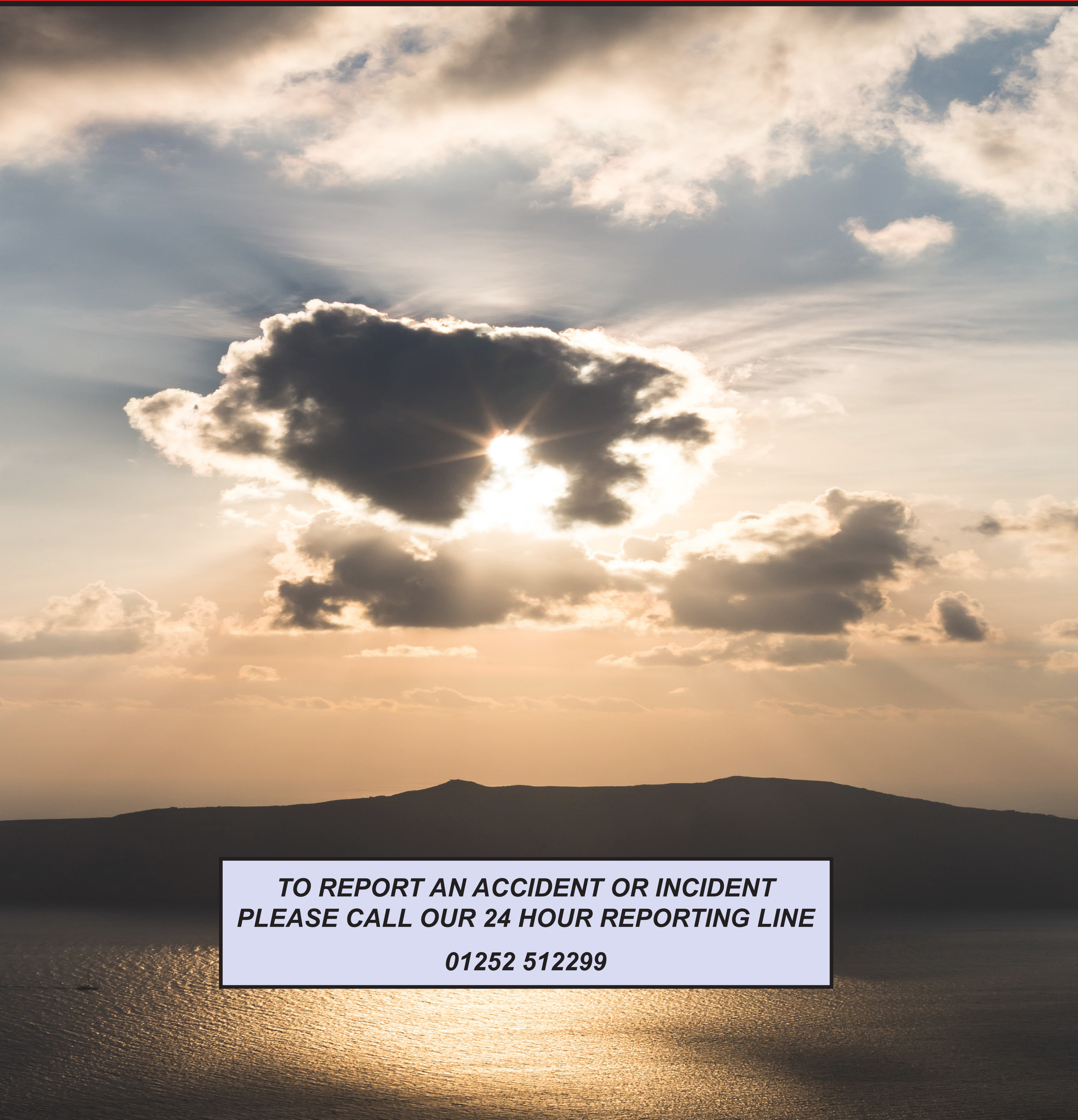
AAIB
Air Accidents Investigation Branch

AAIB Bulletin 3/2016



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(ALL TIMES IN THIS BULLETIN ARE UTC)

AAIB Field Investigation Reports

A field investigation is an independent investigation in which AAIB investigators collect, record and analyse evidence.

The process may include, attending the scene of the accident or serious incident; interviewing witnesses; reviewing documents, procedures and practices; examining aircraft wreckage or components; and analysing recorded data.

The investigation, which can take a number of months to complete, will conclude with a published report.

ACCIDENT

Aircraft Type and Registration:	BAe 146-200, G-RAJJ
No & Type of Engines:	4 ALF502R-5 turbojet engines
Year of Manufacture:	1988 (serial number E2108)
Date & Time (UTC):	23 February 2015 at 1854 hrs
Location:	Guernsey Airport, Channel Islands
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 47
Injuries:	Crew - None Passengers - None
Nature of Damage:	Shock absorber damaged beyond economic repair, damage to left main landing gear and No 1 tyre burst
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	58
Commander's Flying Experience:	8,428 Hours (of which 5,300 were on type) Last 90 days - 32 hours Last 28 days - 23 hours
Information Source:	AAIB Field Investigation

Synopsis

After the aircraft took off from Gatwick, the landing gear was selected UP but the gear position indicators remained red, indicating that the landing gear was not in the position selected. The crew followed the emergency checklist and selected gear DOWN and the indications changed to green, indicating that the landing gear was now down-and-locked. The crew elected to continue to Guernsey, Channel Islands and landed on Runway 27. On touchdown, the aircraft pulled to the left and the co-pilot reported that there was no brake pressure. The commander suspected a tyre had burst and that hydraulic pressure had been lost. He therefore changed to the alternative braking system, slowed the aircraft and vacated the runway. The flight crew continued to taxi the aircraft and eight minutes passed before Guernsey ATC were informed that a tyre may have burst. Another aircraft landed on the runway during this period and before a runway inspection was initiated.

Once G-RAJJ was parked, the crew discovered that the shock absorber on the left landing gear had separated and the tyre on the No 1 mainwheel had burst. Debris from the tyre and shock absorber was subsequently found on Runway 27. The shock absorber separated either as a result of a hard landing, or incorrect gas pressures and oil level in the shock absorber. The physical damage to the shock absorber diaphragm threads and locking bolts started at least two flight cycles prior to the accident flight and may have occurred whilst it was fitted to another aircraft.

History of the flight

The crew reported for duty at Birmingham Airport at 1430 hrs and flew the aircraft to Gatwick for a charter flight to Guernsey, Channel Islands. The aircraft took off from Gatwick at 1807 hrs; it was dark with good visibility and a light south-westerly breeze and scattered showers in the vicinity of the airport.

Once a positive rate of climb had been achieved, the commander who was pilot flying (PF), instructed the co-pilot to move the gear selector to UP. The landing gear was heard to travel and the nose gear indication showed green, but the position indicators for both main landing gear remained red, indicating that neither gear had locked in the UP position. The Standard Instrument Departure was followed and, at a safe altitude, the pilots referred to the emergency checklist for '*Gear Selector UP but Gear Does Not Lock Up'*. At 1811 hrs, ATC instructed the aircraft to climb to FL140. The crew's response was to request to remain at FL120 whilst they dealt with an "issue" with the landing gear. This was the first occasion ATC had been informed of a problem with the aircraft.

The crew actioned the emergency checklist and selected the landing gear DOWN. Shortly afterwards all three gear position indicators showed green, indicating that the landing gear was down-and-locked. The secondary landing gear indicators were checked and these also showed green. To assist with their decision making, the crew followed the DODAR[1] mnemonic. They established that there was sufficient fuel for the short sector with the gear down and, as there were no other abnormal indications, they decided they should continue to the passengers' expected destination. The co-pilot informed ATC that they had dealt with the situation and were proceeding to Guernsey with the landing gear in the DOWN position. The cabin crew were briefed and were subsequently informed that everything was normal and that they could carry on with the cabin service. On handover to Guernsey ATC the crew reported that they expected to make a normal approach and landing, although initially it might be flown at a slower speed than normal. A radar-vectored approach was made to the ILS for Runway 27 and, prior to touchdown, ATC reported the wind as 260º at 21 kt. There were showers in the vicinity and the runway was damp, but there was no low cloud and visibility was greater than 10 km. The aircraft's landing mass was calculated to be 35,206 kg, which was 1,534 kg less than the maximum allowed.

All indications were normal during the approach but on touchdown the aircraft pulled to the left. The commander thought that a tyre on the left side had "blown", but there was no associated noise and he was able to keep the aircraft close to the runway centreline using the rudder. However, the brakes were ineffective and the co-pilot noticed that no pressure was indicated on the Green system gauge. He announced "NO BRAKE PRESSURE SWITCH TO ALTERNATE SYSTEM". The commander selected the alternative brake system[2] and the aircraft then responded "normally" to his braking inputs. He slowed the aircraft and vacated the runway without discussing the suspected tyre burst or brake pressure loss.

Footnote

[1] The pneumonic DODAR is used by the operator as an aid to decision making in abnormal circumstances. The D stands for Diagnose, O is for Options, the second D is for Decide, A is for Allocate and R is for Review.
[2] The normal brake system is the Green system and the alternate system is the Yellow system.

Once the aircraft was on the parallel taxiway, the crew noticed the aircraft was listing to the left. They agreed that it was likely that a tyre had burst and decided it was best to keep the aircraft rolling, so the co-pilot asked ATC, "WOULD YOU MIND GIVING US PROGRESSIVE TAXI, IT'S JUST THAT THERE'S A COUPLE OF ISSUES EMANATING FROM THE GEAR ISSUE, SO JUST KEEP AN EYE ON US AND IF WE COULD GET PROGRESSIVE THAT WOULD BE MUCH APPRECIATED."

One minute later the crew requested a remote parking stand in anticipation of having to investigate the landing gear problems. The aircraft had already passed the remote parking area, so the crew were told to continue along the parallel taxiway towards the Runway 27 threshold. ATC subsequently instructed them to re-enter Runway 27, after another aircraft had landed, and vacate again at the first intersection.

While they continued to taxi the aircraft, the crew noticed it was listing further to the left. The operator's chief engineer, who was there to provide overnight maintenance cover, occupied the flight deck jump seat. He suggested it was possible both tyres on the left side had burst but the commander discounted this. The commander believed an increased level of engine power would have been needed to taxi the aircraft if both tyres had burst. After discussing the matter, the crew decided to continue taxiing but to ask for a vehicle to attend to report on the condition. Consequently, eight minutes after landing, while taxiing along the runway, the crew asked ATC, "COULD YOU POSSIBLY GET SOMEBODY TO FOLLOW US, WE JUST WANTED TO GET A MONITORING... OUR LEFT UNDERCARRIAGE. IT LOOKS LIKE WE'VE LOST TWO TYRES ON TOP OF WHAT WE HAD." ATC asked if this meant that the aircraft had burst a tyre on landing and, when they were told this was the case, they delayed another aircraft's departure to allow the runway to be inspected.

After the aircraft vacated the runway again, ATC passed an observation from Airfield Operations that the aircraft was listing to the left. The Rescue and Fire Fighting Service (RFFS) followed the aircraft to its parking stand and it was subsequently discovered that the outer tyre on the No 1 mainwheel had burst and the left main landing gear shock absorber had separated into two parts.

No debris was found during the initial runway inspection but later a small piece of rubber was found on the parallel taxiway. The next morning, during the airfield's pre-opening inspection, a ring seal and more rubber was found close to the southern edge of Runway 27, approximately 100 m from the threshold. A subsequent inspection found a bolt head, attached to a piece of locking wire approximately 8 inches long, at the threshold.

Crew comments

The commander had previous experiences of unusual landing gear indications on the BAe 146, which he understood to have been caused by faulty microswitches. In this case the departure had felt smooth and he assumed that a faulty microswitch was likely to have caused the red indications when the gear was selected UP.

The commander did not stop G-RAJJ on the runway after landing in order not to block the runway or the taxiway. He considered it safe to taxi the aircraft with a burst tyre and with one failed hydraulic system, given that there were two other working hydraulic systems.

Runway contamination

As the aircraft taxied, another passenger aircraft landed without incident on Runway 27 before ATC was alerted to the possibility of a tyre-burst. The pilot of this aircraft only became aware after landing that the runway might have been contaminated and therefore filed an MOR.

Guernsey Airport's Senior Air Traffic Controller (SATCO) later observed that in previous tyre-burst or deflation occurrences, the aircraft involved halted immediately and notified ATC. This allowed the RFFS and Airport Operations to be alerted. The SATCO commented that if the crew had followed this procedure, the RFFS would have attended the scene and provided safety cover and assistance. Moreover, Airport Operations would have managed the recovery of any debris and informed ATC once the runway was available for the resumption of operations. In this instance, the damage only became apparent after the aircraft had parked and it was realised there was a risk that debris might have contaminated the manoeuvring area.

