ACCIDENT

Aircraft Type and Registration:	EV-97 Teameurostar UK (Eurostar), G-GARB	
No & Type of Engines:	1 Rotax 912-UL piston engine	
Year of Manufacture:	2013 (Serial no: 2013-4104)	
Date & Time (UTC):	18 September 2016 at 1058 hrs	
Location:	Near Builth Wells, Powys	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - 1 (Fatal)	Passengers - 1 (Fatal)
Nature of Damage:	Destroyed	
Commander's Licence:	National Private Pilot's Licence (Microlight)	
Commander's Age:	55 years	
Commander's Flying Experience:	316 hours (of which 316 were on type) Last 90 days - 58 hours Last 28 days - 22 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft was seen cruising at an altitude of around 2,500 ft. At a later point it was seen to pitch nose-up and enter a steep spinning-type descent before striking the ground, resulting in fatal injuries to the pilot and passenger.

The left wing had appeared to fold rearwards in the descent and this was attributed by the investigation to a structural failure near the root of this wing, caused by upward bending of the wing beyond its design limits. No pre-existing material defect, or significant design issue, was found in the wing structure. The failure is most likely to have occurred as a result of an attempted recovery from an inadvertent manoeuvre inducing a structural overload, although the cause of the manoeuvre could not be identified.

One Safety Recommendation is made, relating to the EV-97 Eurostar pitch trim mechanism.

History of the flight

The pilot had arranged to fly with a passenger from Arclid Airfield, Cheshire, to Swansea Airport; a flight expected to take approximately 1 hour 20 minutes.

On the morning of the accident he was seen to arrive at the airfield and park close to his aircraft. He had with him one or more jerry cans and it is likely that he refuelled the aircraft; his car was later seen parked in a different area. Several people spoke with the pilot that morning and later commented that he was in good spirits. Accompanying him on the flight was a passenger who was a friend of his son.

At about 0946 hrs G-GARB took off from Arclid Runway 20 and departed on a south-westerly course towards Swansea. Radar data later showed that the aircraft climbed gradually to an altitude of 3,300 ft amsl; the altitude during the flight varied but remained above 2,000 ft amsl up to the point of the accident. A plot of the vertical profile of the flight is shown in Figure 1.

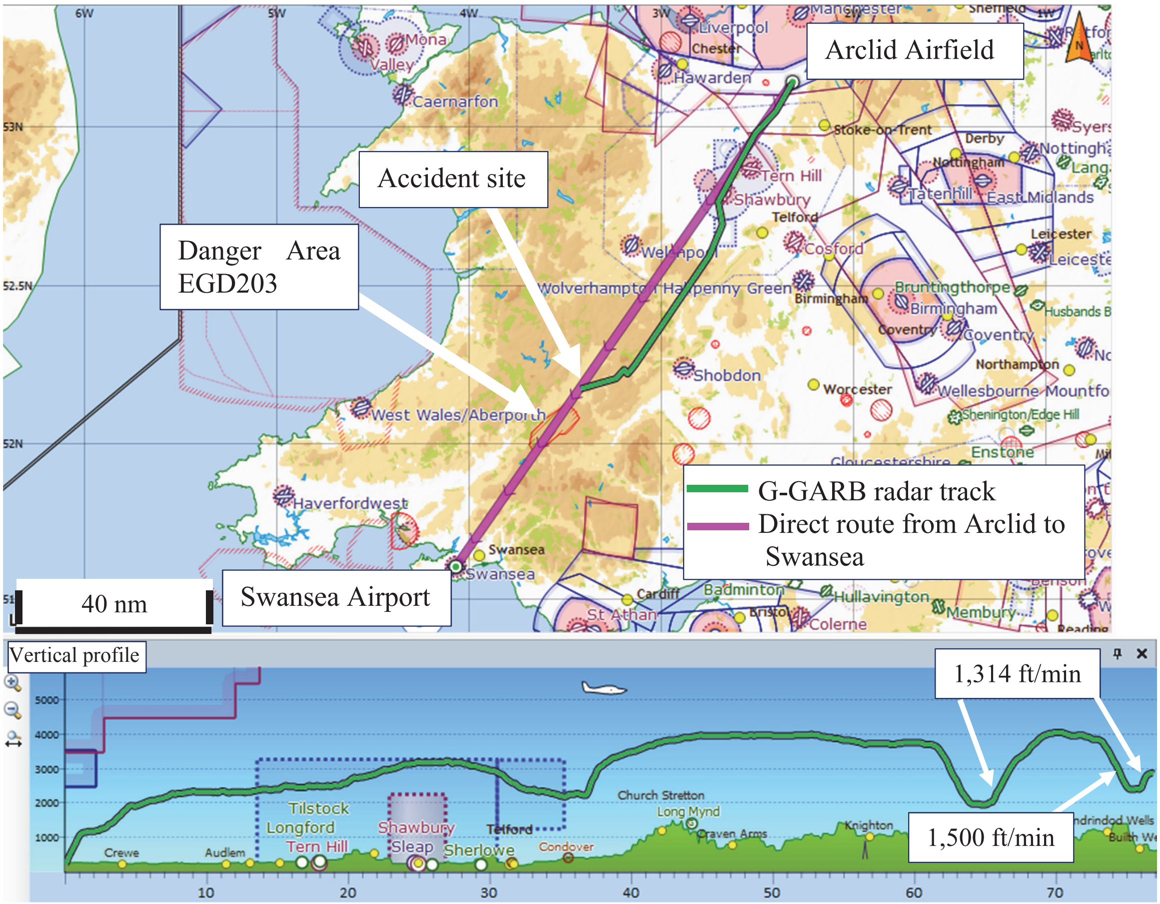

Figure 1

G-GARB recorded radar track with derived vertical speeds
(Chart produced by SkyDemon and used with permission)

The pilot made contact with London Flight Information Service at 0955 hrs. He advised of his route from Arclid to Swansea, his altitude of 2,500 ft amsl and requested a Basic Service[1]. Fifteen minutes later, at 1010 hrs, '*London Information*' contacted the pilot and asked for confirmation of his routeing and estimated time of arrival (ETA) at Swansea. The pilot replied that he was routeing directly to Swansea and gave an ETA of 1145 local time (1045 UTC)[2].

Footnote

1 A Flight Information Basic Service allows the pilot freedom to manoeuvre laterally and vertically.
2 In fact, this was an error, the likely ETA was 1105 UTC.

The pilot continued on the direct track towards Swansea and at 1015 hrs, approaching Shrewsbury, turned left and established on a course parallel to, but 3 nm east of the original track (Figure 1). At 1045 hrs the aircraft, which had been flown generally straight and level up to that point, started a descent followed by a climbing turn to the right, and then a climbing turn to the left, before turning right onto a course to intercept the original track between Arclid and Swansea.

At 1053 hrs, the aircraft started manoeuvring again, turning, descending and climbing before levelling at an altitude of 4,100 ft. Three minutes later, it descended again, levelled at 2,400 ft and then after half a minute started to climb again.

A group of witnesses was walking along a track half a mile to the east of the accident site. They reported that the aircraft had flown over them and at that time was in a normal level, or slightly climbing, attitude. After it had passed they decided to turn round and walk back down the track. As they did so, one of them noticed that the aircraft now appeared to be in a vertical, climbing attitude. After glancing away, this witness looked at the aircraft again and now saw it nose-down and rotating in a spiralling descent. The witness made an exclamation, which alerted the others to the aircraft; as she continued to watch she noticed that one wing had apparently "turned" and was pointing in the direction of the tail. The other witnesses in the group did not see the start of the nose-down rotating manoeuvre but all concurred that the wing position was not normal before the aircraft struck the ground.

Two other witnesses in the area reported having first heard an aircraft engine making an unusual noise when the aircraft was flying straight and level, before seeing the nose dropping and the aircraft "plummeting" down and spinning. Another witness saw the aircraft "corkscrewing" downwards and noted that a wing had "folded back". Several of the witnesses also commented on hearing changes in the engine noise.

