident to help us avoid a full stall and possible spin? …We can draw on the classic list of signs of the approaching stall: increasingly high*

Footnote

[32] AOA is the angle between the oncoming air and a reference line on the aeroplane or wing.

[33] Under-rotate: Too little back pressure applied to the control column during lift off.

[34] Over-rotate: Too much back pressure applied to the control column during lift off.

[35] Ground effect: the increased lift and decreased drag generated by an aeroplane's wings when it is close to the ground.

> *nose attitude (in level flight), reducing control effectiveness, low and decreasing airspeed, and the onset of buffet. These may be augmented by a mechanical stall warning device…*
>
> *One of the most critical phases of flight is just after take-off or when going around from an approach to land. At low level, at relatively low speed and with a high nose attitude, an engine failure will lead to a rapid deceleration and increasing angle of attack…*
>
> *To safely avoid the stall and spin: be alert and be prepared; practice regularly at safe altitude and keep your handling skills current; read and understand the contents of the Flight Manual/POH for your aeroplane; seek advice from a Flight Instructor if you are unsure of any techniques; be ready to apply immediate recovery action whenever you feel the aeroplane is not responding correctly. Now you have time to regain a safe flight path and analyse what happened. If prompt action is taken during the approaching stall, the attitude change required is small and height loss (if any) should be minimal.'*

G-BXON flight test

Performance results and comparison

Table 1 details some of the results from G-BXON's formal flight test on 11 May 2017. Also presented are the published performance figures from the Pilot's Notes and the AOP.9 Flight Reference Cards[36] together with seven flight test results from other AOP.9s, all of which had the same engine/propeller combination as G-BXON. One aircraft was included twice because it was tested at different times under both the LAA and CAA regimes.

The other AOP.9s mainly involved aircraft tested by testing pilots for an initial LAA Permit to Fly. This flight test information was collated by the LAA after the accident in order for them to compare G-BXON with other examples of the type.

Loading

The LAA FTS requires an aircraft to depart at its maximum takeoff weight or maximum landing weight if it is lower. The testing pilot loaded G-BXON to 2,500 lb, which was 150 lb higher than its normal maximum weight and 50 lb less than the overload maximum weight. He stated that using the higher weight was a good practice he had learned during previous CofA aircraft testing.

Most of the other AOP.9s which were analysed had takeoff weights which were within 100 lb of the normal maximum weight. Two of the other AOP.9s had takeoff weights above the normal maximum weight. The highest of these was 2,507 lb, and that aircraft achieved a test ROC of 710 fpm.

Footnote

[36] The AOP.9 Flight Reference Cards are a set of procedures prepared by the MOD Handling Squadron.

	Published figures*	Other AOP.9 flight tests - Average (Range)	G-BXON flight test
Climb performance – ROC at 65 KIAS	800 fpm**	667 (633-720) fpm	450 fpm
Climb performance – rpm at 65 KIAS	Not specified	2,320 (2,240-2,350) rpm	2,350 rpm
Stall speed, zero flap (V_{S1}(f0))	48 KIAS***	48 (46-48) KIAS	54 KIAS
Stall speed, takeoff flap (V_{s1}(t/o))	42 KIAS***	42 (42-45) KIAS	50 KIAS
Stall speed, landing flap (V_S0)	40 KIAS***	42 (40-42) KIAS	46 KIAS
Max static rpm	2,200-2,270 rpm	2,260 (2,200-2,350) rpm	2,200 rpm

* Figures from the AOP.9 Pilot's Notes, except max static rpm, which is quoted from the AOP.9 Flight Reference Cards.

** The Pilot's Notes state that the initial rate of climb is '*about 800 fpm*'.

*** The Pilot's Notes state that these are *'approximate stalling speeds in knots, engine off'*.

Table 1

G-BXON's flight test performance results compared with other AOP.9s and the Pilot's Notes values

Climb performance

The climb performance test assesses the relationship between achieved ROC and engine rpm. There are fields on the FTS for the testing pilot to record the observed ROC, but not the expected value.

The guidance in the *'Climb'* section of the FTS states:

> *'Important notes: Sustained 5 minute climb is normally required to be carried out to establish adequacy of cooling, proper functioning at altitude and to provide sufficient data points to calculate a reliable rate of climb figure. However, where the rate of climb exceeds 1500 ft/min, or an aircraft with a Cirrus Minor or a Gipsy Major engine[37] is fitted, then a 3 minute climb will be accepted. Incomplete climbs due to airspace cloud or other similar reasons will not be accepted.'*

G-BXON underwent a three-minute climb. The LAA stated that had it been unhappy with the shorter duration of climb on G-BXON's FTS, it would have requested a retest.

Table 1 shows that G-BXON's achieved climb rpm was similar to the other AOP.9s, but its average ROC (450 fpm) was substantially lower.

Footnote

[37] While G-BXON's Cirrus Bombardier engine was not listed on the FTS as an engine to which this alleviation applies, the LAA subsequently stated that it would have granted the alleviation if the applicant had requested it.