Operator's investigation

An internal investigation by the operator determined that a PAN call should have been made by the flight crew to alert ATC at Gatwick to the landing gear malfunction. Also, as the crew did not know the cause of the abnormal gear indications, a more suitable decision was to return to Gatwick (which has a longer runway) than to continue to Guernsey with the landing gear in the DOWN position.

Following a suspected tyre-burst or other landing gear malfunction on landing, the operator expects an aircraft to be stopped on the runway, or in certain circumstances to stop once clear of the runway, and alert ATC without delay. An external inspection should be sought and, if this indicated that a tyre had burst, the aircraft should not continue to taxi as this can increase the load on the other tyres.

Recorded information

The aircraft was equipped with a flight data recorder (FDR) and cockpit voice recorder (CVR), both of which used a tape recording medium, and a solid-state quick assess recorder (QAR) which received the same input data stream as the FDR. The CVR was not downloaded as the recording of the accident flight would have been overwritten. The FDR was downloaded at the AAIB and a copy of the QAR data for the accident flight was provided to the AAIB by the operator.

Due to the age of the aircraft and the relevant regulations at the time of manufacture, parameters recorded by the FDR (and QAR) such as Weight on Wheels, gear lever selection and brake pressures, that would have been useful for this investigation, were not recorded. However, the landing gear (all down-and-locked) and landing gear (all up-and-locked) discretes (sampled every second) were captured.

A time history of the salient parameters from the QAR for the takeoff from Gatwick Airport is shown at Figure 1. The data shows that during the climb, at between 75 ft and 99 ft agl, the landing gear was no longer down-and-locked, which was consistent with the gear selector being moved to the UP position. However, the landing gear did not go into the up-and-locked position, which was consistent with the position indicators showing red. The gear returned to the down-and-locked position just over eight minutes later, when the aircraft was at about FL120, which was consistent with the gear selector being moved to the DN position and the position indicators showing green. The landing gear remained in this state for the rest of the flight.

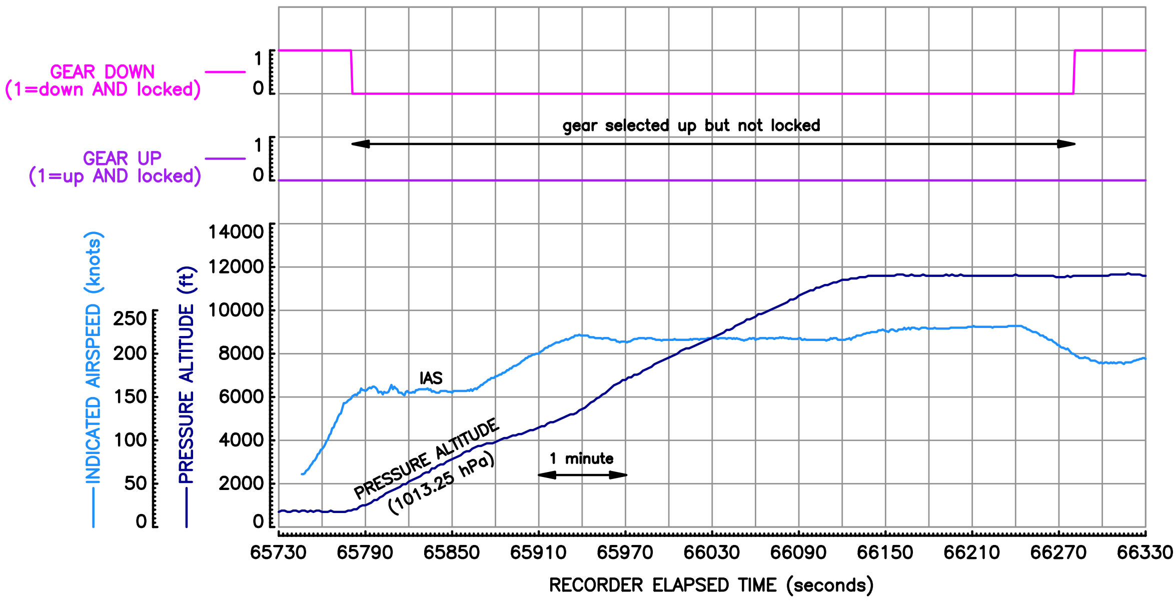

Figure 1

G-RAJJ salient flight data from QAR

FDR data quality

From the downloaded data it was evident that there was a fault with the FDR in that several of the tape tracks, including the track containing the accident flight, contained a significant amount of corrupted data, while the remaining tracks were good. When the operator was asked to provide evidence to show that the FDR was being checked annually for correct operation, in accordance with the regulations[3], it was evident that the QAR data recordings were being used to demonstrate this instead, and that the last overhaul of the FDR had been conducted 25 months previously, in January 2013. A functional check of the FDR had been made in July 2014; however, this did not involve checking the quality or consistency of the data and so did not flag up any faults.

This oversight by the operator has since been rectified and the correct acceptable means of compliance to the requirements of the regulations is now being followed.

Footnote

3 Commission Regulation (EU) No 965/2012 CAT.GEN.MPA.195 Preservation, production and use of flight recorder recordings, requires that "*(b) The operator shall conduct operational checks and evaluations of flight data recorder (FDR) recordings, cockpit voice recorder (CVR) recordings and data link recordings to ensure the continued serviceability of the recordings*". The acceptable means of compliance, given in EASA document Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-CAT (April 2014), requires that this should be done annually for tape-based flight recorders.

Systems description

The main landing gear is a twin-wheel, inward retracting, lever suspension incorporating a nitrogen-charged two-stage shock absorber. Hydraulic pipes for the braking system are mounted on the outside of the landing gear. A side stay is installed between the main landing gear and the airframe to provide a mechanically-locked support when the gear is in the extended position. During the retraction sequence, movement of the direction link causes the shock absorber and the wheel lever to fold, which shortens the landing gear to allow it to fit into the wheel bay. The shock absorber remains fully extended during the retraction sequence, Figure 2.

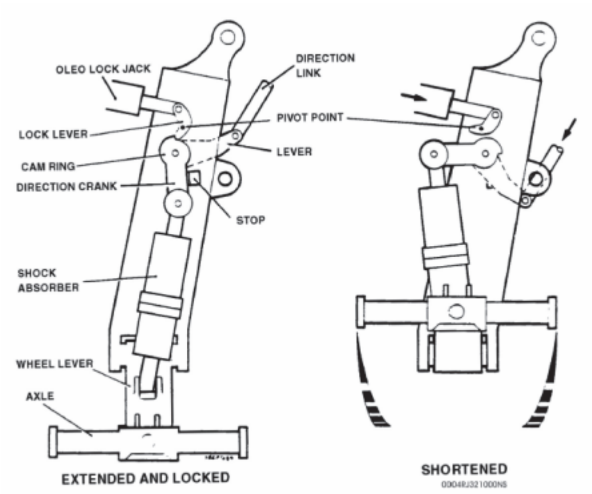

Figure 2

Schematic of main landing gear

The shock absorber assembly consists of three main parts: an outer cylinder, inner cylinder and a piston rod, Figure 3. The stationary outer cylinder is connected at an 'eye end' to the main landing gear assembly by a crank lever and the inner cylinder is connected at an eye end to the wheel lever. The piston rod is bolted to the outer cylinder and the inner cylinder is free to slide within the outer cylinder.

The inner cylinder houses the 1st stage floating piston, which separates the oil from the low pressure nitrogen charge. The cylinder is supported at its upper end by a diaphragm, which incorporates a recoil ring. The recoil ring is free to float between the drilled and slotted flanges of the diaphragm, permitting free or restricted flow of oil, according to its position (one of these slotted flanges had broken during the event). The diaphragm is screwed into the inner cylinder and is torque-loaded and locked in place by two wire-locked bolts.

A 2nd stage floating piston is installed inside the piston rod to separate the oil from the high pressure nitrogen charge. A piston head containing a valve plate is screwed into the lower end of the piston rod and is secured by four locking bolts. The valve plate is free to float between the valve housing and the drilled face of the piston head to permit free or restricted flow of oil between the cylinders and the piston rod, according to the position of the valve plate. A central orifice in the valve plate allows a metered flow of oil across the valve plate.

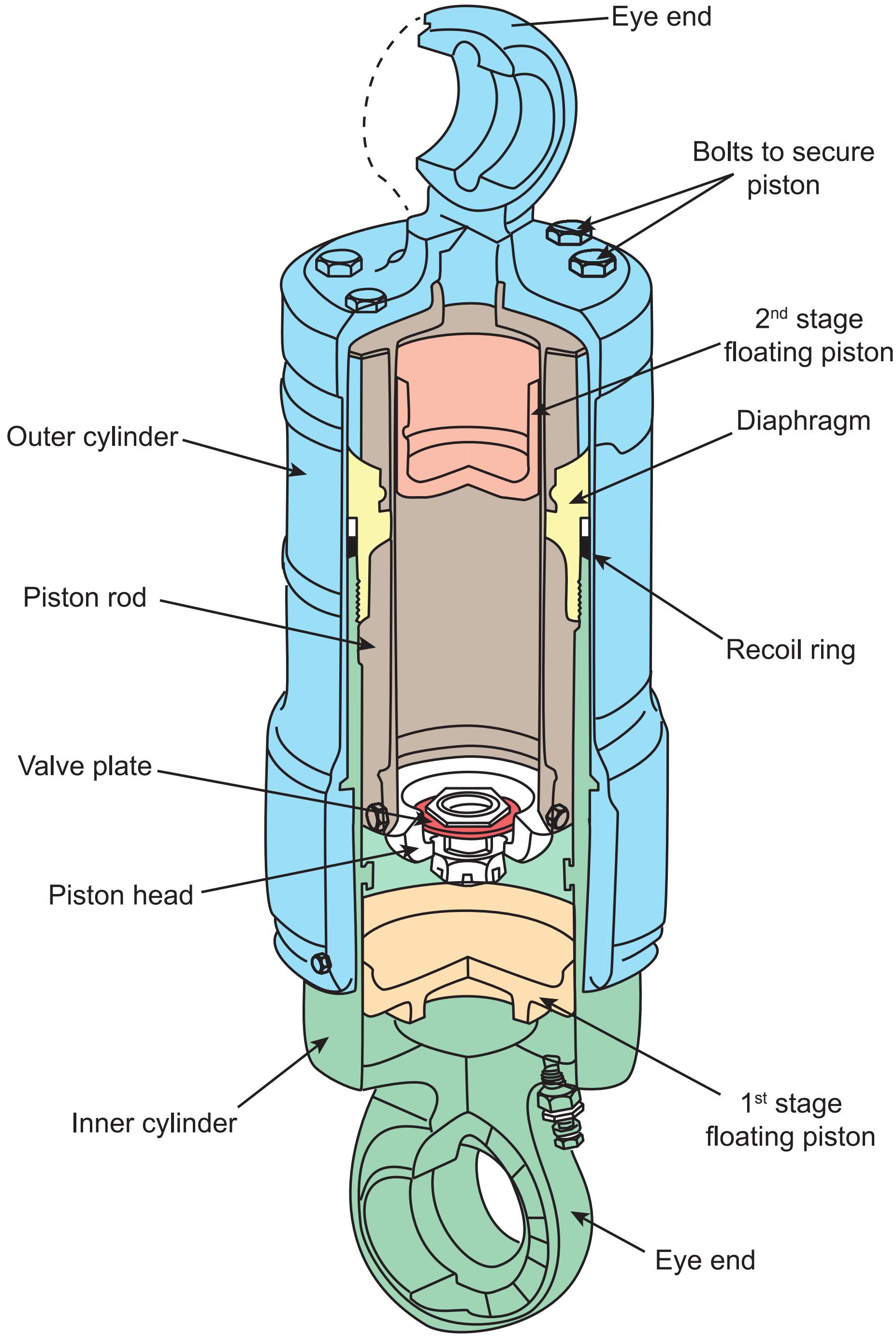

Figure 3

Cutaway of shock absorber assembly

Operation of the shock absorber

When a load is applied to the shock absorber the inner cylinder telescopes into the outer cylinder and displaces the oil above the diaphragm. The oil forced through the orifices in the diaphragm generates pressure against the 1st stage floating piston in the inner cylinder to compress the nitrogen further. The recoil ring is forced against the slotted lower flange of the diaphragm allowing oil to pass freely into the increasing volume around the inner cylinder.

If the load causes more than approximately 50% closure of the shock absorber, the nitrogen pressure above the 2nd stage floating piston in the piston rod equals the nitrogen pressure below the 1st stage floating piston in the inner cylinder. On further closure, oil displaced from the inner cylinder opens the valve plate and flows without restriction to act on the floating piston in the piston rod, causing further compression of the nitrogen. Shock loads are absorbed by the dual action of forcing oil through the orifices and the increase in nitrogen pressures.