A fuller flight track and description derived from radar is provided in the recorded data section of this report and at Figure 4.

The impact with the ground was not survivable.

Accident site

The aircraft wreckage was found in a field near Builth Wells, about 360 m and 102° from the last recorded radar return. The wreckage was resting in its initial impact crater, indicating that it had a high vertical speed and low forward speed at impact (Figure 2). The left wing had folded forwards and had sustained significant impact damage to its leading edge near the root but no damage to the outer portions. The right wing had suffered leading edge compression damage along its entire length, and there was an imprint from the right wing in the ground, indicating a steep nose-down impact. Behind the tail, about 50 m away, was a section of the left wing belly fairing (Figure 3). Between this point and the main wreckage site there were no other parts of wreckage.

Figure 2
Overhead view of the aircraft wreckage at the accident site

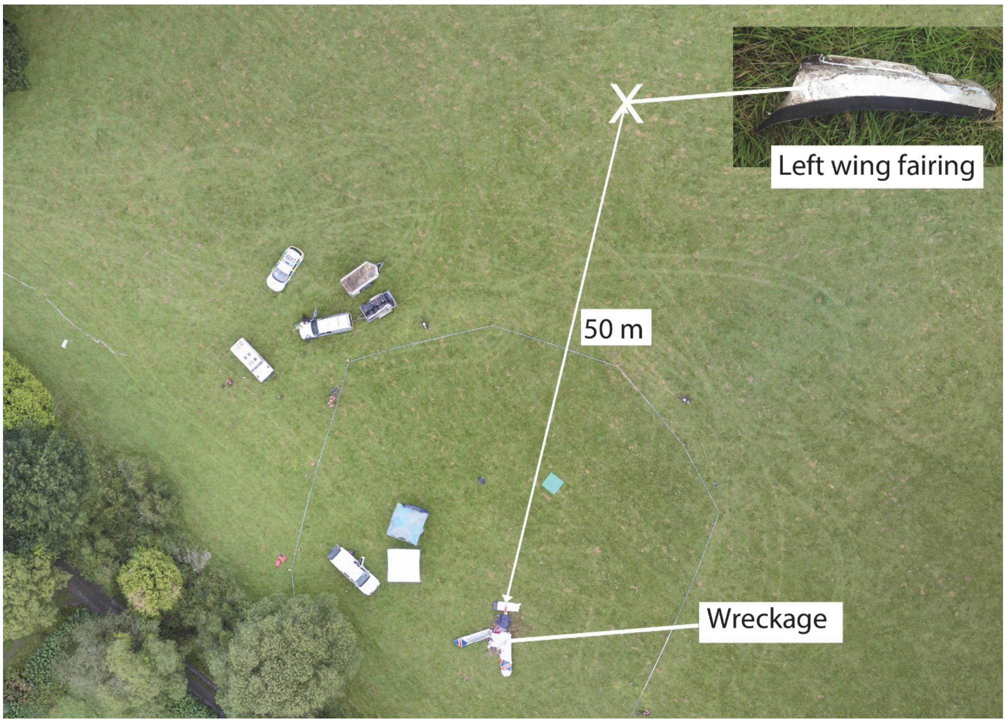

Figure 3
Overhead view of the accident site showing distance to the left wing lower fairing

Recorded information

The aircraft's position and Mode S altitude[3] was recorded by a number of radar heads throughout the flight, which was provided to the AAIB by NATS and is shown in Figures 1 and 4. Mode S altitude received from the aircraft's transponder uses a pressure datum of 1013 hPa which has been corrected to the reported QNH on the day of 1017 hPa. All altitudes are amsl unless stated otherwise.

Radar recording from the Manchester Airport radar head commenced at 0949:11 hrs with the aircraft located just south of Arclid Airfield. The aircraft tracked in a south-westerly direction, climbing initially to 3,300 ft. As the flight continued, the recorded altitude ranged from between 2,050 ft and 4,150 ft with a total recording time of 1 hour 7 minutes and 12 seconds.

As the flight progressed, the aircraft eventually tracked beyond the range of the Manchester radar but closer to the Clee Hill radar, located 33 nm from the accident site, which recorded position and altitude every 8 seconds. Radar position data is of limited accuracy[4] and this, combined with the 8 second sampling rate, meant a detailed flight path analysis was not possible to ascertain whether the aircraft undertook any abrupt manoeuvres during this flight.

Vertical speed was calculated by examining the altitude change over the 8 second recording period. This showed two climbs of +1,314 ft/min (+175 ft over 8 seconds) and a descent of 1,500 ft/min (-200 ft over 8 seconds (Figure 1)).

The final stage of the flight is illustrated in Figure 4, which includes 'error boxes', in red, denoting the limited accuracy of the radar position data. A minute and a half prior to the end of the radar recording, the aircraft started to fly at approximately level altitude and constant heading for 40 seconds. Calculated groundspeed for this period was 87 mph ±18 mph (depending on radar error). Considering the aircraft's approximate heading and a reported wind of 240°/ 10 kt, this equates to an airspeed of 97 mph ±18 mph. At 1055:27 hrs, the aircraft commenced a climb from 2,550 ft to 2,975 ft over 40 seconds. The maximum derived vertical speed during this climb was 1,314 ft/min with an average of 638 ft/min. Between the penultimate and final recorded radar returns, the aircraft descended 325 ft over 8 seconds; a descent rate of 2,440 ft/min. The final recorded radar return was at 1056:23 hrs with the aircraft at 2,625 ft (2,100 ft agl), almost overhead the accident site.

A review of the available radar data in the vicinity of the accident site showed no other recorded traffic visible to the radar heads within 10 minutes of the accident. Twenty minutes after the accident, a motor glider passed approximately 0.5 nm south of the accident site.

Footnote

3 Mode S altitude was recorded to the nearest 25 ft.

4 NATS have stated that they work to Eurocontrol standards and performance for random errors is usually within ±140 m for slant range and ± 0.16° for azimuth for 98% of cases