The DA at aerodrome level for G-BXON's flight test was approximately 1,240 ft. The corresponding DAs for the other AOP.9s[38] ranged from around 170 to 1,000 ft. The aircraft which was tested with an aerodrome DA of 880 ft produced a test ROC of 720 fpm.

After the accident, the testing pilot commented that, based on his experience at the time of the flight test, G-BXON's ROC had seemed acceptable to him. The LAA stated that its post-accident comparison of AOP.9 performance highlighted G-BXON's ROC as being '*somewhat down*' even considering the higher maximum weight that was used.

Stalling

The LAA stated that the stall speeds recorded on an aircraft's FTS are obtained with the engine power at idle. This test is normally performed in level flight. The Pilot's Notes provides an example of the effect of engine power on the stall speed, as related to typical approach conditions. The example indicates that, with full flap and 1,700 rpm, the stall speed is approximately 38 KIAS; 2 KIAS lower than the power off stall speed.

FTS guidance for stalling states:

> *'Required limits: Stall warning 4 KIAS to 12 KIAS… above measured stall speed.'*

On the FTS form against *'Stall warning (knots/mph IAS)'*, the testing pilot entered '*N/A*' [not applicable] and, against *'Type of stall warning (e.g. horn, lamp, natural buffet etc.)'* he noted '*NONE'*. Against '*Other characteristics (e.g. buffet prior to stall)'*, the testing pilot noted '*NONE'*. Against '*sequence of nose and wing drop (if any)* [at the stall]' the testing pilot entered '*NOSE ONLY*' for all three configurations.

There is no place on the FTS form to record the expected stall speeds and the testing pilot stated that he did not study them as part of the flight testing process. Furthermore, as apparent from a photo taken during restoration, G-BXON's ASI was of a type that did not have extra markings depicting airspeed limitations, for example, stall speeds.

From the LAA's post-accident comparison of AOP.9 performance, both the LAA and testing pilot separately commented that, notwithstanding the higher weight, the stall speeds recorded during G-BXON's flight test (Table 1) were relatively high. The LAA questioned whether an improperly calibrated ASI could have contributed to this. The testing pilot suggested that there could have been a blockage in the static system. These items could not be tested after the accident due to the extensive damage.

Maximum static rpm

The FTS requires that, with a wide-open throttle, the engine must not overspeed when the aircraft is static on the ground. The FTS form provides fields to copy the maximum allowable rpm limitation from an aircraft's flight manual, and the maximum achieved static rpm as measured during the flight test.

Footnote

[38] DA information was available for all but two of the other FTSs.

In the maximum allowable rpm field, the testing pilot noted *'2,600 / 2,400'*. In the Pilot's Notes, 2,600 rpm corresponds with the '*takeoff and operational necessity*' figure, 2,400 rpm corresponds with the '*intermediate (1 hour limit)*' value and '*maximum continuous*' is stated as 2,300 rpm.

As can be seen from Table 1, G-BXON's achieved maximum static rpm of 2,200 rpm was within the range specified by the AOP.9 Flight Reference Cards. G-BXON's was the joint lowest maximum static rpm value achieved by those aircraft analysed. One other aircraft achieved the same value but, unlike G-BXON, that specific aircraft had flight test performance figures (Table 1) which were otherwise closely aligned with the Pilot's Notes figures.

The testing pilot explained that he normally used 2,000 rpm as the lowest acceptable limit for an AOP.9 in this test. The LAA stated that it would have queried a value of below 2,150 rpm.

Fast cruise condition in level flight

The fast cruise condition test determines the maximum achieved engine rpm[39] in level flight and the corresponding airspeed (V_h). The Pilot's Notes states values of 2,300 rpm and 90 KIAS, and G-BXON demonstrated values of 2,500 rpm and 89 KIAS.

Performance - general discussion

When advised of G-BXON's relative performance after the accident, the testing pilot suggested that its reasonable fast cruise performance and low climb performance with what he described as being reasonable engine rpm values, may indicate that its propeller was coarse pitched[40,41].

It is not known if the accident pilot had looked in detail at G-BXON's FTS or was aware of the aircraft's deviations from the published performance figures.

Comparison with a CAA flight test report

Although most of the AOP.9s in Table 1 had been test-flown under the LAA regime, one of those aircraft had also been previously subject to CAA flight testing for the purposes of granting a CAA Permit to Fly. The CAA's flight test department has since been dissolved and flight testing has been delegated to suitably approved organisations including the LAA. Nevertheless, the CAA test process for that other AOP.9 served as a comparison to that undergone by G-BXON.

Footnote

[39] With the power lever fully forward in level flight, at an altitude below 2,000 ft.

[40] Coarse pitch: Large angle between the propeller blade chord and the plane of the propeller disc, producing high forward speed for a given rotational speed.

[41] In common with most other AOP.9s on the UK civil register, G-BXON was equipped with a Bombardier Cirrus 20801 engine and a Fairey Reed A66960/X8 fixed-pitch propeller. Two UK AOP.9s are fitted with a similar Fairey Reed A66960/X1 fixed-pitch propeller. On Fairey Reed propellers a different 'X' number on the model number generally denotes a change in pitch, but a higher 'X' number may refer to a higher (coarser) or a lower (finer) pitch value. The pitch of the X1 variant is 4.43 ft but the pitch for the X8 variant was not determined and could not be measured on G-BXON's propeller due to accident damage.