When the recoil action takes place, the shock absorber extends to its full length and the diaphragm makes contact with its mechanical stop. During recoil, nitrogen pressure above the floating piston in the piston rod forces the floating piston downwards and displaces oil into the inner cylinder. This action causes the plate valve to seat on the piston head. Oil can now only transfer through the central orifice in the valve housing and this restriction of flow provides a damping action. As the shock absorber extends, the nitrogen pressure above the 2nd stage floating piston in the piston rod drops below the pressure in the space above the 1st stage floating piston in the inner cylinder. This allows the 1st stage floating piston in the inner cylinder to move upwards and displace oil through the diaphragm. Oil displaced from the decreasing volume around the inner cylinder forces the recoil ring up against the drilled upper flange of the diaphragm causing a restriction to flow, further damping the recoil.

Landing gear indication

The primary landing gear position indication is provided by an array of six annunciators: three red and three green. The annunciators are controlled through the proximity switches and indicate the following:

Green annunciator illuminated:	Gear down-and-locked
Red annunciator illuminated:	Gear not in position selected
Neither annunciator illuminated:	Gear up-and-locked

A visual indication that the landing gear is not in the selected position is provided by a red warning light on the landing gear selector lever (Figure 4). In addition, standby indicators are located beneath the landing gear emergency selection handle. These indicators only provide an indication when the gear is down-and-locked.

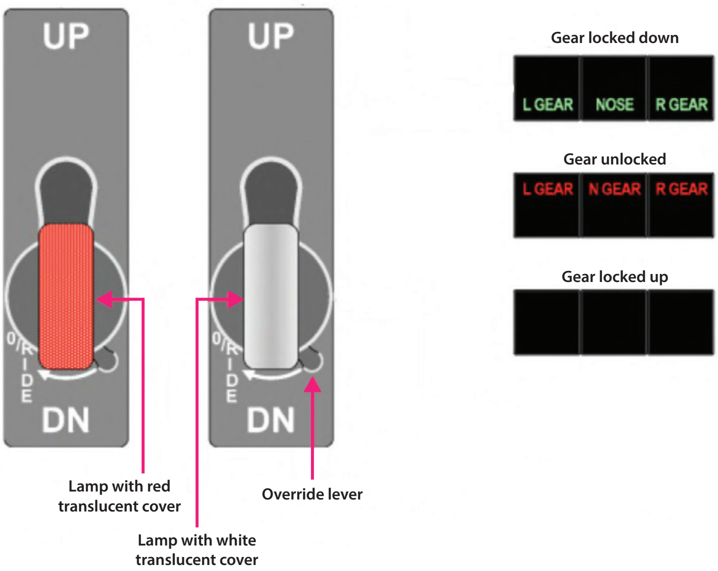

Figure 4

Landing gear annunciators

Wheel braking system

The aircraft is fitted with four mainwheels numbered 1 to 4 from left to right. The mainwheel braking system uses the Green and Yellow hydraulic systems with the Green system used for normal braking[4] and the Yellow system as standby, Figure 5. A selector switch, located on the centre console, allows the crew to select the hydraulic system used for braking. The braking system incorporates hydraulic fuses, anti-skid control valves, a control box and a brake pack fitted to each mainwheel. Two hydraulic pressure gauges, one each for the Green and Yellow system, are mounted on the instrument panel and provide an indication of the hydraulic pressure applied by each of the four Brake Control Valves, which are mechanically linked to the pilot's corresponding pedal. The pressure transducers for these pressure indicators are mounted upstream of the anti-skid valves, which control the pressure from the hydraulic supply to the brake packs.

The anti-skid control box receives signals from rotary Weight on Wheels (WoW) switches and wheel speed transducers fitted to each mainwheel. When the logic determines that the aircraft is airborne, the control box sends a signal to the anti-skid control valves, dissipating the hydraulic pressure in the brake lines. On landing, full anti-skid functionality is obtained when either the outboard or inboard WoW on each axle is active, or at least one wheel on each main landing gear leg has spun up.

Each brake pack is provided with a dedicated Green and Yellow hydraulic hose. The Green and Yellow system hoses are separated and are positioned on either side of the landing gear leg. Each hydraulic brake pipe is equipped with a hydraulic fuse located in the forward

Footnote

4 Most BA146 aircraft use the Yellow system as the primary system; however G-RAJJ, which was pre-mod HCM00967A, uses the Green hydraulic system as the primary.

landing gear bay pressure bulkhead. The hydraulic fuses monitor the pressure downstream and if they detect a drop in pressure they close, preventing the loss of hydraulic fluid from the hydraulic system. Hydraulic fuses can only be reset on the ground. In the case of a single hose failure, the hydraulic fuse only isolates the affected brake pack and brake pressure would still be provided to the other three brake packs. Switching to the alternative hydraulic system would restore braking to all four mainwheels.

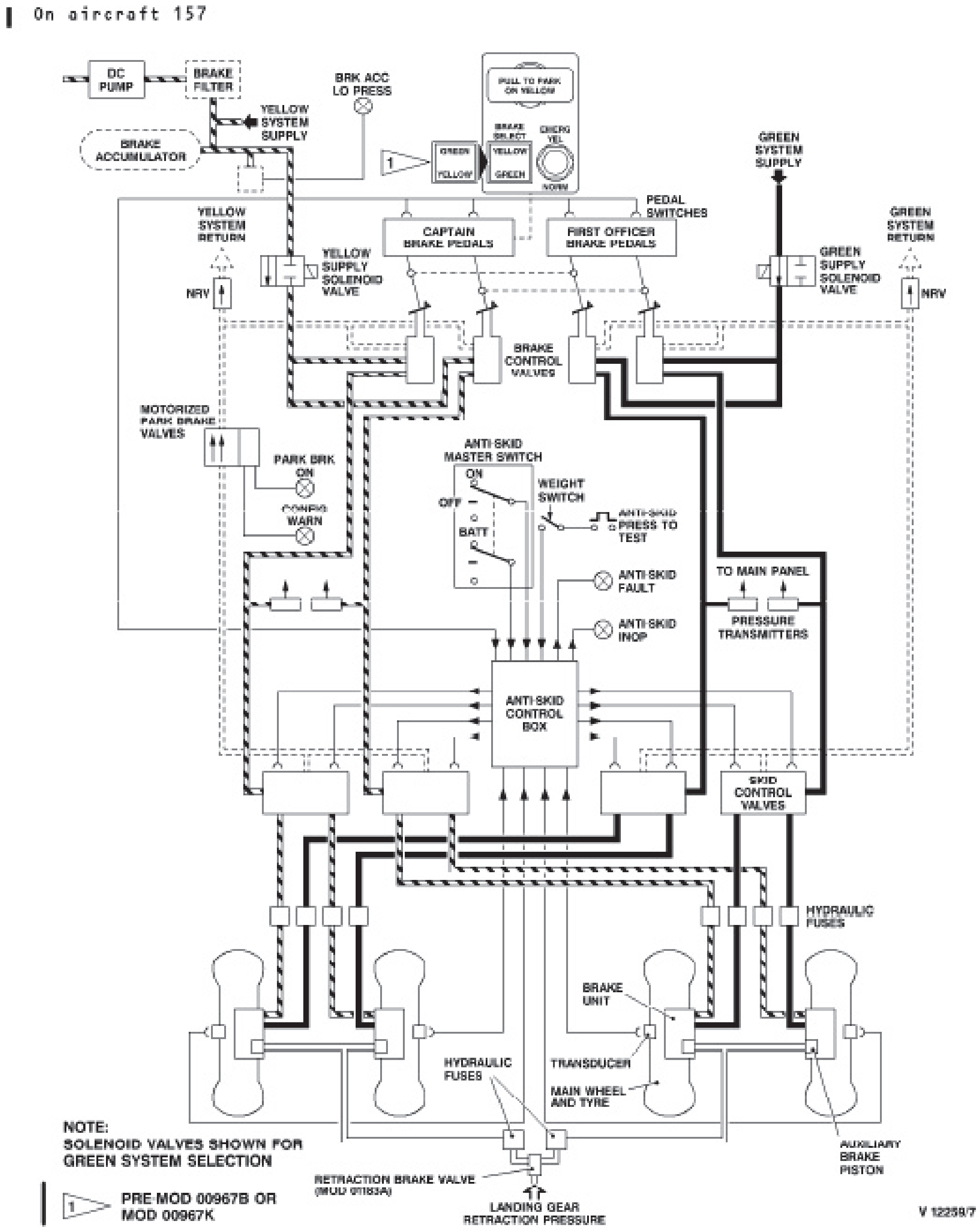

Figure 5

Aircraft hydraulic system

Damage to aircraft

Following the accident the shock absorber inner cylinder was found to have separated from the outer cylinder, Figure 6. The top surface of the wheel lever had sustained damage as a result of contact with the outer cylinder. The inner cylinder had made contact with the No 1 brake pack Green hydraulic system quick release pipe, causing it to detach from its connecting union. The operator's engineers later established that the Green hydraulic system had only lost one litre of fluid.

The inner cylinder also rubbed against the inner sidewall of the outer tyre (No 1 mainwheel), which had punctured and deflated. The frame, which runs down the centre of the lower fuselage between the main landing gear bays, had been damaged. Tyre marks indicate that the No 2 mainwheel caused this damage during the retraction sequence. The sheared bolt head attached to a long section of locking wire recovered from the runway was identified as being from one of the shock absorber diaphragm locking bolts. There was no damage to the bottom of the wheel lever.

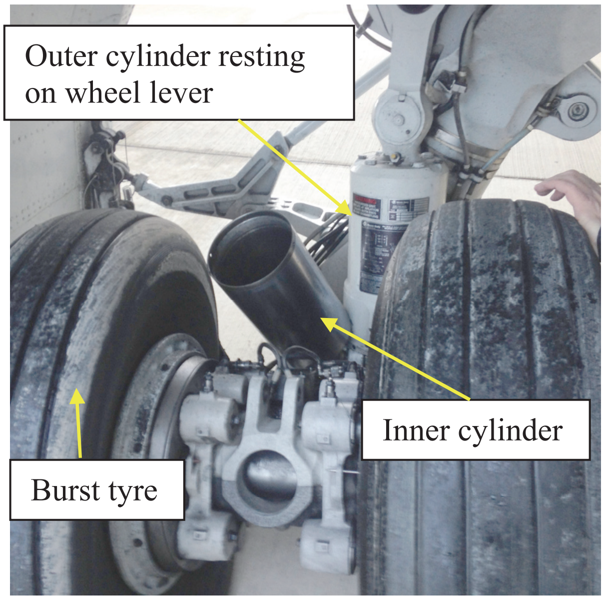

Figure 6
Left main landing gear

Examination of the shock absorber

Initial examination

After the aircraft landed at Guernsey, the operator's engineers refitted the inner cylinder on the shock absorber into the outer cylinder in order to move the aircraft into the hangar. This action damaged the threads on the diaphragm, which subsequently increased the difficulty in establishing the reason why the shock absorber separated. However, prior to reassembling the shock absorber, the engineers carried out a visual inspection of the threads on the inner cylinder, where the diaphragm is located, and reported that they were clean and free from any visible signs of corrosion, contamination or any significant wear.

Detailed examination

The component manufacturer, under the supervision of the AAIB, carried out a detailed examination of the shock absorber. This examination required parts of the shock absorber to be sectioned and established the following:

- There was some damage to the eye-ends on both the inner and outer cylinder caused by contact with the main landing gear.
- The surface finish on part of the outer cylinder had abraded away as a result of having been in contact with the rotating tyre.
- The 1st stage floating piston was missing. This piston would have been forced out of the shock absorber by the pressurised nitrogen when the inner cylinder came out of the outer cylinder during separation.
- The threads on the inner cylinder (steel) were found to be intact, whereas the threads on the diaphragm (aluminium alloy) had sheared in a direction consistent with a compressive load forcing the diaphragm and inner cylinder together.
- Examination of the sheared thread shards from the diaphragm suggested that the threads were intact prior to shearing. This indicates that the threads sheared during one event.
- The location of the diaphragm thread shards within the shock absorber suggested that the shards were present whilst oil was still flowing in the shock absorber. This indicates that thread shearing occurred before separation of the shock absorber.
- The heads of the two diaphragm locking bolts had sheared. The head of one bolt was recovered from the runway at Guernsey. The other bolt head was not recovered.
- The locking bolt fracture surfaces only showed evidence of fracture due to shear overload. These bolts had failed in a direction consistent with a tensile load forcing the diaphragm and inner cylinder to separate.
- One of the slotted flanges had broken away from the diaphragm. It was concluded from the damage to the flange that the sheared diaphragm locking bolt head had become trapped between the flange and the outer cylinder bore causing the flange to break, Figure 7.
- Mechanical damage on the diaphragm, shim, recoil ring and outer cylinder, was assessed as having been caused by the bolt head, which suggests that the locking bolts had sheared some cycles before separation of the shock absorber.