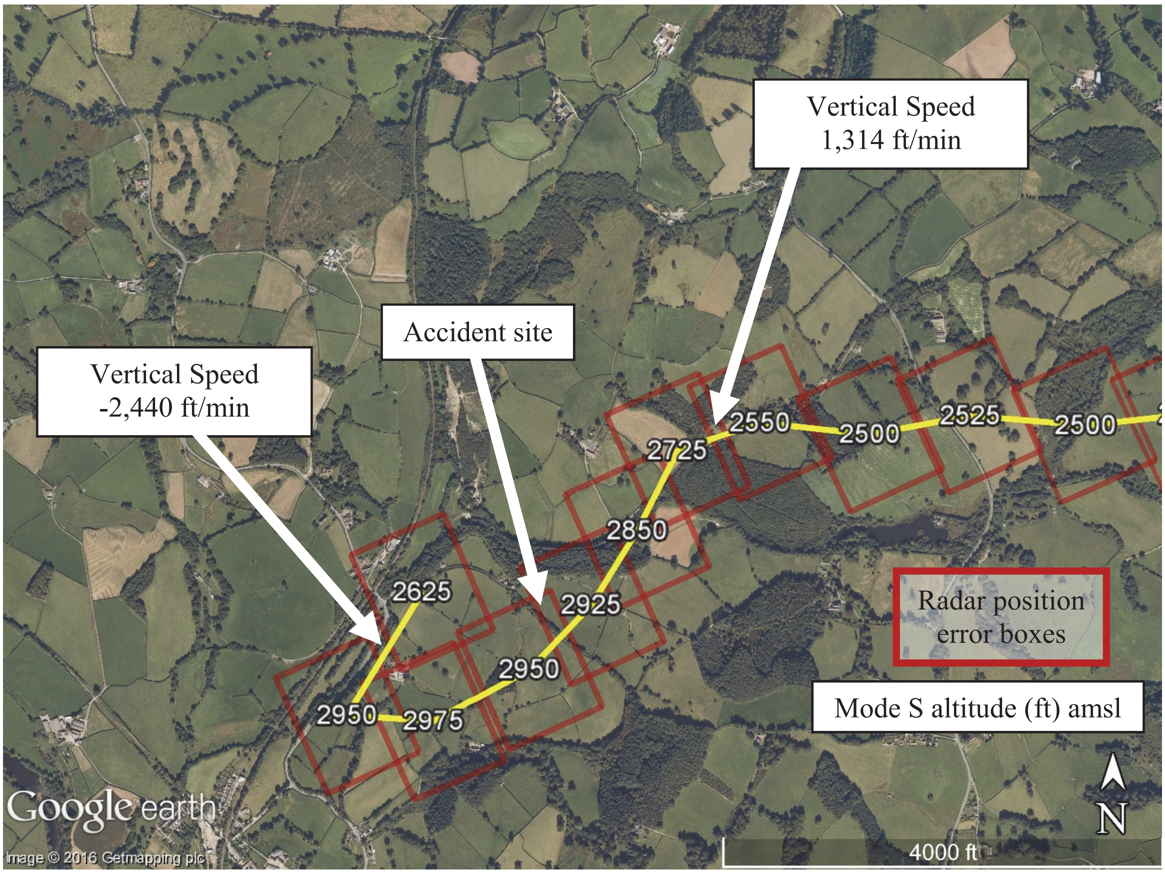

Figure 4

G-GARB recorded radar data showing altitude amsl and position error boxes in red

Flight planning and navigation app

The pilot was known to use SkyDemon, a flight planning and navigation app, on his mobile device. In navigation mode, SkyDemon is able to provide both visual and audio warnings if an aircraft trajectory takes it towards a number of airspace types, including a Danger Area. The default settings, which are then adjustable, will trigger the warning when the aircraft is within 3 minutes flight of a Danger Area.

Danger Area EGD203 (Figure 1) was located 3.5 nm from the end of the radar track and extends from the surface to 23,000 ft. With SkyDemon in navigation mode, and default settings applied, in an aircraft travelling at a groundspeed of 87 mph, the pilot would have received a Danger Area warning at around the end of the radar recording.

Three mobile devices were recovered from the wreckage, all of which were badly damaged in the impact. One had a Velcro strip on the back which matched a Velcro strip on the right side of the instrument panel but this mobile device was too badly damaged to allow extraction of any recorded data.

Meteorology

The weather conditions on the day of the accident were reported as fine with light winds and occasional cloud. An aftercast from the Met Office reported that the wind at 2,000 ft amsl was estimated as 240° at 10 kt. The pilot of the motorglider which flew through the area 20 minutes after the accident reported that any cloud present was above 2,500 ft and that the conditions for flying were fine with only light thermal activity.

Pilot information

The pilot had started flying training in October 2014 and qualified for his National Private Pilot's Licence (NPPL) in June 2015 after 73 hours of training. He purchased G-GARB in March 2015 and flew 20 hours in it as part of his training. A review of his recorded flying since qualifying for his licence showed that he flew regularly, typically several times a week. He flew around the area local to Arclid Airfield and also on longer cross-country flights to land at other airfields. The day before the accident he completed a solo flight from Arclid Airfield to Oban, on the west coast of Scotland, and back, a round trip of some 500 nm.

His flying instructor commented that the pilot was thorough, prepared well for his flights and was conservative in his flying. He had not shown any interest in aerobatics and the instructor did not think that he would have ever attempted aerobatic manoeuvres.

Medical and pathological information

A post-mortem examination of the pilot was carried out and the report noted that there was no evidence of any significant natural disease, such as might account for a sudden collapse whilst in control of an aircraft. Blood tests indicated that carbon monoxide toxicity was not a factor in the accident.

The passenger had not previously flown in a light aircraft. His medical history indicated that in December 2014 he had experienced a seizure which was subsequently diagnosed as a possible epileptic event; medication was not prescribed and there had been no further events.

Aircraft information

The EV-97, also known as the Eurostar, is a two-seat microlight aircraft that is designed and manufactured by Evektor in the Czech Republic. The 'EV-97 Teameurostar UK' version (such as G-GARB) is manufactured in kit form by Evektor and then shipped to the UK for final assembly by Light Sport Aviation Ltd (LSA), which is the UK CAA approved 'A8-1' primary company responsible for the UK design and manufacture. The UK CAA approved the design of the 'EV-97 Teameurostar UK' to be in accordance with '*British Civil Airworthiness Requirements (BCAR) Section S – Small Light Aeroplanes*'. Aeroplanes which have been shown to comply with BCAR Section S are eligible for a Permit to Fly and not a Certificate of Airworthiness.

The 'EV-97 Teameurostar UK' manufactured versions are overseen by the British Microlight Aircraft Association (BMAA), which revalidates their Permits to Fly, while the amateur-built versions of the EV-97 are overseen by the Light Aircraft Association (LAA). There are minor differences between the amateur-built EV-97 and the Teameurostar version but the wing structures are the same. In this report the term 'manufacturer' will be used for Evektor.

The accident aircraft, G-GARB (Figure 5), was built in 2013 and had accumulated 249 hours at the time of the accident, with its last annual inspection completed in January 2016. After the pilot's purchase of G-GARB in 2015, it was initially kept outside at Arclid but was later moved to a hangar at Blackpool Airport during the winter of 2015/16. In April 2016 the pilot-owner brought it back to Arclid where it was parked outside.

Figure 5

The accident aircraft, EV-97 Teameurostar UK, G-GARB
(photo courtesy of and copyright Craig Duffy)

The aircraft was powered by a Rotax 912-UL piston engine and a 3-bladed fixed-pitch propeller. It had a Maximum Takeoff Weight (MTOW) of 450 kg and a CG range of 20 to 34% MAC[5]. According to the flight manual the cruise speed at maximum continuous power was 110 mph IAS (106 mph CAS) at 2,000 ft. The flight manual also listed the flaps-up stall speed V_{S1}, the manoeuvring speed V_A, the maximum structural cruising speed V_{NO}, the never-exceed speed V_{NE} and the design dive speed V_D (Table 1).

	IAS (mph)	CAS (mph)
V_{S1}	44	48
V_A	100	98
V_{NO}	118	114
V_{NE}	146	140
V_D	163	156

Table 1

Flight manual airspeeds

Footnote

5 Mean aerodynamic chord.

At speeds below V_A (manoeuvring speed) the aircraft will stall in a nose-up pitching manoeuvre before the structure exceeds its aerodynamic limit load factor. The limit load factors of the aircraft are +4g and -2g. These load factors should never be exceeded in operation, even though the aircraft is designed with a 1.5 factor of safety so that the wing structure should not fail catastrophically below +6g. The minimum airspeed required to pull 6g without stalling is 124 mph IAS[6] (120 mph CAS). Aerobatics and intentional spins are prohibited.

G-GARB had conventional dual flying controls, with side-by-side control sticks controlling the ailerons and elevator, via push-pull rods, and two sets of pedals operating the rudder via cables.

Pitch trim system

The elevator had a trim tab which was operated via a 'Bowden-type' cable and a lever mounted between the seats (Figure 6). This trim lever was pushed forward to generate nose-down trim and pulled aft to generate nose-up trim.

Figure 6

Pitch trim lever on another EV-97 aircraft

Most pitch/elevator trim systems in certified powered light aircraft are operated by a trim wheel, which allows fine adjustments of trim and makes it impossible to apply a sudden full-aft or full-forward trim input. The BMAA provided the AAIB with six examples[7] of other 3-axis microlight aircraft that have pitch trim levers, but none of these had the lever located between the seats, as on the EV-97. The trim levers were all further forward or, in one case, mounted to the roof.