The CAA flight test was carried out by a qualified Test Pilot[42] who used the same check flight schedule (CFS[43]) as was used for flight testing prior to the issue of a CofA. The Test Pilot compared the aircraft's measured results with expected values from the Pilot's Notes in order to be able to recommend to the CAA that the aircraft be granted a Permit to Fly.

The aircraft in that case was loaded to its normal maximum weight. Its climb performance was tested over a 5-minute duration.

This CFS included space for the Test Pilot to record an aircraft's expected ROC and stall speed values from the relevant operating manual. The CFS also specified permitted deviations from these, stating that:

> *'aircraft with climb shortfalls of more than 70 fpm should not be accepted.'*

And:

> *'Required limits: …Stall speed +3 to -5 kts/mph relative to scheduled stall speed…'*

The Test Pilot recorded that that aircraft demonstrated a noticeable wing drop in all three configurations and noted:

> *'The wing drop would not allow the aircraft to be certified[44] and is a known potential deficiency of this type… The characteristic was repeatedly demonstrated to one of the owners and the other owner was fully briefed on completion of the flight test.'*

Information provided by the LAA

G-BXON worksheets

With respect to worksheets submitted in support of Permit to Fly applications, LAA Engineering commented that worksheets can differ significantly between applicants in terms of content, style and detail. Of the range it receives, it considered that the worksheets for G-BXON contained less than the average level of detail and further worksheets had to be requested before they were accepted. The LAA considered that the brevity of the worksheets may have been due in part to the fact that G-BXON had changed hands part way through the rebuild project, and the absence of worksheets from the previous owners/inspector.

G-BXON test flying

When asked why it did not stipulate a minimum amount of test flying for G-BXON, LAA Engineering commented that homebuilt aircraft normally require a minimum of five hours

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Footnote

[42] CAA Check (Test) Flights were conducted either by the CAA's own experimental test pilots or by pilots specifically briefed and approved by the department following a check flight.

[43] The LAA reported that it developed its FTS from the CAA's CFS, by adapting it to the LAA environment.

[44] The certification referred to is the granting of a CofA.

test flying because they have not flown before, and because there is more variability between examples. However, for factory-built aircraft with published technical documentation, like the AOP.9, a reduced number of hours test flying is often deemed acceptable. The LAA stated that, because G-BXON was unmodified from its original design and the testing pilot was experienced on type, no minimum testing time was stipulated in this case. LAA Engineering indicated that, if it had been aware that defects requiring ongoing rectification and component replacement had been experienced on G-BXON's engine until shortly before the test flying commenced, it would have specified a minimum number of hours to be flown.

LAA test flying – performance

The LAA advised that there is an absence of performance data for some aircraft types and that there can be variation in modification state between individual aircraft of the same type in their fleet (eg different propeller types). As a consequence, assessment of an aircraft's performance at initial Permit to Fly application tends to be based on experience with similar examples and adequacy for the intended role, rather than on closely matching available data for the type.

For each subsequent flight test for a Permit to Fly renewal, the aircraft's climb performance is compared against its values from previous years to identify any trends or anomalies.

Analysis

Introduction

G-BXON departed controlled flight during its takeoff climb from Spanhoe. The investigation has considered factors which may have contributed to this including aircraft and engine performance, pilot handling, and the possibility of a technical failure.

Engine performance

Examination of the engine, propeller and ground marks indicated that the engine was operating with some power at the point of impact. It was not possible to ascertain the position of the throttle or throttle control due to the damage caused by the impact and post-impact fire. While there were a number of distinct propeller strikes on the ground and in the surrounding crop, the dynamic nature of the impact sequence, the orientation of the aircraft at impact and the absence of ground speed information for the accident flight, meant that it was not possible to calculate a meaningful range of engine rpm.

Anecdotal information from witnesses suggested that G-BXON's engine had been developing approximately 2,200 – 2,300 rpm at takeoff setting and the pilot had discussed this with another AOP.9 owner as he was reportedly not satisfied with the engine performance. Pilot B commented that the pilot had specifically asked him to monitor the takeoff rpm on the previous day's flight. He recalled that it was approximately 2,300 rpm, and this was supported by audio analysis of the video recording of that takeoff. The pilot indicated in a text message that the engine performance during the previous day's flight, had been much better than before. Engine speeds recorded during the flight test for the

Permit to Fly indicated that the maximum static engine rpm was 2,200 rpm. The engine performance during climb (2,350 rpm) was average, but the associated ROC (450 fpm) was substantially lower (Table 1).

A detailed engine strip examination identified a number of anomalies. These included poor compression on three out of the four cylinders, which would have limited the engine's ability to develop full power. This was predominantly due to leakage at the exhaust valves, however the presence of oil in some of the cylinders indicates that the piston rings and/or piston may not have been providing adequate sealing. It was possible that the new piston rings had not fully run in to achieve a good gas seal. Additionally, five out of the eight spark plugs exhibited weak and/or intermittent sparks when tested and the magneto timing was not set correctly.