- One small area of fatigue cracking was seen in the threads on the diaphragm, in the first full thread immediately below one of the locking bolt holes. The cracking consisted of two fatigue cracks, one on each side of the thread. This damage was consistent with the threads on the diaphragm and inner cylinder having been cyclically loaded in both tension and compression.
- The hardness of the diaphragm and inner cylinder materials were within specification. The locking bolt hardness was slightly above specification, but this is not thought to have contributed to its fracture, or separation of the shock absorber.
- The material microstructures of the diaphragm and inner cylinder were normal.

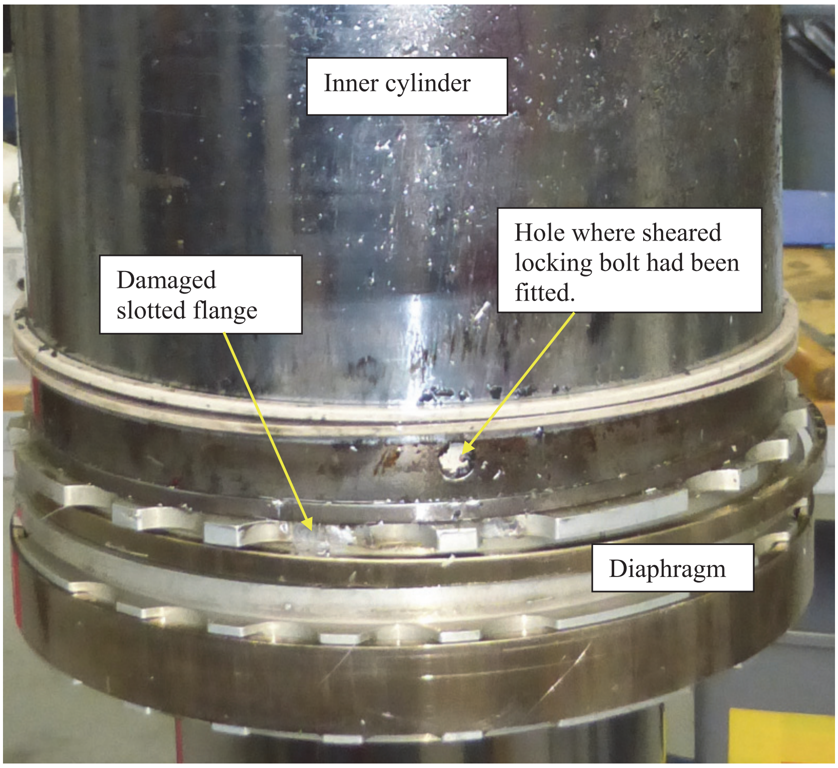

Figure 7

Inner cylinder and diaphragm

Maintenance

The operator reported that the last maintenance on the shock absorber had been carried out during the 'C' check when the shock absorber was replaced and the oil level, nitrogen pressures and landing gear extension would have been checked. There had been no reports during the subsequent daily inspections of the extension of the left landing gear leg appearing to be incorrect. There were also no records of any reports of a hard landing having occurred prior to the accident flight.

History of the shock absorber

The shocker absorber fitted to the left landing gear on G-RAJJ (serial number DRG/5455/87) had a life limit of 60,000 cycles and an overhaul interval of 15,000 cycles or 12 years. It had last been overhauled in June 2003 and then fitted to an Avro RJ-70 and operated until February 2010 when the aircraft was put into storage.

In April 2013 it was removed, in a serviceable condition, from the Avro RJ-70 and visually inspected before being placed in storage. The Cycles Since New (CSN) was recorded as 33,394 and the Cycles Since Overhaul (CSO) as 3,882. An EASA Form 1 for the component was issued on 9 July 2013 (Release number M5754). The shock absorber was subsequently provided to the operator on 5 January 2015.

The shock absorber was fitted to G-RAJJ during the 'C' check, which was completed on 8 January 2015 and flew a further 27 cycles, prior to the accident flight on 23 February 2015. The next overhaul was due on 9 June 2015.

Both the aircraft and component manufacturer reported that they were unaware of any previous occurrences of a separation having occurred on this type of shock absorber.

Analysis

Overview

The investigation concluded that the physical damage to the shock absorber diaphragm threads and locking bolts started at least two flight cycles prior to the accident flight and may have occurred whilst it was fitted to another aircraft. The final failure of the thread on the diaphragm in the shock absorber would have occurred during the landing at Gatwick, but separation did not occur until the next take-off when the recoil forces forced the shock absorber apart.

Separation of the shock absorber

The loss of the 1st stage floating piston and damage to the threads on the diaphragm, caused when it was reassembled, made it difficult to establish why the shock absorber separated. The component manufacturer reported that they had never previously experienced a BAe 146 shock absorber separating, nor were they aware of other occasions when the diaphragm locking bolts had sheared or fatigue damage had been found on the threads on the diaphragm.

The number of score marks on the bore of the outer cylinder indicated that the head of the locking bolts had sheared off at least two flight cycles before the shock absorber came apart. Shards from the sheared thread on the diaphragm were found throughout the shock absorber indicating that the oil had moved them as the shock absorber cycled.

From the physical damage it was assessed by the component manufacturer that the initiating factor was most likely to have been the threads on the diaphragm jumping across the threads on the inner cylinder. This jumping movement of the threads would have applied a shear load on the diaphragm locking bolts causing them to fracture. Thread jumping could have occurred one thread pitch at a time, or several at a time, thereby reducing the number of threads in engagement. During the subsequent landing at Gatwick, the compression damping load on the diaphragm exceeded the shear fracture load of the reduced number of engaged threads causing them to shear and thereafter shearing the non-engaged threads. As the aircraft departed Gatwick the shock absorber would have extended during recoil; however, because the threads on the diaphragm had sheared, there was no longer a mechanical stop to prevent the shock absorber from separating.

At some time prior to the fracture of the locking bolts, the torque between the diaphragm and the inner cylinder would have reduced, allowing fatigue cracks to develop on the first full thread on the diaphragm. These fatigue cracks did not cause, or contribute, to the separation of the shock absorber.

As a consequence of the separation, during the retraction sequence the left main landing gear would not be able to 'shorten' and fit into the bay, which resulted in the No 2 mainwheel fouling on the frame. It is likely that the right main landing gear, No 3 mainwheel, then fouled on the No 2 mainwheel preventing it from fully retracting. This resulted in the illumination of both main landing gear position red indicators.

Examination of the shock absorber indicated that it had been correctly manufactured and assembled. Therefore, for the threads on the diaphragm to jump, and the locking bolts to shear, the shock absorber must have experienced recoil loads beyond its design load. This load could have resulted from a hard landing, with a subsequent bounce, or incorrect gas pressures and oil level in the shock absorber. The aircraft operator reported that the shock absorber had not had any maintenance since it had been fitted to the aircraft and there had been no reports of it having experienced a heavy landing. The shock absorber had not been disassembled since its last overhaul in 2003 and the physical damage to the diaphragm thread and locking bolts may have occurred whilst it was fitted to another aircraft.

Loss of Green hydraulic pressure

The co-pilot reported that shortly after touchdown he noticed that there was no brake pressure reading on the Green system brake indicator. However, the investigation could not establish why this should be the case.

For there to have been no brake pressure, there must have been either no hydraulic fluid or pressure available. However, neither pilot noticed any hydraulic warnings and the engineers reported that the Green system had only lost one litre of hydraulic fluid. This indicates that the hydraulic fuse in the Green No 1 brake supply line operated after the union became disconnected.

The brake pressure transducers, which supply the brake pressure gauges, are upstream of the anti-skid control valves and operation of the anti-skid system has no effect on the brake pressure displayed to the pilots. Therefore the anti-skid valve could not have caused the loss of pressure. Moreover, the anti-skid control box does not differentiate between the Green or Yellow system with regards to anti-skid and, therefore, any anti-skid signal would be the same regardless of which hydraulic system the pilot had selected.

A brake pressure check is carried out during the landing checklist. On the accident flight the crew did not detect a loss of brake pressure during this check. Switching between the hydraulic systems is performed by solenoid valves in the Green and Yellow systems. Since the accident there has been no indication of a fault with the solenoid valves and therefore it is unlikely that a solenoid valve failed.

The disconnection of the Green hydraulic hose to the brake pack would only have affected the braking on the No 1 mainwheel and would not have affected the braking efficiency of the other wheel on the axle. Therefore the pilot should have been able to stop the aircraft in a controlled manner using the Green hydraulic system.

Crew response

The pilots followed the emergency checklist correctly and resolved the abnormal landing gear indication, but they did not appear to have considered the possibility that this indication was caused by a mechanical malfunction. This was because the takeoff run felt smooth and the commander's thinking was influenced by his previous experience of abnormal gear indications.

There was a delay before ATC was informed of a problem but no PAN call was made and no details were shared other than there was an "issue" with the gear. The crew believed they properly assessed the situation before deciding to continue to their passengers' destination; it was a short sector, the only abnormal indication was that they were cruising with the gear down and there was plenty of fuel to cope with the extra drag. The operator's assessment was that a more suitable decision would have been to return to Gatwick.

The landing roll was well-controlled by the crew in response to a burst tyre and the failure of one brake system. However, the operator and ATC expect an aircraft with a suspected burst tyre to be brought to a halt and not to continue taxiing until an external check has been completed. In this case the aircraft was not stopped and a protracted taxi routing was followed, even though the crew suspected a burst tyre and knew the Green brake system had failed and the aircraft was listing to the left. Their decision-making was influenced by not wanting to block the runway or taxiway and to continue to a parking stand.

Communication with ATC

Airport air traffic controllers expect prompt communication from aircraft when the crew are alerted to a circumstance that could cause contamination of the manoeuvring area. This allows an immediate inspection to be carried out before other aircraft are placed at risk.

In this instance, Guernsey ATC were not informed by the crew about the possibility of a tyre-burst on landing until the aircraft had taxied and some eight minutes had elapsed. Consequently ATC were unaware that the runway was contaminated and allowed another aircraft to land.

ACCIDENT

Aircraft Type and Registration:	Alpi (Cavaciuti) Pioneer 400, G-CGVO
No & Type of Engines:	1 Rotax 914F piston engine
Year of Manufacture:	2011
Date & Time (UTC):	3 January 2015 at 1528 hrs
Location:	Near Popham Airfield, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 2
Injuries:	Crew - 1 (Fatal) Passengers - 2 (1 Fatal) (1 Serious)
Nature of Damage:	Destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	201 hours (of which 5 were on type) Last 90 days - 7 hours Last 28 days - 2 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft departed Bembridge Airfield, Isle of Wight for a VFR flight to Bidford Airfield, near Evesham. However, occasional low cloud and poor visibility may have precluded flight that was clear of cloud and in sight of the surface at all times. The aircraft approached Popham Airfield and manoeuvred as if preparing to land, before continuing in what appeared to be a low level, left-hand circuit. Whilst in the circuit, the aircraft stalled and struck trees before hitting the ground. Two of the occupants died at the scene, a third passenger survived with serious injuries. A defect was identified with the engine turbo (turbocharger) control, which likely resulted in the engine manifold air pressure limit being exceeded and the engine seizing in flight. Four Safety Recommendations are made.

Background

On 2 January 2015 the pilot flew the aircraft for approximately 50 minutes, from Bidford, near Evesham to Bembridge on the Isle of Wight. An adult passenger occupied one of the two rear seats and a young child was a passenger in the front right seat. The VFR flight was made in good weather conditions and passed over three areas where the terrain rose to approximately 800 ft amsl and close to two tall masts, the highest of which was seven miles north of Popham and is recorded as a 1,225 ft amsl obstruction.

The pilot planned the flight using navigation software and his flight log stated that there were 80 litres of fuel on-board, giving an estimated endurance of 3 hours 30 minutes. He flew close to the military airfield at Brize Norton before proceeding towards Popham. While transiting Brize Norton's airspace, the aircraft radio became stuck on transmit for several minutes. The pilot was unaware of this until he next spoke to ATC but the problem resolved itself when he terminated that call.

From a position just west of Popham, the pilot headed south-east, to keep clear of controlled airspace around Southampton Airport. After making radio contact with Solent Radar he was offered a more direct route and transited the eastern edge of the Southampton Control Zone. A recording of these exchanges indicated that the aircraft radio functioned normally and that the pilot used correct RTF procedures. However, he was told by ATC that the secondary radar indications from his transponder were "FLUCTUATING WILDLY" and did not show the aircraft at 2,400 ft amsl, as reported. The pilot remarked that the transponder was "BRAND NEW" and at the request of ATC he turned off the altitude encoding function (Mode C). He stated that he would have the system checked on the ground.

The flight continued south and crossed the Solent (the strait between the English mainland and the Isle of Wight) before landing at Bembridge. The airfield was unmanned and the aircraft parked there overnight. The pilot and his passengers travelled the nine miles to Cowes to spend an evening with friends.

History of the flight

On the morning of 3 January 2015 the pilot and his passengers met with their friends again and remained in their company until departing for the return flight to Bidford that afternoon. The weather in Cowes was overcast and misty and the pilot indicated that this might preclude the flight so provisional arrangements were made to stay a second night if necessary. The forecast for the following day was also poor and the only known reason to return home was to attend a social function.