Footnote

6 This figure was calculated by multiplying V_A in CAS (98 mph) by $\sqrt{(6/4)}$, and then converting to IAS.
7 Flight Design CT, Sky Ranger Nynja, Sky Ranger Classic and Swift, EuroFOX, X'Air, Dynamic.

On the EV-97, pitch trim lever friction is not adjustable in flight. It can only be adjusted during maintenance by tightening a nut beneath the floor. According to the maintenance manual the nut should be adjusted to ensure that there is a minimum 1.0 kgf force required at the lever's end to move it.

BCAR Section S includes a requirement '*S 677 Trim System*' which states that:

> *'Proper precautions must be taken to prevent inadvertent, improper, or abrupt trim operation'.*

The position of the trim lever between the seats on the EV-97 has resulted in occasions of inadvertent movement (see flight evaluation section). The BMAA was not aware of any issues of inadvertent operation on the other six aircraft types that had trim levers.

Weight and balance

The empty weight of G-GARB was 267 kg. The pilot and passenger weighed 115 kg and 74 kg respectively, and there was 4.8 kg of baggage on-board at the time of the accident. The fuel on-board was unknown because the fuel tank had ruptured at impact, but if the tank had been full on departure then, based on estimated fuel burn, the maximum fuel at the time of the accident would have been about 35 kg. The minimum fuel on-board was estimated to be an amount sufficient to reach Swansea plus a 30-minute reserve; this was 9.4 kg. Therefore, the weight of G-GARB at the time of the accident was probably between 471 and 496 kg, at least 21 kg above the MTOW. The CG would have been within limits, between 28.9 and 31.2% MAC.

Aircraft examination

The flying controls were examined and there were no disconnections apart from overload failures associated with impact. The canopy appeared to have been in the closed and latched position at the impact with the ground. Two of the propeller blades were undamaged and one blade had snapped near its root, indicating that the engine was stopped, or producing low power, at impact. The engine strip examination did not reveal any faults that would have precluded normal operation.

The left aileron and its hinge were found undamaged, with no evidence of the aileron having hit its stops which could have been indicative of an aerodynamic 'flutter' situation. The right aileron had suffered some damage from striking the lower wing which most likely occurred at ground impact. The left side leading edge of the horizontal tail had crumple damage as did the leading edge of the vertical tail. The rudder was undamaged. As a result of the disruption of the cockpit structure, the pre-impact position of the pitch trim lever could not be determined.

The section of left wing belly fairing, which was found 50 m away from the main wreckage, had torn holes where it had been attached by screws to the underside of the left wing. This fairing is not physically attached to the fuselage, but rests against its underside with a strip of Velcro to avoid fretting. There was an indentation in the fairing consistent with it having been pulled against the flap control rod (Figure 7).

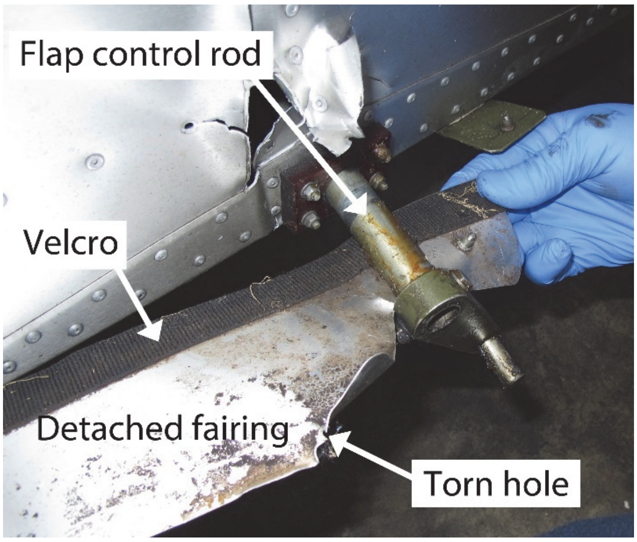

Figure 7

Detached left wing belly fairing held alongside the left fuselage of a different EV-97 aircraft

The right wing had remained attached and had suffered some internal damage as a result of crushing damage along the length of its leading edge. The left wing had suffered from a structural failure of its lower spar cap and the upper 'carry-through' spar cap in the fuselage had also failed (Figure 8). Both the upper and lower 'main-spar-to-fuselage' attachment fittings were intact; the lower fitting was cut on the fuselage side to enable the wing to be removed. The left wing aft attachment fitting had separated from inside the fuselage. These parts were sectioned and taken to a forensic organisation for detailed metallurgical examination.

The wings and the horizontal tail did not exhibit any signs of buckling.

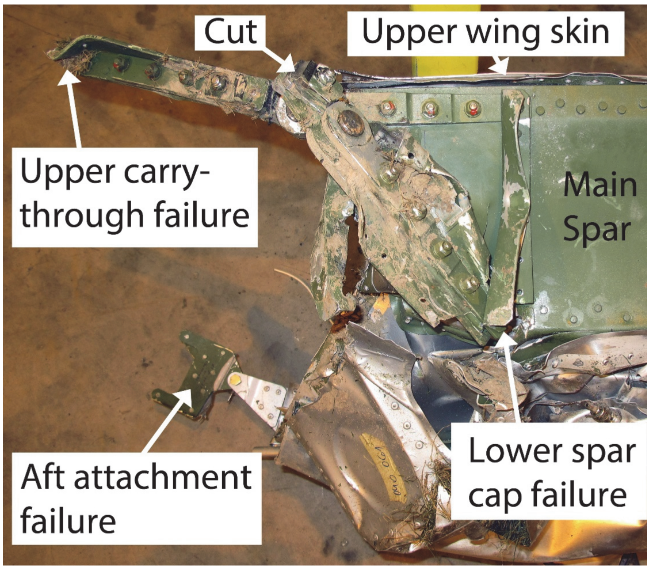

Figure 8

View of the forward face of the left wing main spar showing the three failure locations and where the lower forward fuselage attachment was cut in order to remove the wing

Metallurgical examination of left wing and attachments

The lower wing spar cap consisted of two strips of 2024 T3 aluminium plate fastened together. Each strip had a cross-section of 25 x 5 mm, with the forward facing strip, known as the 'long cap', having a machined radius on one edge. The aft facing strip was known as the 'short cap' due to its shorter length. At the inboard end of the cap, the two strips, along with the web, were sandwiched between two steel attachments which were held together by five 6 mm diameter bolts. The fracture of the spar cap had occurred at the fifth outer bolt (Figure 9).

There was mechanical damage on the forward face of the web in the area of the fracture which suggested that there had been forward movement of the outboard section of the spar cap relative to the inboard section after failure, when the outboard section of spar was inclined upwards by about 25°. Both spar cap fracture surfaces were found deformed in a manner consistent with upwards bending, and there was 'necking' which is characteristic of overload failure. The fracture surfaces were examined in a scanning electron microscope (SEM) which revealed that both had failed in tensile overload with no evidence of fatigue or corrosion.