When tested after the accident, the mechanical fuel pumps did not deliver fuel at the required fuel flow rate and examination revealed anomalies with the internal diaphragm, which would have prevented the pumps from functioning correctly. However, it is likely that in the installed condition, gravity-fed fuel from the high wings tanks and the presence of the electrically-driven booster pump in the fuel collector cell, may have, at least partially, compensated for the poor performance of the mechanical fuel pumps.

The timing of the fuel injection pump, which had been replaced a number of times, was found to be incorrectly set and did not coincide with the induction period of the engine. Although fuel would have been delivered to the cylinders it would not have been delivered at the point in the engine cycle to produce optimum engine performance. The fuel injection pump did not display any obvious impact damage and it was considered likely that the incorrect timing could have occurred during installation. The fuel injection pump operated normally when tested but was out of calibration in that it was running lean. Additionally, during testing, leaks were observed from two of the fuel injection nozzles which may also have been present prior to the accident.

Due to the extent of accident damage, it was only possible to examine and test individual components from the aircraft's fuel system; it was not possible to assess whether collectively, the fuel system with its various fuel pumps, could adequately meet the fuel demands of the aircraft's engine. Nor was it possible to make a comparison with the results of the fuel flow checks previously recorded on the supplementary worksheet.

The anomalies identified during the engine examination could account for less-than-ideal engine performance during the accident flight. In contrast, the testing pilot, who was very familiar with the aircraft and its engine in his capacity as its LAA inspector, reported being satisfied with the aircraft and engine performance during the initial test flying and formal flight test. This indicates that either engine performance issues were not present, or not identified, during the test flying. Furthermore, it was reported that additional work was undertaken on the engine between the test flight and the accident flight, which may have had an effect on engine performance.

Notwithstanding these observations, reduced engine performance in isolation would not have accounted for the departure from controlled flight during the accident flight. But its effects, which may have been insidious, could have contributed to the less-than-ideal aircraft performance or served as a distraction to the pilot.

Fuel

Analysis of the fuel used to refuel G-BXON indicated low levels of contamination by a substance consistent with automotive gasoline. It was considered that the jerry cans in which the fuel was stored, may previously have been used to store automotive gasoline. The sample from the fuel injection line was broadly similar to the jerry can sample. It also exhibited particulate contamination and trace contamination including plasticisers. This may have been as a result of the fuel coming into contact with rubber fuel hoses, or plastic storage containers.

An aircraft engine is designed to operate most efficiently on a specific type of fuel conforming to pre-determined specifications. The use of fuel that deviates from these specifications can reduce operating efficiency and, under some conditions, lead to engine failure. It was not possible to determine whether the presence of low levels of contamination in the fuel would have adversely affected engine performance in this case.

Technical failure

The left aileron control rod was found to have separated at the forward end-fitting. Metallurgical analysis determined that all four of the failed attachment rivets had been carrying load at the time of failure, although two also exhibited evidence of pre-existing intergranular corrosion and stress corrosion cracking. At least one third of the fracture surface on the outboard rivet was attributed to a pre-existing intergranular crack, which would have reduced its load-carrying capability. The inboard rivet may also have been subject to intergranular cracking, but mechanical damage on the fracture surface prevented a definitive assessment.

The investigation considered whether the left aileron control rod could have detached in flight and contributed to the departure from controlled flight. The strength of the aileron control rod riveted joint was calculated to be sufficiently strong to carry the maximum expected normal flight loads, even if pre-existing cracking had led to complete failure of two out of the four rivets.

However, the critical load case for the rivets was the maximum pilot effort case and, given the potential for reduced load-carrying capability in two of the rivets, if large forces had been applied to the control stick, the aileron control rod riveted joint may not have been sufficiently strong to withstand such loads. While there was no evidence of a control restriction which might have necessitated application of such loads, it was not possible to definitively rule out the presence of a restriction as any evidence may have been destroyed in the post-impact fire. This scenario was not consistent with the eye-witness description of the takeoff and subsequent departure from controlled flight and is therefore considered unlikely. However, the possibility that the control rod failed due to the pilot applying large forces to the control stick during attempts to recover to controlled flight could not be ruled out.

Examination of the wreckage indicated that the aileron control rod had most likely detached due to impact loads being transmitted, via the aileron mounting structure, to the aileron hinge and control rod when the left wingtip struck the ground.

In addition, examination of the wreckage, although limited due to the extent of fire damage, did not identify any other technical issues which may have contributed to the accident, but there were parts of the primary flight controls, some systems and flight instruments which could not be examined.

LAA flight testing process

Notwithstanding some variation in DA and aircraft weight, G-BXON's FTS showed that its stall speed values were substantially higher, and its ROC substantially lower, than other AOP.9s[45] and the Pilot's Notes figures. Its climb performance was tested over three minutes instead of five minutes, despite it not automatically qualifying for that alleviation. Nevertheless, G-BXON's FTS was reviewed and accepted by the LAA on the basis that it considered that the results did not indicate that the aircraft was unairworthy.