Later in the morning the pilot noted sufficient improvement in the weather to express some optimism for a flight later that day. He was observed using his smartphone and tablet computer to evaluate the weather, but the friends were not conversant with aviation procedures and he did not discuss the details with them. At approximately 1400 hrs he stated that the weather should be good enough for the flight and one of the friends drove him and his passengers to Bembridge.

The airfield was again unmanned and the pilot reportedly spent approximately 20 minutes preparing the aircraft prior to start-up. There was no indication that any fuel was uplifted at Bembridge and a friend used a mobile phone to take a short video recording as the aircraft taxied to the runway. It was seen to backtrack the runway before the engine sound increased. A second video recording was made at approximately 1500 hrs as the aircraft took off and was lost from sight in misty conditions.

The aircraft's departure was also witnessed by a retired military aviator who was on a hill approximately 0.6 nm south of the Runway 30 threshold. His attention was drawn to the aircraft when he heard the engine being run at high speed. He spotted the stationary aircraft near the threshold and stated that the engine remained at high rpm for approximately one minute. Shortly after this the witness watched the aircraft take off and depart on a northerly track. The aircraft appeared to remain clear of cloud, but he lost sight of it due to poor visibility when it was approximately two miles north of his position. He estimated that the cloud base was probably not higher than 1,000 ft agl and he noted that approximately 30 minutes later it began to rain and the cloud base and visibility reduced to an estimated 300 ft agl and half a mile respectively.

No route plan or flight documentation for the return flight was found and it is presumed that this information was held on the pilot's badly damaged tablet computer (see *Recorded flight data*). Recorded radar evidence suggests that the pilot was backtracking the route that he had flown the previous day, keeping clear of controlled airspace around Southampton and remaining in Class G airspace. The route between Bembridge and Popham traverses ground with an elevation of 400-600 ft amsl but there are spot heights above this within two nautical miles of track.

No evidence was found to indicate that any radio transmissions were made from the aircraft during the flight and there were no reports of it being seen after departure from Bembridge, until it reached the vicinity of Popham. The poor weather had discouraged any other general aviation activity at Popham and airfields nearby that day.

Several witnesses saw the aircraft overfly Popham and turn on what appeared to be a left-hand circuit before it was lost from view. The radio operator at Popham alerted the police at 1528:34 hrs, as he was concerned for the aircraft's safety after it disappeared from view. The front seat passenger later stated that at some point he was told to brace for impact but was unable to recall any other significant evidence concerning the accident flight.

An air ambulance helicopter was already airborne in the vicinity and it quickly located the wreckage of the aircraft in woodland about ¼ nm southeast of the airfield. It landed in a field nearby at 1541 hrs and two paramedics proceeded to the aircraft and found the fuselage inverted. There were signs of life inside but they had to wait for the fire service to arrive and the aircraft to be lifted before they could free the occupants. At 1635 hrs the passenger was rescued from the front right seat with serious injuries. However, the pilot and the rear seat passenger had received fatal injuries as a result of the impact.

Witness accounts

At approximately 1525 hrs a motorist who was driving west on the A303 road (Figure 1), briefly observed the aircraft heading towards the airfield at low level. He believed it to be north of the road and presumed it was approaching to land on the westerly runway (Runway 26).

Two pilots at the airfield heard the sound of an engine, and one of them stated that it sounded as if an aircraft was executing a go-around. They then spotted G-CGVO just to the east; it appeared to be flying level and to make a "gentle left turn" as it passed over the airfield. Another pilot, also standing outside, saw the aircraft above the clubhouse. He thought it was tracking west and was "straight and level" at a speed which he estimated as 50-60 kt. He had the impression that the aircraft was not using full power.

In the clubhouse, several people heard the sound of an engine and looked out to see an aircraft heading in a west-south-westerly direction. Opinions about the aircraft's height varied from 150 ft to 400 ft agl but all the witnesses thought it was just below the base of the cloud and its description matched that of the accident aircraft. One person in the clubhouse, who was a pilot and also a qualified technician on Rotax engines, later remarked that the engine sounded as if it had a problem. He thought the aircraft was climbing slightly when he saw it. The recollection of other witnesses, who were also pilots, was that the engine sounded steady and did not appear to be rough-running.

Some witnesses left the clubhouse to watch the aircraft while the air/ground radio operator tried unsuccessfully to make contact on Popham's frequency. When the aircraft was close to the western airfield boundary, near the Runway 08 threshold, it was seen to turn south and to cross the A303 road. The motorist, who was still approaching from the east, caught sight of it again as it turned. Another witness, a private pilot and former air traffic controller, thought the aircraft crossed the A303 at an estimated 70-80 kt and 200 ft agl, before turning to parallel the road on an easterly heading. He stated it appeared to be on a left base for Runway 03 but to be "too low". This witness was therefore surprised when the engine seemed to throttle back and become quieter while the aircraft descended gently. Other witnesses also saw the aircraft descending and to pass through the extended centreline of Runway 03 tracking east, until it was hidden from view by trees.

The motorist slowed down and watched the aircraft for short intervals as he passed the southern airfield boundary. After the aircraft turned east he observed it, with wheels down, flying level and seemingly under control above the trees, but "not very high". The next time he saw it, the aircraft was almost due south of his position and he realised "it was descending rapidly in a flat attitude". The wings were "wobbling" (rolling), it was "turning on its own axis" (yawing), and the nose went "down and then up" but it did not seem to climb. When the motorist glanced back again he could not see any sign of the aircraft. He suspected it had crashed and he later phoned the emergency services.

Accident site and wreckage

The aircraft came to rest in woodland approximately 350 m south of the service station on the westbound carriageway of the A303. The initial contact point of the aircraft was identified by damage marks on a large tree approximately 60 ft above the ground, with material from the aircraft wing retained in the branches. Roughly half the right wing had detached from the aircraft and was scattered between the base of this tree and the location of the main fuselage 40 m away on a bearing of 080º. A second tree adjacent to the main wreckage also exhibited a number of damage marks approximately 10 ft above the ground, with sections of the left wingtip scattered a few metres away from its base.

The main fuselage lay inverted, with the tail section detached at a point just aft of the rear seat and baggage section. The cabin roof, windscreen and doors were detached. The nose section forward of the front seats was also largely detached, with the engine only retained by peripheral wiring and hoses. The turbo wastegate was found in the fully closed position. One of the propeller blades had detached from the hub at the root, but was located directly under the engine. Both blades were in good condition with no impact marks on the tip or leading edges. The fuel tank selector was set to the right tank and the ignition key was selected to both ignition systems. The landing gear was down and locked, which was consistent with the gear selection lever position. Only one flap remained attached to the wing and was in the fully up position; it was not possible to verify the selected position. Both wing fuel tanks contained some residual fuel, but had been damaged during the impact. Statements provided by the emergency service responders confirmed that fuel had been steadily leaking from the tanks when they first arrived on scene.

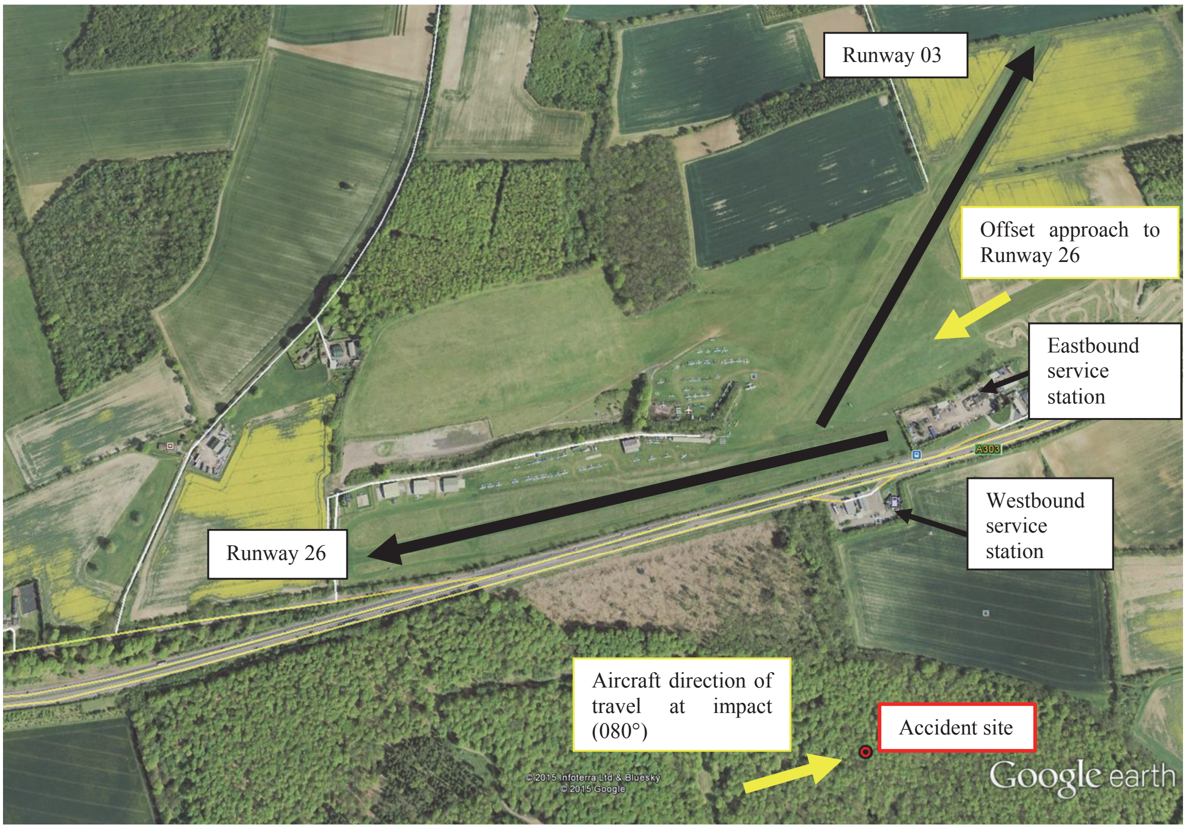

Figure 1

Popham Airfield and accident site

Popham Airfield

The A303 runs parallel to Popham Airfield boundary and there is a prominent road service station located on a rise in the ground on the northside of the road just before the threshold of Runway 26. The promulgated approach to Runway 26 involves an offset final approach to avoid the need for a steep descent on late finals and to keep aircraft clear of the service station. A large white arrow is marked on the ground to highlight this. Circuits are normally flown to the north of the airfield at standard circuit height of 800 ft.

Meteorological information

Three emergency services helicopters attended the site soon after the accident. The pilots of all three helicopters estimated the lowest cloud to be at approximately 400 ft above the accident site when they arrived. They reported that conditions further east gave patchy cloud extending to the ground in some places. The coastguard pilot recalled that on departing Lee-on-Solent Airfield (close to G-CGVO's track) at 1510 hrs, the lowest cloud had a base of approximately 800 ft agl and estimated the visibility to be 5,000 m. Approximately 40 minutes later, when flying inland towards the accident site, from the southeast, visibility had deteriorated to an estimated 2,000 m in places.

The UK Met Office reported that a series of fronts, associated with a centre of low pressure, passed over southern England on the afternoon of 3 January 2015. The aircraft was likely to have encountered a band of rain associated with an occluded front soon after crossing the coast near Portsmouth. South of the front there was a strong westerly airflow but this turned northerly and the temperature dropped by approximately 6ºC north of the front. The air was saturated on either side of the front and there was little difference between the reported temperatures and the dew points. The lowest reported cloud was likely to have caused hill fog to form over higher ground north of Portsmouth.

Weather information was not recorded at Popham but the witnesses there estimated that, when they saw the aircraft, wind direction was somewhere between 360º and 045º with a strength of between 6 and 12 kt. It was misty and the consensus of opinion was that visibility was approximately 3,000 m while the cloudbase was approximately 300 ft agl. This information accorded with the Met Office's analysis.

The Met Office aftercast agreed with the forecast chart (F215) for weather below 1,000 ft between 0800 hrs and 1700 hrs. It was issued at 0300 hrs on 3 January 2015 and indicated the expected positions of the fronts at 1200 hrs (Figure 2).

Study of this chart shows that the origin of the flight was within area D and that the aircraft would have had to fly through the occluded front (depicted in magenta). The forecast for the area was for scattered or broken stratus cloud with a base at 400-1,000 ft amsl and tops at 1,500 ft amsl. Above this a broken or overcast layer of cumulus and strato-cumulus extended up from 1,500-3,000 ft amsl with tops at 6,000-8,000 ft amsl. Visibility was forecast to reduce to 6,000 m in rain and drizzle but in isolated places it was forecast to reduce to 3,000 m or to 1,200 m near the coast. The freezing level was forecast to be no lower than 2,000 ft amsl to the north of the occluded front; measurements taken at Gatwick Airport, after the front had passed there, indicated the freezing level was above 4,000 ft amsl.