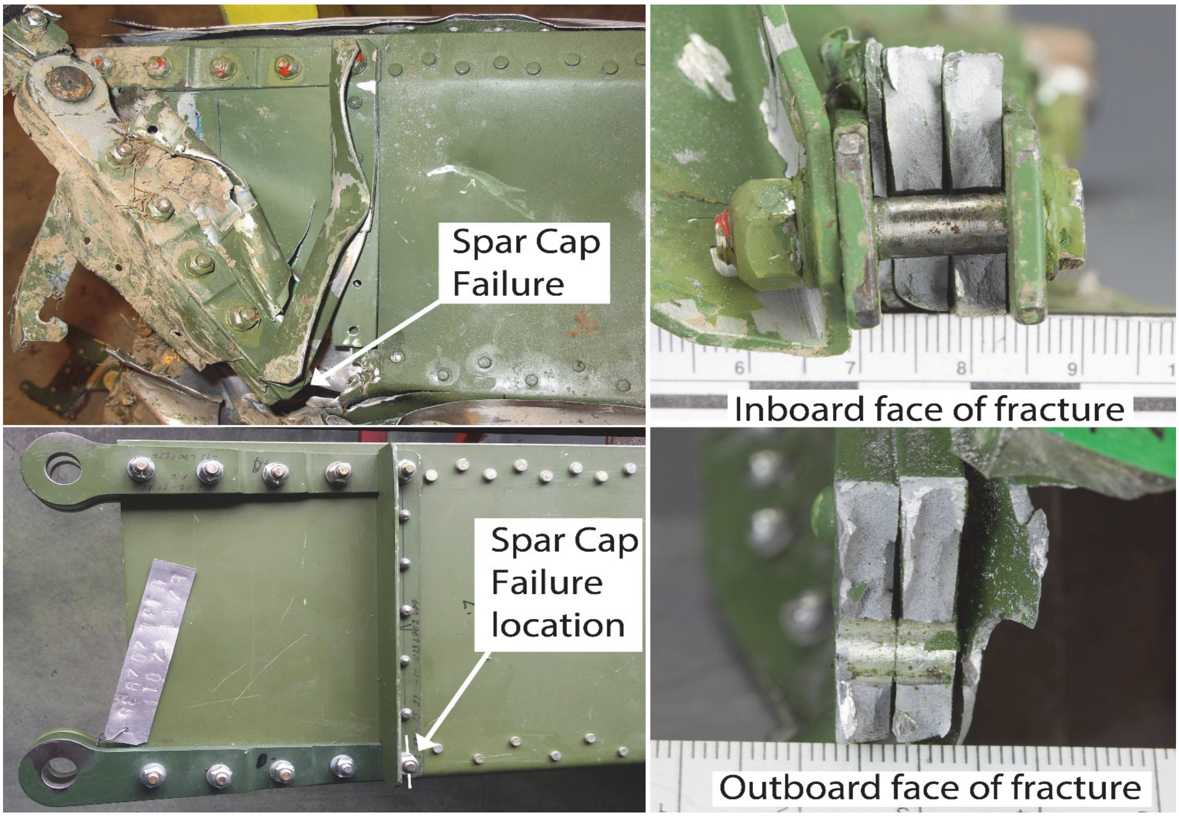

Figure 9

Top left: view of spar cap failure.
Bottom left: location of spar cap failure on a new main spar.
Top right: View of spar cap fracture looking inboard.
Bottom right: View of spar cap fracture looking outboard

Hardness tests were carried out at a location inboard of the failure and the average equivalent Brinell (HB) hardness was 120 HB for the short cap and 121 for the long cap; the typical hardness result for 2024 T3 is 120 HB. Tensile tests of three specimens from each of the long and short caps, from a location outboard of the failure, were carried out. A specimen from a new long cap supplied by the manufacturer was also tensile tested. The average results of the tensile tests are shown in Table 2. The '0.2% proof stress' is a standard indication of the stress at which the material starts to yield, and the ultimate tensile strength (UTS) is the stress at which failure occurs. The short and long caps on G-GARB exceeded the material specification's minimum UTS by 10%.

Section	0.2% Proof Stress (MPa)	UTS (MPa)	Elongation (%)
G-GARB - long cap	359	487	33
G-GARB - short cap	346	485	31
New - long cap	358	486	30
Specification 2024 T3	Min 290	Min 441	Min 15

Table 2

Average tensile strength test results from long and short caps compared to a new cap and the material specification

The microstructure of the failed long and short caps was also examined. The microstructures of the caps were similar and were typical for 2024 T3 aluminium alloy. There were no apparent metallurgical defects in the samples examined.

The dimensions of the spar caps were checked and the cross-section was found to be slightly larger than the manufacturer's specification, a minor difference in the 'safe' sense. The diameter of the spar cap holes were found to be within specification.

The upper carry-through spar had failed inside the fuselage beneath the left pilot's seat and this area had suffered significant crushing damage during the impact after the landing gear collapsed. There was extensive deformation of the lightweight aluminium structure around the fracture, which was consistent with the left wing moving forward. The steel centrepiece (Figure 10) was also found deformed, with an 'S' shape characteristic of buckling. However, SEM examination revealed that the fracture surfaces had ductile 'dimples' characteristic of tensile overload failure with no evidence of shear or compression. It appears that the upper spar was deformed in compression before failing in tension. There was no evidence of fatigue or corrosion.

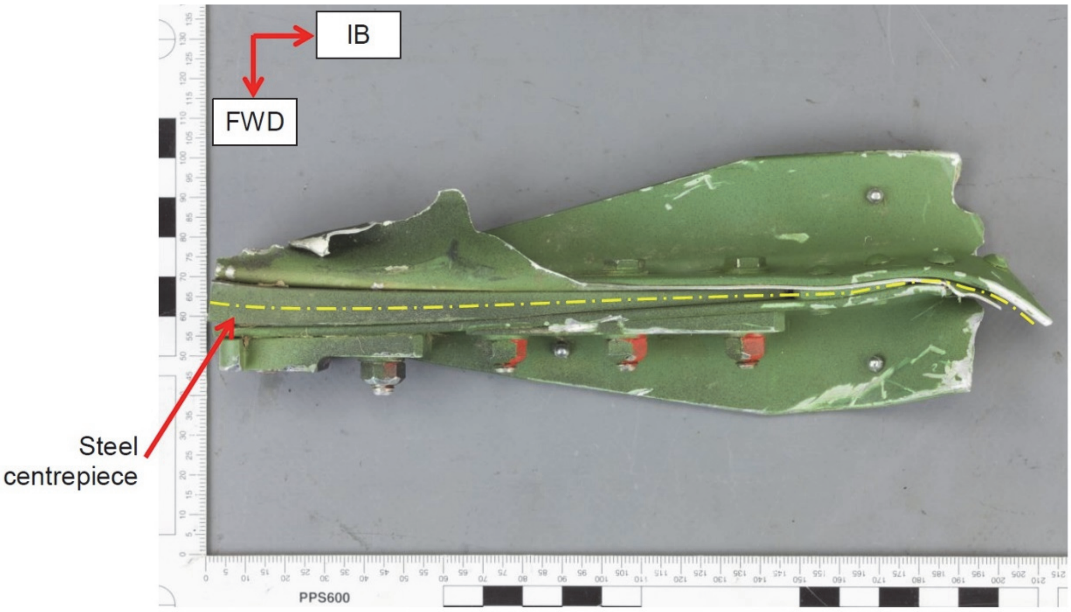

Figure 10

Lower surface of upper carry-through spar. Cut on left side and fractured on right side. Centre section is made of steel. Fractured parts are aluminium

The aft wing attachment fitting had separated from inside the fuselage and the lightweight structure around the fitting was fractured and severely deformed; the fitting itself was not fractured, although it had deformed. The lower surface of the fitting was relatively straight, whereas the upper edge was deformed in a forward direction. The fracture surfaces were examined under a stereo optical microscope and the surfaces were dull and fibrous, consistent with static overload failure. There was no evidence of fatigue or corrosion.

Previous EV-97 accident involving wing failure

On 24 June 2006 a Eurostar EV-97 model 2000 version R ultralight aircraft, with Danish registration 9-249, suffered an in-flight left wing separation 17 nm north-east of St. Moritz, Switzerland. The fatal accident was investigated by the Swiss Aircraft Accident Investigation Bureau and published in Report No. 2053[8]. The left wing failure was similar to that of G-GARB in that the lower spar cap had also failed at the outer fifth bolt (Figure 11). The upper carry-through spar had also failed in a similar location to that on G-GARB.