The CAA no longer performs flight testing. However a CAA Permit to Fly flight test for one of the other AOP.9s provided a comparison to the process used for G-BXON. In that example, the CAA testing was carried out by a qualified Test Pilot using a CFS form which had been designed for CofA flight testing. The form allowed the Test Pilot to record expected values, and it also specified permitted deviations from those. The Test Pilot analysed the aircraft's results and made a recommendation for its permit to be issued. In that case, the Test Pilot demonstrated and briefed the owners on their aircraft's wing drop tendency in the stall. Given the less formal nature of the LAA testing process, the LAA stated that whilst an owner and testing pilot would normally discuss a flight test informally, there was no formal mechanism for testing pilots to research expected performance results and compare those with achieved values, nor to brief owners on their aircraft's FTS results. Testing pilots are expected to supply the aircraft's FTS to its owner, who would then be responsible for sending a copy (along with any other requested information) to LAA engineering for review.

Whilst the LAA had a process for continued monitoring an aircraft's climb performance at each permit renewal, there was no formal process, during the initial permit application, to compare achieved performance results with expected values. Instead, it relied on its knowledge of the aircraft type.

Since this accident, the LAA has created a database of flight test performance results for all types and introduced an additional process to compare an aircraft's performance results at initial permit application with others of the same type. In the case of factory-built aircraft, the scheduled performance figures, when available, will also form part of this consideration.

G-BXON's testing pilot recorded on the FTS that no stall warning had been demonstrated and thus he noted '*N/A*' for the stall warning speed. The stall test in the FTS requires that stall warning occurs between 4 KIAS to 12 KIAS above the measured stall speed. However,

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Footnote

[45] All of which had the same engine/propeller combination.

the FTS does not make it clear what stall warning, if any, a subject aircraft is required to have, and so the form could be misleading in this respect. The LAA has stated that this requirement refers specifically to artificial stall warning devices. It has clarified the wording on the FTS to emphasise that it relates only to aircraft with such devices, and to reflect that some LAA aircraft may not be so equipped.

Furthermore, the LAA has undertaken to write to owners with any safety related observations on an aircraft's submitted flight test results. This will include highlighting the absence of any stall warning, particularly when the reported characteristics deviate markedly from those normally expected, but which have nevertheless been deemed acceptable by the LAA for permit issue.

G-BXON performance

It was not determined what caused the high stall speed values and low ROC demonstrated during G-BXON's flight test. Due to the extent of the damage, it was not possible to test the ASI calibration, or determine if any aspects of G-BXON's configuration could have contributed to these results.

There was no recorded data for the accident flight. However, information was derived from the video of the pilot's takeoff on the day before and, in the absence of evidence to the contrary, it is assumed that he flew G-BXON during the accident flight in a similar manner.

The AOP.9 Pilot's Notes indicate that, with takeoff flaps set, the power off stall speed is approximately 42 KIAS, and the aircraft can be 'pulled off' during departure at around 45 KIAS. However, G-BXON's demonstrated V_{S1}(t/o) of 50 KIAS was 8 KIAS higher than the Pilot's Notes value and 5 KIAS higher than the speed at which the Pilot's Notes state an AOP.9 can become airborne during departure. The application of engine power may lower an aircraft's stall speed but the power off V_S values provide a stall speed reference for pilots. Furthermore, the example provided in the Pilot's Notes relating to the stall speed under typical approach conditions shows that a power setting of 1,700 rpm reduces V_{S0} by around only 2 KIAS.

During the flight on the previous day, with takeoff flap set, the pilot elected to climb at 60 KIAS and video analysis showed that, for lift off and climb, G-BXON achieved a true airspeed of between 56 and 60 kt. Notwithstanding a slight difference[46] between indicated and true airspeed, this would have provided a minimum margin of around 6 kt above G-BXON's demonstrated power off stall speed in this configuration.

The experienced AOP.9 pilots that were interviewed indicated that, particularly due to its lack of stall warning, they habitually fly the aircraft at higher speeds than those published. Some said they would climb at an airspeed of more than 60 KIAS when departing using takeoff flap on a hot day, and this would give a margin of more than 18 kt against the Pilot's Notes expected V_{S1}(t/o) of 42 KIAS.

Footnote

[46] Under normal circumstances, the difference would be insignificant at low altitudes.

Those interviewed highlighted the AOP.9 as being generically low-performing. For G-BXON, this low performance may have been further exacerbated by an underperforming engine. A ROC of 450 fpm was recorded on the FTS and 500 fpm was achieved on the previous day's flight, both figures being substantially less than the Pilot's Notes value. High density altitude conditions present over the weekend of the accident would have affected the aircraft's performance.

As someone reported to 'fly by the numbers', and possibly less by 'feel', if the accident pilot had chosen a target climb airspeed using the Pilot's Notes but was unaware of G-BXON's higher indicated stall speeds, poor ROC, and the issues surrounding AOP.9 handling, then it is likely that he would have been flying closer to the stall regime than he realised. During the accident departure, if the pilot had over-rotated the aircraft without having built up sufficient airspeed, or if he had perceived the ROC to be low and then eased back on the control column to increase it, then the airspeed may have reduced enough for the aircraft to stall. During the takeoff on the previous day, the pilot asked Pilot B to monitor the engine rpm. On the accident flight, the pilot may have conducted the additional monitoring of the engine rpm himself and this could have provided a distraction to his monitoring of the airspeed.