Before deciding to proceed with the flight, the pilot may have studied the forecast weather for airports near his route along with weather reports (METARs) issued at 1350 hrs. Among the airports he could have considered were, Southampton (44 ft amsl and approximately 10 nm west of the aircraft's route), Odiham (405 ft amsl and 11 nm east-northeast of Popham (550 ft amsl)) and Brize Norton (288 ft amsl). The relevant information which these airports provided was:

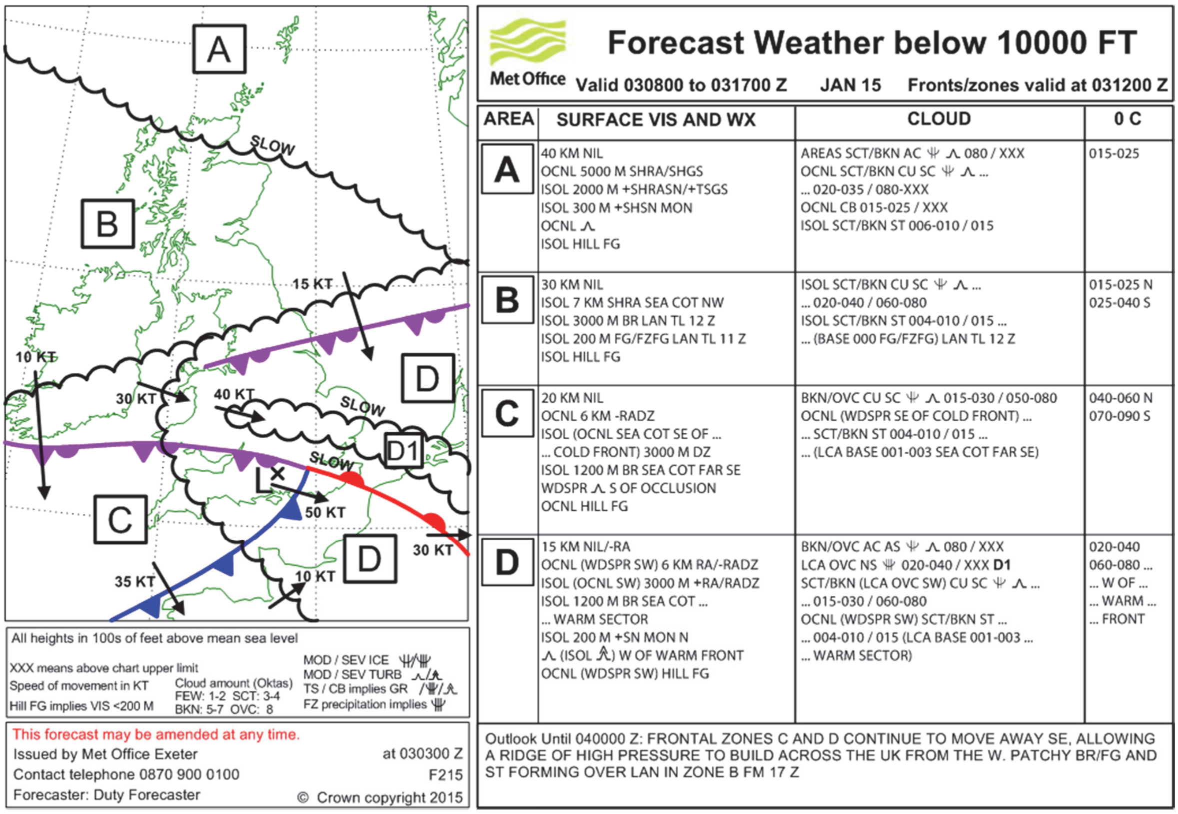

Figure 2

Forecast weather below 10,000ft (F215)

Southampton

- 1350 hrs: Wind, mean direction, from 290º at 12 kt gusting to 22 kt, visibility 8 km but reducing to 4,000 m to the north of the airfield, rain, scattered cloud 1,200 ft agl, broken cloud 2,300 ft agl, temperature 12ºC and dew point 10ºC.
- 1403 hrs: The forecast for the period between 1500 and 1800 hrs was for the wind to veer to be 020º at 7 kt, visibility to decrease temporarily to 7,000 m in rain with broken cloud at 1,000 ft agl
- 1450 hrs: Wind, mean direction, from 290º at 12 kt, visibility 6 km, rain, scattered cloud 1,200 ft agl, broken cloud 1,600 ft agl, temperature 12ºC and dew point 11ºC.
- 1520 hrs: Wind, mean direction, from 340º at 15 kt, visibility greater than 10 km, showers in the vicinity, scattered cloud 800 ft agl, broken cloud 1,300 ft agl, temperature 9ºC and dew point 7ºC.

Odiham

- 1350 hrs: Wind from 270º at 16 kt, visibility greater than 10 km, broken cloud at 800 ft, overcast cloud at 1,500 ft, temperature 11ºC and dew point 9ºC.
- 1450 hrs: Wind from 330º at 15 kt, visibility greater than 10 km, broken cloud at 400 ft agl, overcast cloud at 1,600 ft agl, temperature 6ºC and dew point 5ºC.
- 1550 hrs: Wind from 360º at 12 kt, visibility greater than 10 km, cloud overcast at 400 ft agl, temperature 5ºC and dew point 4ºC.

Brize Norton

- 1350 hrs: Wind from 020º at 9 kt, visibility 6 km, rain, scattered cloud at 600 ft agl, broken cloud at 1,200 ft agl, temperature 5ºC and dew point 4ºC. A temporary deterioration in visibility to 4,000 m with scattered cloud at 400 ft agl was also reported, while the forecast was for broken cloud at 800 ft agl and temporarily, between 1500 and 1800 hrs, the visibility was expected to fall to 3,000 m in rain and drizzle, with broken cloud at 400 ft agl.

The airfields which issued forecasts and were closest to Bidford, the aircraft's destination, were Birmingham (about 20 nm to the north) and Gloucester (about 20 nm south-southwest). Both airfields reported cloud cover below 500 ft agl at 1350 hrs but the forecasts for two hours later, when the aircraft should have arrived at Bidford, were for visibility to be greater than 10 km with no cloud cover expected below 1,200 ft agl.

Private pilots' weather awareness

Private pilots under training have to demonstrate a good understanding of meteorological conditions and how to obtain and interpret weather forecasts. The UK CAA also publishes Safety Sense Leaflet 1e *'Good Airmanship'*[1]. This states that continued flight into bad weather is one of the main causes of fatal accidents in the UK and offers the following advice:

> *'Get an aviation weather forecast, heed what it says and make a carefully reasoned GO/NO-GO decision. Do not let 'Get-there/home-itis' affect your judgement and do not worry about 'disappointing' your passenger(s)…'*

The leaflet mentions a booklet produced by the UK Met Office, titled *Get Met*[2] as a reference for the various methods of obtaining aviation actual and forecast weather and for the codes used in them.

Footnote

[1] The UK CAA produces Safety Sense leaflets to promote safe practices to UK pilots. They can be downloaded from the CAA website www.caa.co.uk. Similar, complimentary material is published by the European General Aviation Safety Team at www.easa.europa.eu/essi/egast/

[2] (see www.metoffice.gov.uk/aviation/ga)

Pilot information

The pilot gained a PPL in 2008 and added an IMC rating in 2010. Most of his experience was gained on Piper PA-28 Cherokees and on 17 August 2012 his Single Engine Piston (SEP) Class rating was revalidated by way of a licensing skill test on this type. The pilot had not flown for seven weeks prior to that date but the examiner recalled that he "had no worries about him". The examiner's opinion was that the pilot was a level-headed, competent and steady PPL holder, who demonstrated good airmanship and had no handling issues during this flight or during renewal of his IMC rating during February 2013.

An EU Part-FCL PPL was issued to the pilot in July 2013 and in August 2014 his SEP Class rating was revalidated to 13 August 2016, on the basis of his flying experience over the preceding 24 months. Also in August 2014 he gained a FAA Private Pilot certificate, while two months earlier he had commenced helicopter lessons. His total recorded flying experience included 14 hours helicopter flying, with the last such flight taking place on 5 December 2014.

The accident aircraft was acquired by the pilot in October 2014, as a replacement for the smaller two seat version of this type, which he had owned since July 2013. Both aircraft had retractable undercarriage and a variable pitch propeller but, unlike his previous aircraft, the engine in the accident aircraft was turbocharged.

EU Part-FCL requires differences training to be completed when pilots first fly aircraft with certain systems (see *Differences training*). This training has to be provided by an instructor who is required to annotate the pilot's logbook on completion. No relevant training was recorded in the pilot's logbook to reflect that this requirement had been met. The log book recorded that he had accumulated 35 hours as pilot-in-command on the previous aircraft until October 2014. The person who imported the aircraft into the UK was an experienced pilot on both types. Although not a qualified instructor, he assisted the pilot in becoming familiar with both aircraft. This individual recalled that prior to starting familiarisation training[3] on G-CGVO, the pilot had stated that he had received the necessary differences training.

The pilot recorded a little less than three hours experience in the aircraft during October 2014 and then made a further flight lasting 50 min on 6 December 2014. There was no evidence that he carried out any further flying, in this or in any other aircraft, until 2 January 2015.

Medical and pathology

The pilot held a Class 2 Medical Certificate with an expiry date of 18 October 2015 which required him to have corrective spectacles for near vision. Several pairs of such spectacles were found at the accident site.

Post-mortem examinations were conducted on the pilot and the rear-seat passenger by a specialist aviation pathologist. He stated that both '*died of injuries which were sustained at*

Footnote

[3] Familiarisation training does not necessitate the involvement of an instructor and there is no requirement to record it. (See *Differences training*).

the time G-CGVO crashed in woodland'. Toxicology tests indicated levels of over-the-counter pain killers in the pilot's body that were consistent with therapeutic use. The reason for taking them was uncertain but the pathologist stated he had '*no reason to believe that medical factors played any role in the causation of the accident*'.

Aircraft description

Although designed as a Permit-to-Fly, self-build kit aircraft, because it was the first of the type to be imported to the UK, G-CGVO was built by the original owner whilst being supervised by the manufacturer at their facility in Italy. It was subsequently used as a flight test aircraft to enable type acceptance by the Light Aircraft Association (LAA).

The Pioneer 400 is a low-wing, lightweight, wood and composite design for general aviation use. It has a retractable tricycle undercarriage and electrically actuated flaps. The engine is connected to a two-blade constant-speed propeller controlled by a hydraulic governor, via a gearbox with a slip clutch to prevent shock-loading. The 400 model is a derivative product introduced to add a rear seat, increasing the number of passengers to three compared to the original 300 model design which only had two front seats.

G-CGVO was a 400T variant fitted with a turbocharged engine to increase the maximum power available. The turbo primarily operates during takeoff, when the throttle is advanced beyond the 100% maximum continuous setting to a 115% takeoff setting. This increases the engine power (ISA) from 73.5kW (98.5 hp) to 84.5 kW (113.3 hp). This power increase is achieved by intake air being compressed as it passes through the turbo, increasing the air pressure and thus air mass entering the intake manifold for the engine. An impellor in the turbo is connected to a turbine driven by the exhaust gas from the engine. A spring-loaded wastegate opens and closes under the action of a servo motor, to increase or reduce the amount of exhaust air passing through the turbine. This in turn controls the speed of the impellor and thus the air pressure within the intake manifold.

The wastegate servo motor is controlled by a Turbo Control Unit (TCU). This receives input from sensors on the engine and an ambient air pressure sensor, to achieve a target manifold pressure and thus engine speed for a given throttle position through different altitudes. It provides electrical power to the servo to move the turbo wastegate, based on feedback from the manifold air pressure sensor. The engine manual recommends that the throttle should be moved directly from 100% to 115% when required, as fine control of the turbo is not practical between these throttle positions. The TCU then controls the servo to maintain the manifold pressure at the target figure. It also has protection logic to prevent the engine from overspeeding.

The published manifold pressure limit at takeoff power is 1,350 hPa (39.9 in Hg), with a nominal maximum engine rpm of 5,800. The engine is limited to five minutes continuous time at this power. If the TCU senses an exceedence beyond 5,900 rpm, it will reduce the target manifold pressure, thus controlling the servo to open the wastegate further. The manufacturer advised that exceedences below 1,550 hPa or 6,200 rpm should be reported to the maintenance provider for assessment but, for exceedences above these figures, rapid catastrophic damage is likely. The manufacturer advised that service information for the engine indicated that a manifold pressure of 2,200 hPa or more could overcome the interference fit of the sections of the crankshaft causing a misalignment.