The Swiss investigation identified that there was an 'extrusion weld' in the short cap in the area of failure which would have weakened the strength properties of the material. The material strength at the failure location could not be determined but several hardness tests and tensile tests were performed away from the failure location which revealed a UTS range of 437 to 522 MPa. This aluminium material was different from that on G-GARB and was designated PA 7. According to the material manufacturer it was specified to have

Footnote

8 https://www.sust.admin.ch/inhalte/AV-berichte/2053_e.pdf

a UTS of 515 MPa. The Swiss investigators also tested the strength of the spar cap on another EV-97 which revealed a UTS of 366 to 385 MPa. As a result of these findings the spar caps on all new EV-97 aircraft, including G-GARB, were replaced with 2024 T3 material (minimum UTS 441 MPa) which was cut from plate instead of being extruded. An inspection programme was also carried out to check the strength of all in-service spar caps[9].

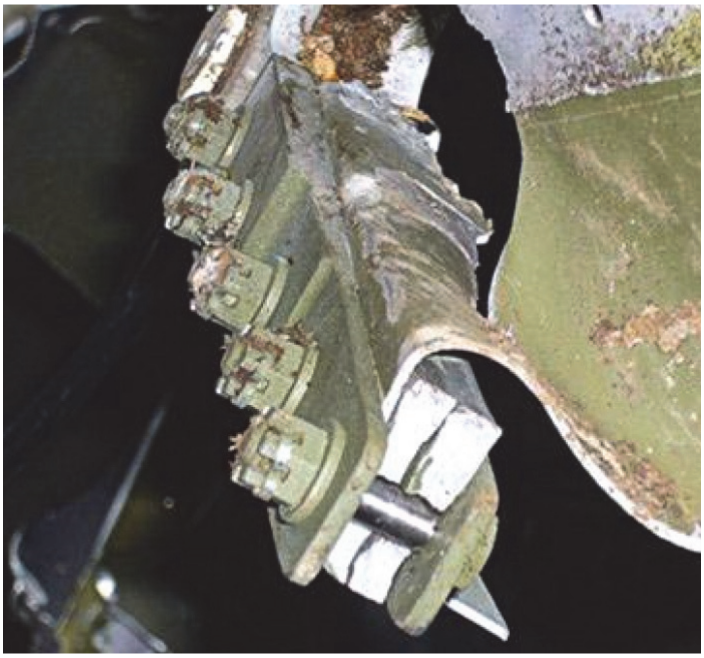

Figure 11

Left wing lower spar cap failure of EV-97 registration 9-249 in Switzerland in 2006

According to the Swiss investigators the wings on 9-249 did not exhibit any signs of buckling. The lower spar cap had failed in tension, and although the fracture face of the upper carry-through spar had not been examined, they stated that it had not failed in compression.

A significant factor to the accident to 9-249 was that it was flying through a mountainous valley in weather conditions that were forecast to have a high probability of significant convective activity. The pilot did not have experience of flying in mountainous terrain and the report concluded that:

> *'it is conceivable that the pilot was taken by surprise by local turbulence. In the process, the structure of the aircraft must have been overloaded as a result of the forces induced by turbulence or possibly during a corrective manoeuvre, after a brief loss of control'.*

Footnote

9 In the UK this inspection was mandated by the CAA. Mandatory Permit Directive 2010-003 published 29 April 2010.

Manufacturer's structural wing tests and calculations

The aircraft's wing structure was designed to a limit load factor of 4g and an ultimate load factor of 6g. Although microlights are restricted to 450 kg MTOW in the UK, the EV-97 was designed for an MTOW of 480 kg. At a weight of 480 kg and 6g loading, the stress in the wing must be less than the ultimate strength of the respective materials.

The manufacturer's structural design report on 'Wing Spar Load Capacity' included calculations for stress in the critical parts of the wing, including at the lower spar cap failure location on G-GARB. This location is at 0.703 m from the fuselage centreline so is referred to as the z=0.703 position. The critical upward bending moment in this location occurs at the design condition for dive speed V_D (186 mph, 300 km/hr) and load factor of 4g. At 1.5 times this condition (6g) the maximum bending moment was calculated to be 15,460 Nm[10]. This results in a calculated tensile force in the lower spar cap, at this location, of 97,848 N. This force is reacted over a cross-sectional area of spar and web (excluding the bolt) of 248.8 mm^2, with a resulting stress of 393.2 MPa. This is less than the minimum specified strength of the spar cap material of 441 MPa, so there is a positive calculated reserve factor of 1.12. The presence of the bolt hole in the spar cap is significant for fatigue calculations as it introduces stress concentrations, but according to structural experts the hole does not affect ultimate strength calculations apart from the reduction in cross-sectional area.

In 1999 the manufacturer conducted a wing strength static test to evaluate whether the wing design met the increased strength requirements to increase V_D from 156 mph (250 km/h) to 186 mph (300 km/h)[11] for its model 99 EV-97. One of the load cases involved a symmetric load to 4g at V_A and a mass of 480 kg. The fuselage was secured to the ground while a lifting force was applied to a series of collets around the left wing and an anti-drag force[12] was applied using load bags attached via cables and pulleys to the leading edge of the collets.[13] No permanent deformations were found after unloading from the limit load and no permanent deformations were found after unloading from the ultimate load (1.5 times higher than limit). The load was then further increased until, at 1.6 times the limit load, the upper carry-through spar buckled (Figure 12).

Footnote

[10] The figure of 15,460 Nm was determined by BRNO University after the accident in Switzerland to 9-249 in 2006, using the Glauert wing lift distribution. The original certification figure was 14,189 Nm using the less conservative, although still approved, Weissinger lift distribution.

[11] This would enable the never-exceed speed V_{NE} to be raised from 140 mph (225 km/hr) to 171 mph (275 km/hr) for the model 99. These speeds are equivalent airspeed (EAS). The V_{NE} for the EV-97 Teameurostar UK remained at 140 mph EAS which is 146 mph IAS. The reason for this is that the LAA-approved amateur-built EV-97 still had a V_{NE} of 146 mph IAS and it was considered that there was little mission requirement to increase it, and the safety margin would be higher by keeping the existing V_{NE}.

[12] The anti-drag force simulates the aerodynamic forward force, relative to the wing, that is applied at high angles of attack.

[13] The forces applied were those determined using the Weissinger lift distribution.

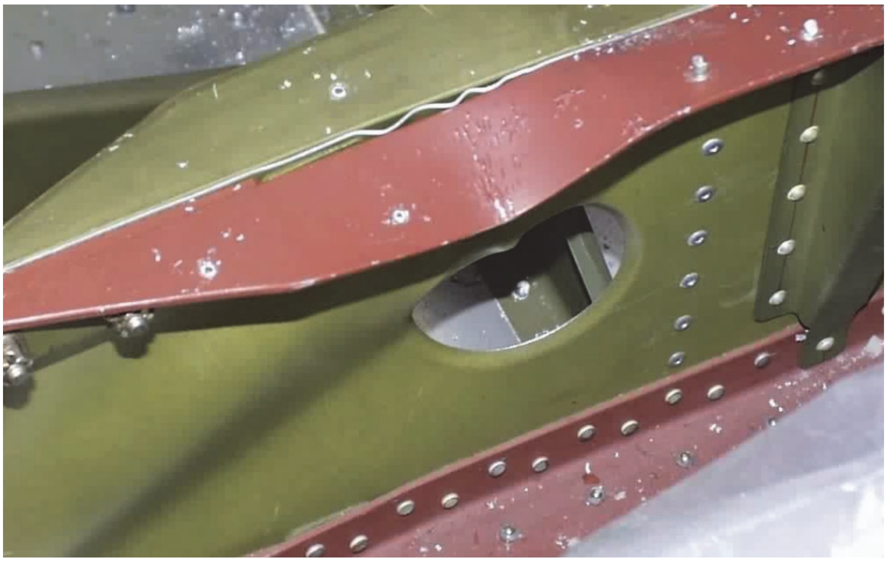

Figure 12

Upper carry-through spar buckling which occurred at 1.6 times limit load during the wing strength static test

The fuselage was not the subject of the test as it had been subjected to strength tests several times before, so the left wing was removed from the fuselage and attached to a stand welded to the floor. The wing loading method was the same as before and when the load was increased to 1.68 times limit load wing failure occurred. There was deformation of the upper wing skin, some main spar web buckling, and web failure around the attachment bolts (Figure 13). The lower main spar caps did not fail. There were no strain gauges fitted to the spar caps during the test, so as part of the G-GARB investigation, Evektor calculated that at wing failure (1.68 times limit load) the stress in the lower spar cap, at the outer bolt, would have been 402 MPa.