It is not known if the pilot was aware of the AOP.9's stalling characteristics and the absence of stall warning features on G-BXON. The type is prone to dropping a wing during the stall and, if the back pressure on the control column is not promptly released, then a spin may develop. The presence of drooped ailerons and the high power setting used for takeoff further increase the likelihood of a wing drop in the stall. The Pilot's Notes state that stall recovery will involve a height loss of around 200 ft, so particular care should be taken whenever near to the ground at low airspeeds. An instinctive, rather than deliberate, reaction to the associated wing drop and loss of height could involve aileron and nose-up elevator inputs. This would exacerbate any tendency to spin from which, in this instance, there was insufficient height to recover.

The eyewitness description of G-BXON's behaviour during the accident is consistent with the AOP.9 Pilot's Notes description of a stall with an associated wing drop.

Flight preparation

At the time of the accident, the LAA noted on its website that, based on USA data, 20% of homebuilt aircraft accidents occur during the first two flights, and that the same is true of the first flight of any unfamiliar aircraft, whether it is a homebuilt, vintage, or microlight.

The LAA's Pilot Coaching Scheme assists owners in familiarisation with their aircraft but it is not known whether the accident pilot was aware of this. The related documentation reminds pilots not to underestimate the challenges posed by some aircraft types and to recognise that, even for experienced pilots, tuition may be appropriate when first flying a new type.

The investigation did not determine how much preparation the pilot had done for flying the AOP.9. Prior to his first flight on this type, he had performed two flights, in the preceding

90 days on other types. He was reportedly eager to fly his newly-restored aircraft and the agreement to fly with Pilot B occurred a short time before they departed on their 10-minute flight together the day before the accident. Therefore, there would have been limited time for a briefing to take place. On the accident flight, he was accompanied by a passenger who had no pilot qualifications. Both days were warm.

The LAA already promulgates a self-briefing tool for testing pilots and, since the accident, it has produced similar guidance for owners on how to prepare for flying a new type: it has published two magazine articles on the topic and, in December 2018, produced a Technical Leaflet (TL 2.30 '*Converting to a new type*') for use as a preparation tool, similar to the one provided for testing pilots. Subjects addressed include: researching a new aircraft type (eg by reviewing its operating manual, operating limitations and handling peculiarities); the planning and content of a first flight on type to become familiar with the aircraft alongside a suitably experienced pilot; the importance of beneficial weather conditions (eg consideration of density altitude); and consideration of the desirability of carrying passengers both in terms of aircraft weight, and pilot recency and experience on type.

It is likely that the pilot was not prepared for the aircraft to stall after takeoff, and it is not known whether he was aware of G-BXON's higher stall speeds. The absence of any stall warning and the wing dropping would have added to his surprise. Therefore, he is unlikely to have been prepared to take immediate and appropriate recovery action.

The CAA's advice on stall and spin awareness reminds pilots to be prepared, particularly whilst flying at low level, to recognise both the 'approaching' and 'full' stall indicators, and to take immediate recovery action if the aircraft is not performing as expected. This prioritises the recovery of a safe flight path.

Survivability

The aircraft suffered extensive damage during the impact, however the steel tubular structure of the fuselage maintained a substantial 'survivable space'. Although the impact forces were survivable, the post-mortem concluded that the pilot died from burns sustained in the post-impact fire.

The post-mortem report suggested that an injury sustained in the impact may have impeded his ability to exit the aircraft. Additionally, the seat harness QRF found near the left seat may have suffered deformation during the accident and did not release when subsequently operated by the AAIB. Nevertheless, the post-mortem findings supported an indication that the pilot '*died relatively quickly*' after the post-impact fire started. As such it was not determined whether the injury or QRF would have influenced the outcome.

Both occupants were wearing normal clothing which would not have offered any protection from the effects of fire. Prior to this accident, in July 2016, the LAA published an article in its magazine relating to mitigating post-accident survival risks. Since this accident, the LAA has indicated its intention to incorporate advice relating to choice of flying clothing in a new Technical Leaflet.

Other issues identified

Maintenance documentation

The worksheets submitted to the LAA in support of the Permit to Fly application listed the maintenance tasks performed during G-BXON's rebuild. Where the tasks referred to component or system checks, the results of these checks were not initially documented. Results of the fuel flow checks and engine were subsequently provided on a follow-up worksheet, but the results of flight instrument calibrations were not recorded.

The worksheets had been completed by the LAA inspector and each task was certified by him. Although a substantial amount of work on the aircraft would have been conducted by the pilot, the pilot's signature only appeared against a single task relating to duplicate inspections of the flight and engine controls.

In accordance with the LAA inspector's preferred approach, the maintenance tasks had not been individually documented as the restoration had progressed but had instead been collectively grouped together and retrospectively documented. It is evident that the pilot relied on the LAA inspector to document the work undertaken on G-BXON and to manage the Permit to Fly application process on his behalf. The manner in which the worksheets had been documented made it difficult for the investigation to determine the chronology of the work performed on G-BXON. Additionally, it was not possible to differentiate work done by the pilot and certified by the inspector under his LAA remit from work performed by the inspector.