The TCU is wired to red and orange warning lights fitted on the top left side of the instrument panel. If a wiring or sensor defect is identified by the TCU, a flashing orange warning is triggered. If the five-minute time limit at takeoff power is exceeded, the red warning light will flash until the manifold pressure is reduced. If an engine manifold pressure of 1,550 hPa is exceeded a continuous red warning is triggered, until the pressure is reduced below the limit threshold. The TCU has a small amount of internal memory. It records, at one minute intervals, the maximum readings that occurred during the previous minute for a number of sensors. The recording covers the last 20 minutes of operation before the oldest data is overwritten. It also records alerts for parameter exceedences for the life of the engine, with the last 100 alerts retained in the memory. The 12 Vdc power supply for the TCU is wired to a thermal circuit breaker positioned next to the warning lights on the instrument panel. The installation manual states that an electrical power isolation switch should be installed for the wastegate servo motor. On the accident aircraft pulling the TCU circuit breaker was the only means of isolating the motor.

The aircraft instrument panel was equipped with a small Engine Information System (EIS) display (Figure 3). This was a user-configurable display that provided information such as flight time, fuel flow, exhaust gas temperature and other relevant parameters relating to the engine. It provided the only display of engine manifold pressure, which was sensed directly by the EIS from an air pressure tapping on the manifold[4]. The EIS also displayed engine rpm, which was an electronic tacho signal generated by a magnet on the engine flywheel passing a coil. The signal was fed to the EIS via the TCU. The rpm display could be configured so that it changed to yellow, then red as it passed trigger thresholds set by the user. In the case of G-CGVO these were set at 5,770 and 5,800 rpm respectively. The manifold pressure display did not have any form of limit exceedence warning. The rpm signal was also supplied from the EIS to a traditional rpm dial gauge on the aircraft instrument panel.

Figure 3

EIS on test bench showing rpm and manifold pressure display

Footnote

4 The TCU was connected to its own air pressure tapping but on the same manifold as the EIS.

Recorded data

The aircraft was not fitted with a flight recorder but information was recovered from a GPS unit, the EIS, the TCU, the radio navigation and communication system and the transponder. Two tablets and a smartphone were also recovered from the accident site but were too damaged to yield any data. Sources of data external to the aircraft included radar recordings, and video recordings of the start of the flight. Recorded radio transmissions were also reviewed and relevant content is provided in the history of the flight section.

GPS

The GPS unit was a FlymapL, set up to record flight paths. Normally, flight track data is stored in volatile memory[5] until an end-of-flight condition is met, at which point the flight information is transferred to non-volatile memory[6]. The accident flight did not trigger the end-of-flight actions and thus did not transfer the data to the non-volatile memory prior to loss of electrical power. Whilst data was successfully downloaded for previous flights, no data could be recovered for the accident flight.

Turbo control unit

The 20 minutes of TCU data was successfully downloaded, but was found to be consistent with the start of the flight, not the end of the flight; 42 alerts were also downloaded. The TCU stops recording data either due to the loss of an rpm signal or loss of the 12 Vdc power supply. There is no way of knowing from the data which occurred. Notwithstanding the premature end of the recording, no anomalies with the 20 minutes of data were identified.

One of the parameters that the TCU records is cockpit ambient air pressure; the sensor was recovered from the wreckage and calibrated. The effects of airspeed on ambient cockpit pressure were measured on a similar aircraft. The recorded maximum ambient pressures were then converted into minimum altitudes. Boost time is recorded as the period when the throttle is beyond 108% and reflects the time during which increased manifold air pressure from the compression provided by the turbo results in a higher engine power output. The data is shown in Figure 4.

TCU alert log

The TCU records alerts triggered by engine parameter exceedences. All 42 recorded alerts had been triggered by a manifold pressure that exceeded the 1,350 hPa threshold. The level of exceedence varied but was mostly within the 1,400 – 1,500 hPa range, with the maximum pressure recorded as 1,542 hPa. The TCU does not provide a warning to the pilot for exceedences below 1,550 hPa. The exceedences all occurred with a throttle position above 100%, but the associated wastegate servo position was not always recorded as being 100% (fully closed). No reference to these exceedences was found in

Footnote

5 Volatile memory requires a battery to maintain the memory. If power is lost, the data is lost.
6 Non-volatile memory will retain data with or without power.

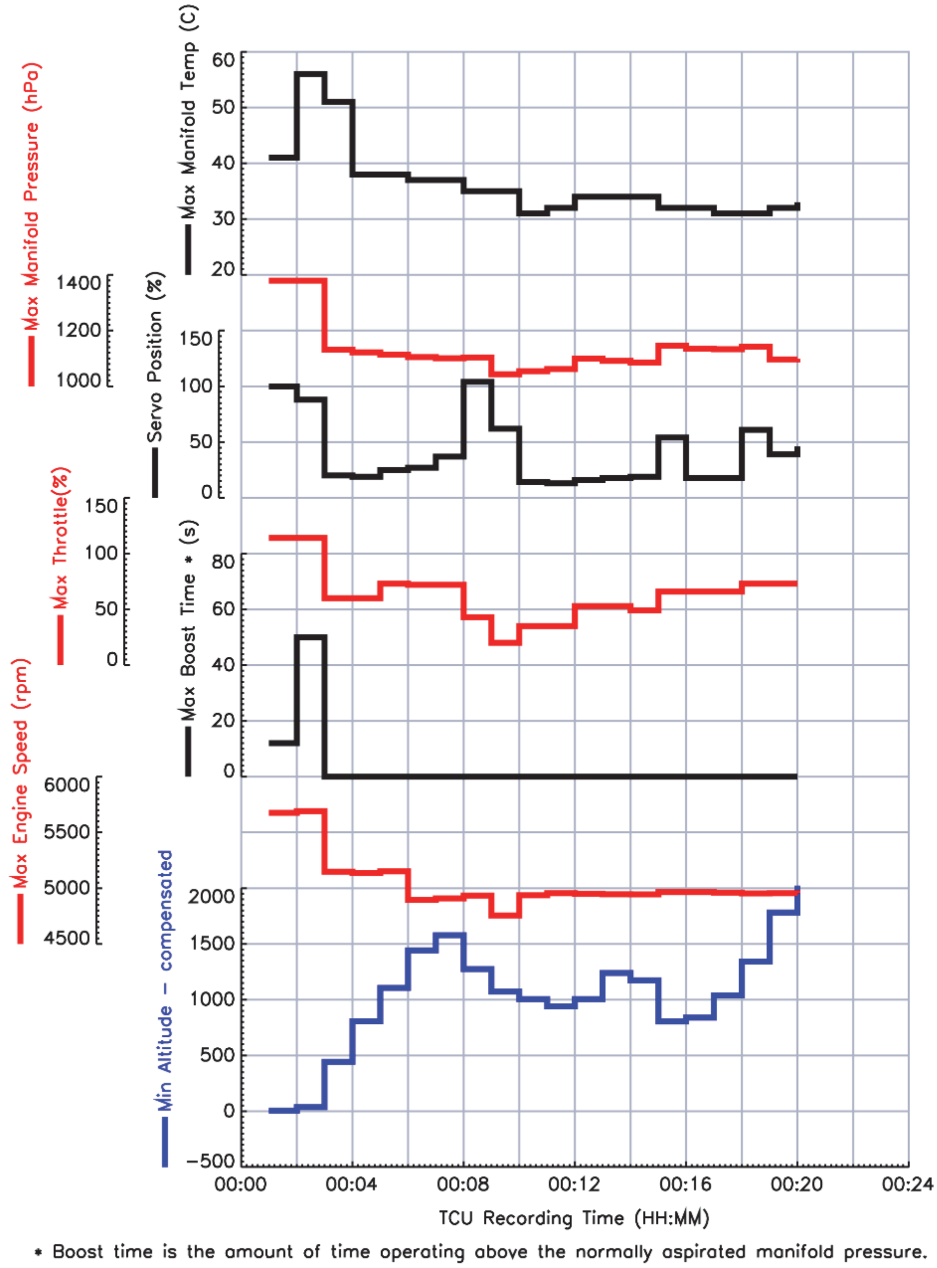

Figure 4

TCU download of the last 20 minutes of recorded operation

either the engine or aircraft log books. The manufacturer requires that such exceedences are recorded but unless the exceedences are observed whilst they are displayed on the MAP readout on the EIS screen, the pilot may be unaware they had occurred.

Engine indication system

The EIS was removed from the instrument panel. Though later models record more, this earlier model recorded only limited information. The unit showed a total engine operating time[7] of 200 hours and 42 minutes, of which 7 hours and 15 minutes was above the yellow threshold but none above the red threshold for rpm. The maximum engine speed recorded by the unit over all flights was 5,800 rpm.

The unit also records the duration of the last flight and the maximum engine speed during that flight. The flight timer was configured so that if the engine speed increased above 4,000 rpm for more than approximately 35 seconds, it would reset and start counting whole minutes until the engine stopped, freezing the flight time displayed. The unit recorded a flight time of zero hours and zero minutes and an engine speed of 4,890 rpm. The displayed data indicated that at some point the tacho signal input no longer reflected a running engine. An engine speed of more than 4,000 rpm was then sensed, with a valid tacho signal continuing for between 35 seconds and 90 seconds, with a maximum engine speed of 4,890 rpm. It could not be established whether this was the last of many cycles or a single event. It may also have been the result of a loss of wiring continuity in normal operation or as a consequence of the accident. These values would also have been preserved through subsequent periods of tacho activity provided that the engine speed remained less than 4,000 rpm or only exceeded 4,000 rpm for less than 35 seconds. Given the lack of time stamps, the limited recorded data could not be definitively related to the accident flight.

Takeoff video

The first recordings relating to the accident flight were videos taken by a witness at Bembridge Airport using a smartphone. These showed the aircraft taxiing and then taking off. The takeoff roll started at 1459:29 hrs.

Radar

The flight on the previous day was continuously visible to secondary radar. When the altitude reporting function was active, the reported altitudes were erratic compared to the altitudes recorded by the GPS.

Secondary radar recordings from Pease Pottage, Heathrow, Gatwick and Bovingdon, and primary radar recordings from Heathrow, Southampton and Farnborough, provided flight path information for the accident flight. The recorded tracks were intermittent compared to the previous flight with none of the sources capturing the manoeuvring in the vicinity of Popham at the end of the flight.

Footnote

[7] The total engine operating time reflects the total hours for the aircraft but this was accrued on two separate engines following replacement after an unrelated incident.

Transponder and navigation/communication units

The transponder was removed from the aircraft and powered. It showed a squawk of 0011 and indicated it was in standby mode.

The aircraft's navigation and communication radio system was also interrogated. The active and standby communications frequencies were 120.225 (Solent Approach) and 123.250 (Bembridge) respectively. The active and standby navigation frequencies were 117.45 and 116.40 respectively; neither were relevant to the accident flight. No logged faults were relevant to the investigation.

Amalgamated data

The pertinent recorded information is shown in Figure 5. The aircraft took off from Bembridge at 1500 hrs. The aircraft transponder was not reporting altitude but was initially squawking 7000 and then switched to the Solent listening squawk of 0011 whilst over the Solent, approximately 2 nm south of Gosport. The aircraft altitude reached approximately 1,600 ft amsl in the vicinity of Gosport after which the aircraft started to descend and the secondary radar track stopped.

The TCU data indicates that the aircraft flew between 1,300 ft amsl and 800 ft amsl for the next nine minutes. At 1519 hrs, the aircraft climbed through the line-of-sight limits of Heathrow and Farnborough primary radars, both at approximately 1,500 ft amsl in that location. The TCU stopped recording shortly after this, with a last minimum altitude value of 2,000 ft amsl.

The aircraft stayed above the radar line-of-sight limit of approximately 1,500 ft amsl for 5 minutes whilst tracking towards Popham. The subsequent loss of radar track by Heathrow and Farnborough primary radars indicates that the aircraft descended below 1,500 ft amsl approximately 2.2 nm south of Popham, and then below 900 ft amsl (about 600 ft agl) 1.4 nm south of Popham. There is no recorded information that relates to the flight path after this point.

No secondary radar returns were recorded for this aircraft after the initial track, despite the aircraft later being within line-of-sight of a number of secondary radar heads.

Differences training

Differences training for systems such as retractable undercarriage, variable pitch propellers and turbochargers is required in accordance with European Commission (EU) Regulation No 1178/2011 at FCL.710 and its associated Acceptable Means of Compliance (AMC) and Guidance Material (GM). UK AMC and GM can be found in CAA publication CAP 804 (Section 4, Part H, Subpart 1, paragraph 4.3). Holders of UK, JAR-FCL and National Private Pilot's Licences are also required to have this training; UK Air Navigation Order 2009, Schedule 7, Part B, Section 2 refers.