Figure 13

Upper wing skin buckling (left) and main spar web failure (right) at 1.68 times limit load during the wing strength static test

This wing strength static test was carried out with the original spar cap material, PA 7, which had a reported UTS of 515 MPa. Following the accident to 9-249 the spar caps from the test wing were examined for strength. According to conductivity and hardness tests the long cap was estimated to have a UTS of 465 to 560 MPa, while the short cap was estimated to have a UTS of 320 MPa to 430 MPa[14]. No tensile tests of the material from these caps were carried out, but the following year tensile tests were carried out on material from the same batch that was used to make those caps and the UTS was measured to be between 425 and 524 MPa.

The manufacturer's wing strength calculations and test reports were reviewed by the LAA as part of the AAIB G-GARB investigation. Their initial analysis concluded that there were no significant shortfalls and that no design changes were necessary, particularly with the more conservative V_D speed that was in place for both the LAA-approved amateur-built EV-97 and the Teameurostar version. However, during the draft consultation period for this report, the LAA carried out further analysis and discovered that a tip correction factor to the spanwise lift distribution had not been applied[15]. Applying this factor would reduce the reserve factor for the upper carry through spar which had been calculated to be 1.05. It would not affect the reserve factor for the lower spar as a more conservative lift distribution had been used for its analysis following the accident to the EV-97 (9-249) in Switzerland. The aircraft manufacturer stated that applying the tip correction factor would make a difference '*in the order of several percent*', but disputed the need to apply the tip correction factor for the calculation of the upper carry-through spar loads. It said that this method, without the tip correction factor, was widely used by aircraft manufacturers in the Czech Republic and other light aircraft manufacturers. At the time of publication discussion is continuing between the manufacturer and the LAA to resolve this issue.

Flutter analysis is not a requirement in BCAR Section S, but the aircraft manufacturer had carried out a flutter analysis to satisfy another country's requirements. This analysis revealed adequate flutter margins up to V_D.

Stick force requirements

BCAR Section S requires that the pitch control force required to impose the limit load factor on the structure be at least 70 N (7.1 kgf), from a 1g trimmed condition. According to an Evektor flight test report the force required to pull 4g was measured as 6.8 kgf at the top of the control stick and 8 kgf at the centre of the control stick. The CG during the test was 30.4% MAC, which meant that the forces would have been lower at the aft CG limit of 34% MAC. The certification 'Compliance Checklist Response' submitted by the UK manufacturer[16] stated that the aforementioned flight test:

> *'shows compliance with S155 and a stick force at 4g of 8 kg'.*

Footnote

14 The higher values of UTS were determined based on conductivity and the lower values based on hardness. The more reliable method of determining strength is to conduct tensile tests.
15 FAA AC23-19A refers to tip corrections required in accordance with NACA TN606 which will tend to increase the calculated spar bending moment when using the Weissinger method of lift distribution.
16 The UK manufacturer was the predecessor to LSA.

There was no analysis to consider what the stick force might be at aft CG and, according to the CAA, the stick force would normally be measured close to the top of the stick to be conservative. The CAA accepted that the aircraft complied with S155 on the basis of the statement in the 'Compliance Checklist Response' and the fact that no non-compliances or partial compliances to S155 were declared.

The control force requirements for certified light aircraft are different from those approved under Section S and EASA[17] Certification Specification CS 23.155 has a different requirement depending on whether the control is a wheel or a stick. For a control wheel the minimum force to impose limit load must be greater than W/10N, or 89 N whichever is greater, where W is the MTOW in kg, and need not be greater than 222 N. For a control stick the minimum force must be greater than W/14N or 66.8 N, whichever is greater, and need not be greater than 156 N.

So, in theory, if a 450 kg microlight with a stick had to meet CS 23.155 it would only need a minimum stick force of 66.8 N, which is less than Section S. If a 450 kg microlight had a wheel it would need a minimum stick force of 89 N which is greater than Section S.

A typical certified light training aircraft like a Piper PA28-181, which has an MTOW of 1,159 kg and a control wheel, would be required to have a minimum control force of 115.9 N which is 65% higher than the Section S requirement. If an aircraft of the same weight had a stick, it would be 82.8 N, 18% higher than Section S.

Flight evaluation

During the AAIB investigation, a flight was carried out in an EV-97 aircraft with a professional test pilot to examine the effects of inadvertent pitch trim movement and to estimate what the pitch attitude might have been during the rapid climb that preceded the loss of radar data. The aircraft used was a newer SL variant of the EV-97 which had a different tail fin and canopy, and wing-mounted vortex generators, but the test pilot considered that it would perform and handle in effectively the same manner as the accident aircraft. The aircraft was loaded to 472.5 kg[18] and an aft CG of 29% MAC.

An EV-97 flight instructor informed the AAIB that he had experienced "a couple" of occasions when a student pilot or passenger had inadvertently pressed down on the trim lever causing a 'bunt type' manoeuvre. He said this could happen when someone was trying to shift their weight in the seat by pushing down with their left hand (Figure 6). The flight evaluation used an incremental approach to determine the effect of sudden changes in trim lever position from straight and level cruise flight. During trim changes the control stick was held loosely and allowed to move until recovery action was taken.

The total trim lever travel was measured at 12.1 cm and a scale was added with 0 full-aft and 12.1 full-forward. In straight and level flight at 2,800 ft and 104 mph IAS the trim

Footnote

[17] European Aviation Safety Agency.
[18] This aircraft had a ballistic recovery parachute which permitted the higher maximum takeoff weight of 472.5 kg.

position was 9.2. When full-forward trim was rapidly applied (a forward movement of 2.9 cm) the aircraft pitched down to 0.3 g in 1 second and reached a minimum pitch of -20° in 3 seconds before recovery action was taken. During the incremental aft trim tests it was found that a sudden aft trim input of 2.7 cm (from 9.9 cm) caused the aircraft to pitch up to 2 g in 1.2 seconds and reached a maximum pitch of 27° in 3 seconds before recovery action was taken. A further 7.2 cm of aft trim was available but the tests were stopped at the 2g point.

An attempt was also made to match the rapid 1,314 ft/min climb rate that preceded the loss of radar and also occurred earlier in the flight; in both cases this was a height gain of 175 ft in 8 seconds. At a power setting of 4,800 rpm and a cruise speed of 104 mph IAS, a pitch attitude of between 10° and 20° was required to achieve a 175 ft climb in 8 seconds, depending upon the pull rate. Adding full power while pitching up did not significantly reduce the pitch angle required. The pitch up was considered in excess of a normal cruise manoeuvre.

Analysis

The aircraft, while en route on a cross-country flight, was seen in apparently normal flight and then in a steep spiralling or spinning descent. At some point the left wing failed in upwards bending.

Structural failure of the wing

The investigation considered whether the left wing lower spar cap had failed in flight or at impact.

Metallurgical examination showed that the lower spar cap had failed in upwards bending as a result of a load that was in excess of its material strength. However, the outer portions of the left wing were found undamaged and all the impact damage was more consistent with aft loading, rather than an upwards bending load, at impact.