Furthermore, the worksheets submitted in support of G-BXON's Permit to Fly application did not fully reflect the status of the aircraft or all the work which had been undertaken. Substantial work is reported to have been carried out on the aircraft's engine between September 2016 and April 2017. The supplementary worksheet submitted on 10 April 2017 made no reference to this work, and it did not appear to have been recorded elsewhere.

It was not established to what extent the LAA inspector was aware of, or involved in, this additional work or whether this work had been re-inspected. Work on the engine is reported to have included replacement of the fuel injection pump, ignition leads and adjustment of the OPRV. A number of anomalies were noted with these components during the post-accident examination of the engine. This suggests that either the work had not been inspected, or not been inspected effectively.

The initial worksheets dated 16 September 2016 referenced the installation and timing of an overhauled fuel injection pump. However, the fuel injection pump was subsequently replaced some months later. The absence of a formal record of this work meant it was not possible to establish whether the replacement pump had been correctly timed and tested. However, an invoice dated 22 February 2017 to the pilot from the LAA inspector's maintenance company referred, among other items, to investigation of an engine problem and timing and installation of a new fuel [injection] pump.

The LAA process for aircraft build and rebuild projects places the onus of responsibility on the aircraft owner for ensuring that the finished aircraft meets accepted standards for build quality and airworthiness. The investigation found that LAA guidance regarding owner responsibility for the quality and conformity of a completed aircraft project differed for newbuild and rebuild aircraft. In particular, TL 2.21 lacked any specific guidance on this subject, although relevant guidance was available in other TLs.

In October 2018, the LAA revised TL 2.21 to include additional guidance relating to completion of worksheets and the expected level of detail required. The revised TL also includes information on owner responsibility for the quality and conformity of rebuild projects, to reflect guidance already published for newbuild projects.

Permit to fly application process

Throughout G-BXON's Permit to Fly application process LAA Engineering repeatedly sought clarification from the LAA inspector on a number of worksheet items, to ensure that the submitted paperwork met an acceptable standard to form the basis of an LAA recommendation for a Permit to Fly. The LAA commented that the worksheets submitted for G-BXON contained a less than average level of detail. Nonetheless, following receipt of the supplementary worksheet submitted on 10 April 2017, the LAA satisfied itself that the paperwork was adequate and cleared the aircraft to proceed to the flight testing stage.

Although LAA guidance published in TL 2.21 for rebuild projects specified a minimum of five hours flight testing followed by a formal flight test, LAA Engineering did not impose a minimum number of flight testing hours or landings for G-BXON. Instead it left this determination up to the testing pilot, having taken into account his level of experience on type. The LAA was not aware of the additional work undertaken on G-BXON's engine, following submission of the original worksheets in September 2016. It subsequently indicated that had it been aware of the difficulties experienced in getting the engine to run smoothly in the lead up to the flight testing period, it would have specified a minimum number of hours to be flown. While this may not have influenced the outcome of the accident flight, additional flight testing may have allowed any post-rebuild engine performance issues to become evident.

Following the accident, the revised TL 2.21 includes updated information to bring the LAA's published guidance on minimum flight testing hours into line with actual practice and to describe the factors that LAA Engineering takes into account when determining the initial flight test requirements for a given aircraft.

Aileron control rod rivets

The rivets installed in the left aileron control rod were of a different type and lower strength than those specified on the AOP.9 post-modification drawing. The AOP.9 Type Record indicated that the original aileron control rod rivets were AGS 2048-420 and had a reserve factor of 1.004 in the critical loading case. This may provide an explanation for stronger rivets specified in the revised post-modification drawing, but it was not determined whether there was any mandatory requirement for the change to Chobert rivets to have been embodied on G-BXON.

All the rivets from G-BXON appeared to conform with the material properties of the original AGS 2048-420 rivets, but only the green rivets conformed with respect to colour. The two rivets on the left aileron control rod which had suffered corrosive attack were grey and may have been from a different batch, or differed in some other respect, introducing the possibility that they were fitted at a different time.

All eight rivets from the right aileron control rod end-fittings were grey and visually similar to the two grey rivets from the left aileron control rod. One of them had failed and metallurgical analysis determined that the failure was due entirely to intergranular fracture and that the rivet had not been carrying any load when it failed. It was concluded that the rivet had failed at some point prior to the accident flight, but it was not possible to determine when.

There was no reference to work being carried out on either aileron control rod in the worksheets from G-BXON's recent restoration, and the absence of historic technical records and/or worksheets from the previous owners meant it was not possible to determine whether the failed rivets were replacement or original rivets.

A total of three aileron control rod attachment rivets examined exhibited partial, or total, pre-existing intergranular failure as a result of stress corrosion cracking. While it was determined that the aileron control rod joints could sustain normal flight loads, even with two failed rivets, the failure of fasteners on a safety-critical flight control connection is highly undesirable from an aircraft safety and airworthiness perspective. Only the failed rivets were subject to metallurgical examination during the investigation, so it is possible that the remaining rivets, although intact, could exhibit stress corrosion cracking.