The left wing belly fairing was found 50 m aft of the main wreckage which indicated that it almost certainly detached in flight. An upwards bending of the wing in flight, while the fairing was initially snagged on the flap control rod, would create the tears around the holes seen in the fairing and there was no other practical explanation for this fairing damage or for its location. This physical evidence, from the upward bending failure and the belly fairing, combined with the evidence from a number of eye witnesses who reported observing something wrong with one wing as the aircraft descended, resulted in the investigation concluding that the left wing failed in upwards bending in flight. This would have caused a spinning-type descent as observed by the witnesses.

The upper carry-through spar may have suffered some compression damage in the air, but this was not conclusive and the final failure of the upper carry-through spar could have occurred in flight or at impact with the ground. The aft wing attachment probably pulled out at final impact when the wing was thrown forwards, although it may have also been damaged by the landing gear leg moving aft at impact.

Possible causes of the structural failure in flight

Metallurgical examination did not reveal any evidence of corrosion or fatigue on the left wing lower spar caps and there were no defects at the microstructure level. Tensile strength tests revealed that their strength was 10% more than the minimum specification of 441 MPa. Therefore, it was concluded that aerodynamic loads resulted in the stress in the lower spar caps exceeding their material strength.

The possibility of aerodynamic flutter was considered but there was no damage to the left aileron or its hinge, and although the ailerons are not mass-balanced, they are rod-operated (as opposed to cable-operated), which reduces the risk of flutter. Further, the aircraft manufacturer had carried out a flutter analysis which revealed adequate margins up to V_D.

Therefore, either the aircraft exceeded its limit load of 4g, possibly exceeding 6g, or there was an error in the structural design, or a combination of the two. The static wing test had revealed that the lower spar cap was capable of withstanding loads in excess of those experienced at 6g. This was carried out using a different spar cap material but with similar strength to the spar caps in G-GARB. A wing structure could respond differently when dynamic aerodynamic loads are applied. In a wing strength static test the loads are applied slowly, but in flight the loads could be applied quickly if a sudden and rapid control input were made, and this could affect the failure mode. However, the manufacturer's wing strength calculations were reviewed by the LAA, who concluded that there were no significant shortfalls in the calculations for the lower wing spar. At the time of publication there is an unresolved issue between the LAA and the aircraft manufacturer in relation to a tip correction factor which could reduce the reserve factor of the upper carry-through spar by several percent. This might mean that calculations will show that the upper carry-through spar could fail at slightly below 6 g. However, in the case of G-GARB, the lower spar cap has failed in tension and both calculations and ground tests indicate that this will occur above 6 g.

It is therefore concluded that the most probable cause of the left wing failure was a high aerodynamic load, in excess of the 4g limit load, probably closer to 6g and possibly exceeding 6g. An airspeed of 98 mph CAS is sufficient to pull 4g with a large aft stick input, and an airspeed of 120 mph CAS is sufficient to pull 6g, which is 20 mph less than V_{NE}. The aircraft's speed before it made the sudden right descending turn could not be accurately determined from radar data, but it was approximately 97 mph about a minute before the last recorded radar point. Airspeed can be gained by increasing power or descending, and it would not have taken a significant height loss at cruise power to increase speed from 97 mph to the 120 mph airspeed required to pull 6g. It is probable that some upset, or planned descent to increase airspeed, would have occurred first, before a significant nose-up elevator input to exceed 4g and approach 6g.

Possible reasons for the aerodynamic overload of the wing

One possibility for generating high structural loads would be embarking on planned or impromptu aerobatic manoeuvres. However, this would not match the perceived profile of the pilot, especially in the view of the flight instructor who knew him. The possibility that aerobatic manoeuvres were carried out intentionally cannot be entirely discounted, but it appears highly unlikely.

The low-wing configuration of this aircraft allows a good forward and upwards view but to see features on the ground below might require a turn. For much of the flight the aircraft was in straight and level flight, although there were several occasions en route where it changed height and direction quite rapidly, climbing or descending at rates in excess of 1,000 ft/min. On these occasions a climb or descent was associated with a turn; these turns could have been made to view ground features or may have been clearing turns prior to a change of height.

The reason for the final sudden deviation from straight and level flight was not determined but it is possible that the pilot was startled by an unknown event which led to excessive force being used on the flight controls, thereby overloading the wing structure. The elevator control forces are relatively light, 8 kgf to pull 4g at a CG of 30.4% MAC[19], and a substantial input could have the potential to exceed the structural limit of the aircraft, especially if combined with aileron loads in, for instance, a ‘rolling pull-out’.

It is possible to envisage a number of events which could have startled the pilot and led to an instinctive action on the controls. The position and design of the elevator trim control is such that it is possible to move the lever accidentally through a large part of its range and, anecdotally, this has occurred in the past. The flight evaluation revealed that this can cause a significant nose drop in a short period of time. During the flight evaluation the nose drop was expected so the test pilot could respond to it quite quickly, but if it occurred unexpectedly a pilot would react more slowly and the nose attitude could drop further, with further speed increase. A natural reaction by a startled pilot would be to apply an immediate corrective control input by pulling back on the control stick, and if he was aware that the trim lever had been knocked forward, he might pull the trim lever aft rapidly as well. Moving the trim lever aft in these circumstances would have the effect of reducing the aft stick forces and, in conjunction with a pull back on the control stick, reduce the feedback leading to a greater possibility of an excessive aft control input.

The flight evaluation revealed that a sudden aft trim movement of just 2.7 cm was sufficient to generate 2g, with 7.2 cm of further aft travel remaining. So a sudden aft movement of the trim lever alone could also possibly cause the ultimate load of the wing to be exceeded.

Other possible events which could have affected the pilot’s inputs to the flying controls include something within the aircraft taking the pilot by surprise, such as a SkyDemon alert as the aircraft approached Danger Area EGD203. A medical event or incapacitation of either pilot or passenger is possible or, alternatively, an unknown external event such as a potential collision with an object or bird, could have led the pilot to take abrupt avoiding action.

Footnote

[19] This is at the centre of the stick grip. The stick force would have been lower if the pilot had held the stick closer to the top. The accident cg was between 28.9 and 31.2% mac.

Pitch trim control design

It was not possible to determine what events led to the structural overload in this accident but it is of concern that the trim lever in this aircraft type is located in a position, and is of a design, where there is a potential for it to be moved rapidly full-range, either by accident or intent.

There are other microlight aircraft that have pitch trim levers but the LAA and BMAA were not aware of any other that had a pitch trim lever located between the seats as on the EV-97. There have been occasions of inadvertent operation of the trim lever on the EV-97 and the flight evaluation revealed the potential for this causing a significant upset. According to BCAR Section S 677, the trim system should be designed to prevent '*inadvertent, improper, or abrupt trim operation*'. Therefore:

Safety Recommendation 2018-001

It is recommended that the Civil Aviation Authority require the Light Aircraft Association, the British Microlight Aircraft Association, Light Sport Aviation Ltd and Evektor to conduct a joint review of the design and location of the pitch trim mechanism on the EV-97 Teameurostar UK, and the amateur-built EV-97 Eurostar, to identify whether modification is required to prevent inadvertent, improper or abrupt input.

Conclusion

The aircraft was seen to pitch steeply nose-up, enter a steep spinning-type descent and then strike the ground. The left wing appeared to fold rearwards in the descent after a structural failure near the root of this wing, caused by upward bending of that wing beyond its design limits.

No pre-existing material defect, or significant design issue, was found. The left wing failure was therefore probably as a result of a high aerodynamic load, in excess of the 4g limit load, probably closer to and possibly exceeding 6g. It is most likely to have occurred as a result of an attempted recovery from an inadvertent manoeuvre inducing the structural overload.

The cause of the manoeuvre could not be identified, but could have been due to inadvertent trim operation as there is a potential for the pitch-trim lever to be moved rapidly full-range by accident, for which a Safety Recommendation has been made. Other possible reasons include an event within the aircraft taking the pilot by surprise, a medical issue or incapacitation of either pilot or passenger, or avoiding a potential collision with an object or bird.