Intergranular stress corrosion cracking in these rivets may not be visually evident until the point of final failure and the only means to detect the presence of cracking would be via an inspection using a non-destructive testing (NDT) technique. There is currently no requirement for historic aircraft being restored under the LAA regime to be subject to NDT inspections.

As a result of the findings of this investigation, in January 2019 the LAA issued Airworthiness Information Leaflet MOD/920/001 *'AOP.9 Inspection of rivets securing the aileron operating rod end fittings'* which requires an inspection of the aileron control rod rivets on all AOP.9s with an LAA permit to fly to identify the type and condition of rivets installed, and appropriate rectification according to the findings of the inspection. The LAA has also included additional guidance in the updated TL 2.21 relating to the integrity of riveted joints in rebuilt aircraft. The updated guidance includes the following additional statement:

> *'… at rebuild all rivets should be examined critically and consideration given to replacing rivets that may be internally corroded especially where they carry out a critical function….In particular it would be well worth drilling out and replacing as a matter of course any rivets that are not part of a large multiply-redundant group, and are performing a function that's critical to safety e.g. strut ends, pushrods, wing and tail attachments, engine mount brackets etc, even though they might appear to be still in good condition.'*

Conclusion

The investigation concluded that it was most likely that G-BXON departed from controlled flight because it stalled at a low height after takeoff. G-BXON, as is common to type, did not demonstrate any stall warning in its Permit to Fly flight test. It also demonstrated substantially higher stall speeds and a lower rate of climb in comparison with other AOP.9s and the Pilot's Notes figures. The pilot was likely to have elected to fly at a departure airspeed which he perceived to provide an adequate margin from the stall regime. In the absence of prompt and appropriate pilot actions, recovery from a stall at a low height was unlikely.

Examination of the wreckage, although limited to some extent due to impact and fire damage, did not identify any other technical issues which may have contributed to the accident, but there were some systems and flight instruments which could not be examined.

Although the aircraft's engine was operating at the time of the accident, the investigation identified a number of anomalies which could have contributed to less-than-ideal engine and aircraft performance. In isolation, these would not have accounted directly for the departure from controlled flight but may have served as a distraction to the pilot.

Additionally, the investigation identified issues relating to the documentation of maintenance and the integrity of safety-critical rivets.

The LAA has taken action to reinforce its existing processes and published guidance in areas relating to the Permit to Fly application process, documentation of aircraft maintenance and pilots undertaking their first flights on type. No Safety Recommendations are made.

Safety action

The following safety actions have been taken:

The Light Aircraft Association (LAA) has:

- Created a database of initial flight test performance results and introduced a process to compare future aircraft against other examples of the same type prior to permit issue. In the case of factory-built aircraft, scheduled performance figures, when available, will also form part of this consideration.

- Clarified the wording of the stall requirement in the Flight Test Schedule which relates to the speed at which stall warning will occur. The new wording emphasises that this requirement relates only to aircraft with artificial stall warning devices and reflects that some LAA aircraft may not be so equipped.

- Introduced a procedure whereby, when it issues a newly-constructed or newly-rebuilt aircraft with a Permit to Fly, it will write to the owner with any safety related observations on the submitted flight test results. The observations will include highlighting the absence of any stall warning features, particularly when the reported characteristics deviate markedly from that expected or from published data for the type.

- Produced guidance for pilots preparing for their first flight on a new type: it has published two magazine articles on the topic and has also produced a Technical Leaflet, TL 2.30 '*Converting to a new type*', for use as a preparation tool, similar to the one provided for testing pilots. Subjects addressed include: researching a new aircraft type (eg by reviewing its operating manual, operating limitations and handling peculiarities); the planning and content of a first flight on type to become familiar with the aircraft alongside a suitably experienced pilot; the importance of beneficial weather conditions (eg consideration of density altitude); choice of appropriate flying clothing; and consideration of the desirability of carrying passengers both in terms of aircraft weight, and pilot recency and experience on type.

- In October 2018, revised TL 2.21 *'Rebuilding an aircraft under the LAA system'* to include additional guidance on the completion of worksheets, the expected level of detail to be recorded, and reiterated the respective responsibilities of owners and inspectors for the quality and conformity of rebuild projects. Additional guidance relating to the integrity of riveted joints in rebuilt aircraft was also included, as was updated information to bring the LAA's published guidance on minimum flight testing hours into line with actual practice, and to describe the factors that LAA Engineering considers when determining the initial flight test requirements for a given aircraft.

- In January 2019, issued Airworthiness Information Leaflet MOD/920/001*'AOP.9 Inspection of rivets securing the aileron operating rod end fittings'* which requires an inspection of the aileron control rod rivets on all AOP.9s within its fleet to identify the type and condition of rivets installed, and appropriate rectification according to the findings of the inspection.

Bulletin Correction

A bulletin correction was issued concerning this report prior to publication.

In order to provide additional clarification, the information in the section titled '*Passenger*' (page 36) and the last two sentences in the first paragraph of the '*Engine maintenance*' section (page 52) have been amended.

Full details regarding the correction can be found on the AAIB website (https://www.gov.uk/aaib-reports/aaib-investigation-to-auster-aop-9-g-bxon).