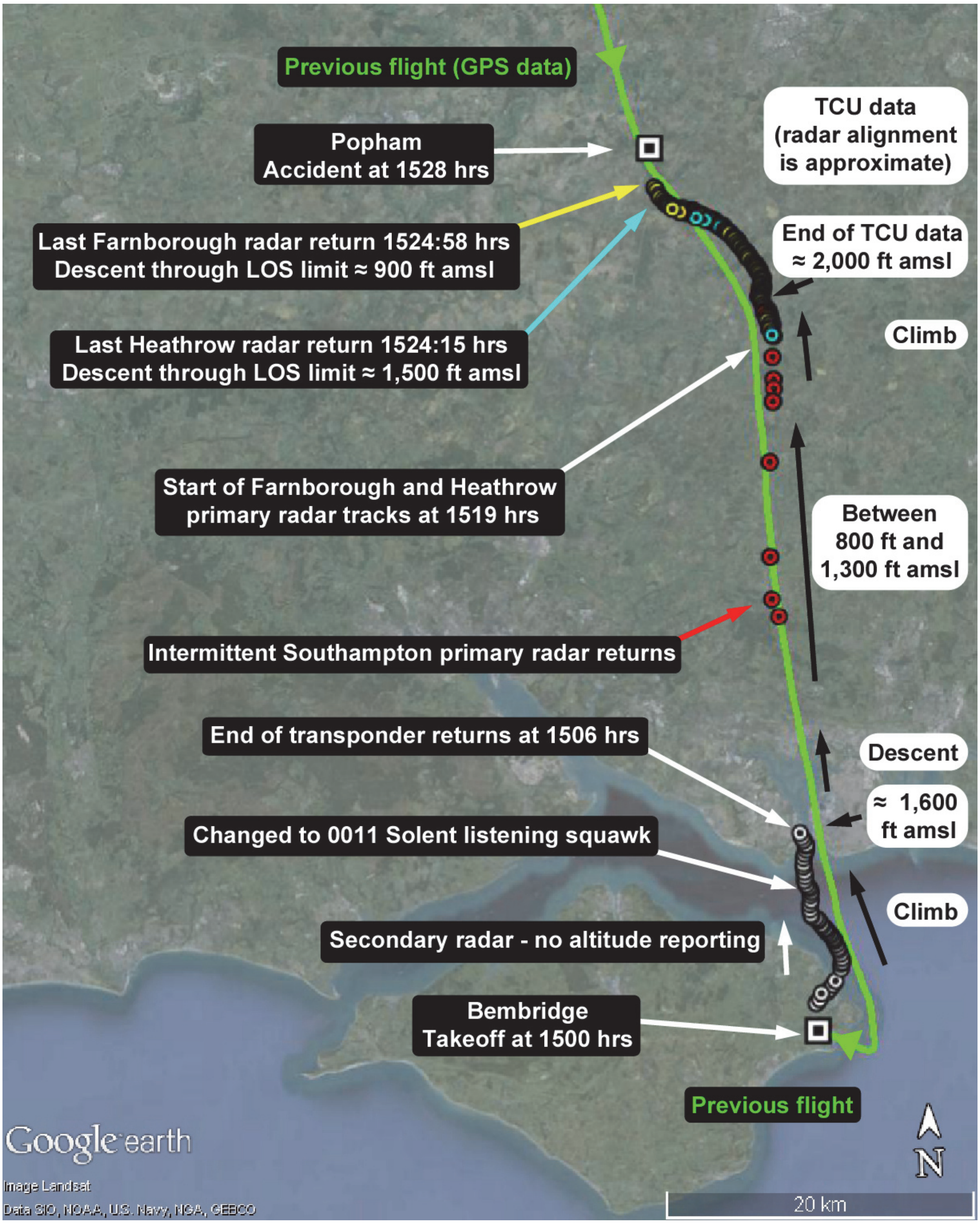

Figure 5

Amalgamated recorded data

Holders of EU pilot's licences containing an SEP Class rating are required to undertake differences training or familiarisation training prior to operating another '*variant of aircraft* within the SEP Class for the first time. There is no definition for a *'variant'* but differences and familiarisation training is defined by the GM to FCL.710 as:

> '(a) *Differences training requires the acquisition of additional knowledge and training on an appropriate training device or the aircraft.*
>
> (b) *Familiarisation training requires the acquisition of additional knowledge.'*

FCL.710 specifies that:

> *'The differences training shall be entered in the pilot's logbook or equivalent record and signed by the instructor as appropriate.'*

There is no requirement for familiarisation training to be recorded. Differences training within the SEP Class is only required when a pilot converts for the first time to a *'variant'* with a system such as a turbocharger or retractable undercarriage. Otherwise only familiarisation training is required and this, at its simplest level, can be achieved through self-study.

CAP 804 lays out the recommended scope of the differences training and one of the areas to be addressed is '*In-flight failures and emergency handling*'. The differences training that is undertaken will be appropriate to the specific aircraft the pilot is going to fly and, once such training is completed, it is valid for other '*variants*' in the SEP Class that incorporate such a system. Therefore, once turbocharger differences training has been completed on one *'variant'* within the SEP Class it is valid for any other '*variants*' in that Class with a turbocharger, no matter what technical difference may exist.

Local rules and resident instructors at flying clubs will tend to ensure pilots receive differences training and/or familiarisation training as appropriate before they fly a *'variant'* that is new to them. In other circumstances, pilots need to understand the requirements themselves. Without reference to CAP 804 or the Regulations, they might learn about differences training through study of the CAA's website or by reading the CAA Safety Sense Leaflet No 1e *'Good Airmanship'*. Alternatively this pilot, being a member of the Light Aircraft Association (LAA), might have been aware of its pilot coaching scheme which covers differences training. Details of this coaching scheme, which can provide pilots with tailored training before flying a *'variant'* that is new to them, are available on the LAA's website and in a leaflet which is distributed to new owners of light aircraft. Familiarisation training is not a requirement for pilots exercising the privileges of a UK national licence.

Applicable regulations

Pre-flight duties of the aircraft commander

The Air Navigation Order 2009 (ANO), which was applicable to the accident flight, listed the pre-flight duties of an aircraft commander at Article 86. It included the following;

> *'A commander must, before taking off on a private flight, an aerial work flight or a public transport flight, take all reasonable steps so as to be satisfied (that) … the flight can safely be made, taking into account the latest information available as to the route and aerodrome to be used, the weather reports and forecasts available and any alternative course of action which can be adopted in case the flight cannot be completed as planned.'*

Flight Rules

The Air Navigation Order 2009 (ANO), which was applicable to the accident flight, stated at Article 23 (5) that, without the prior permission of the CAA, an aircraft flying in accordance with a Permit-to-Fly might only be flown by day and in accordance with the Visual Flight Rules (VFR). This meant the pilot had to adhere to the Rules of the Air Regulations 2007[8] and Rule 28 (4) which required that an aircraft being flown outside controlled airspace at or below 3,000 ft amsl, with an indicated airspeed of 140 KIAS or below, to remain clear of cloud with the surface of the ground in sight, and with a minimum visibility of 1,500 m. For flight at a speed greater than 140 KIAS, the minimum visibility permissible was 5 km.

The pilot was also required to respect the Low Flying Rule (Rule 5). This stated that an aircraft should not be flown closer than 500 ft to any person, vessel, vehicle or structure and that it should not be flown below 1000 ft above the highest obstacle within a 600 m radius when over the congested area of a city, town or settlement. An aircraft is exempted from this rule while taking off or landing.

Evaluation flight

As part of the investigation the AAIB conducted an evaluation of a similar aircraft, with a similar weight and balance to the accident aircraft. This was flown by a qualified test pilot, who is also an EASA qualified flying instructor for SEP aircraft. The flights were carried out to gather data on the aircraft and its equipment and to assess the aircraft's handling characteristics in certain circumstances. The test pilot stated that it was a capable four-seat aircraft with a modest takeoff performance, but which achieved a good cruise speed. He observed a subtle pre-stall buffet and a benign stall with no tendency to drop a wing. In the normal landing configuration, with gear down and full flap, a stall warning was recorded at 41 KIAS and the aircraft stalled below 40 KIAS which was the minimum speed shown on the ASI.

Footnote

[8] After this accident, on 30 April 2015, the Rules of the Air Regulations 2007 were replaced by the Rules of the Air Regulations 2015 along with the Standardised European Rules of the Air Regulation (SERA).

The test pilot evaluated the aircraft's performance during a go-around with the gear down and full flap and assessed it as poor. At 57 KIAS and with a rate of descent of 200-500 ft min, application of full throttle did not immediately arrest the descent and only a very gentle rate of climb was achieved at 60 KIAS without changing the configuration.

In regard to the performance of the engine the test pilot stated that the response of the turbo was very gentle with no noticeable surge of power or difficulty in engine operation – it took approximately 3 seconds to go from cruise power of 32-34 in Hg Manifold Air Pressure (MAP) to 39-40 in Hg which indicated full takeoff power. The test pilot's evaluation concluded that, from a handling perspective, there were "no issues with engine operation that warranted additional training over and above operating a normally aspirated version of the engine."

Detailed wreckage examination

Once the wreckage had been returned to the AAIB HQ at Farnborough, the engine was stripped with the assistance of an engineer experienced on the type. It was noted that it was not possible to turn the crankshaft in the engine's 'as found' condition. The engine was then progressively disassembled. No findings of significance were identified during this process, other than the removal of these components had no effect on releasing the crankshaft. The engine crank case was then separated and the crankshaft was found to have twisted due to a torsional load. This distortion had caused the shaft to impinge on the engine crank case, such that it was seized in position.

A detailed inspection of the aircraft instrument panel and aircraft wiring was also carried out to identify any defects which may have resulted in the loss of power supply or tacho signal to the TCU. The power supply circuit breaker for the TCU was found in the open position, although several other circuit breakers close to it on the panel were still in the normal closed position. The wiring looms on the engine and behind the instrument panel had suffered damage during the accident sequence, but there was full continuity for the TCU rpm and power supply wiring. However, one of the wires from the throttle position sensor to the TCU was damaged approximately three centimetres from the sensor connector, in a manner that was not consistent with the other examples of impact damage. On closer inspection the inside of the wire's insulation was found to be coated with residue. Inspection of the wire under a microscope showed that the copper conducting wires had been worn flat, with the surface covered in microscopic striations oriented in slightly different directions. (Figure 6)

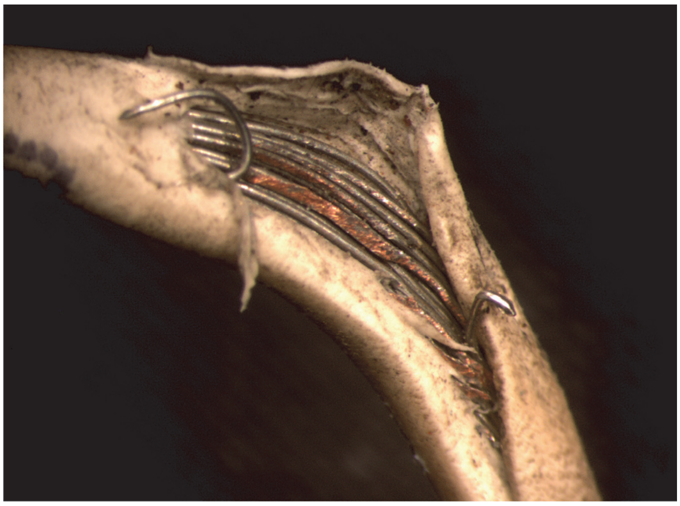

Figure 6

Magnified image of damaged throttle position sensor wire

TCU and EIS test loom

A test loom was created using a combination of original sensors and wiring from the aircraft and a digitally generated tacho signal to replicate the engine rpm input. The TCU was first tested to determine that it functioned as expected, driving the servo motor to the appropriate position as the rpm and MAP were varied, including the overspeed protection logic[9]. No anomalies were found and the EIS indicated the correct rpm figure.[10] The equivalent wire from the throttle position sensor that was found damaged on the aircraft, was then shorted to earth. This resulted in the orange warning light flashing and the servo motor being driven to the 100% position (nominally resulting in the wastegate being fully closed), and remaining there for as long as the wire was grounded. The power to the TCU was then isolated and the servo remained in the same position. This response was consistent with the manufacturer's Operator's Manual. Despite the TCU power being removed, the EIS continued to display an accurate rpm reading.

Engine manufacturer's Operator's Manual

The Operator's Manual for the engine states that in the event of an orange TCU warning being triggered, the pilot should:

> *'Reduce speed and boost pressure manually to be within the operating limits.'*

It also states:

> *'Limited flying operation, as this may indicate the boost control is no more or insufficiently possible and may affect engine performance.'*

There is also a statement which says:

> *'NOTICE: If the manually controlled variable is not possible, then turn off the servo motor.'*

Aircraft manufacturer's operating manual

There is no requirement, for a permit-to-fly aircraft, such as G-CGVO, to have an approved operating manual. However, the manufacturer provided an Aircraft Flight Manual for this aircraft including a limitations section and some checklists to deal with normal and emergency procedures. The powerplant limitations did not include the manifold air pressure limit for the engine and the emergency procedures did not address the illumination of either the orange or red TCU warning lights.

Footnote

[9] Only the servo function was tested. When fitted to the aircraft a calibration sequence is required to ensure the wastegate position matches the servo position. It was not possible to assess the calibration for G-CGVO due to the accident damage but the 20 minutes of recorded data is broadly consistent with a correctly calibrated system.

[10] The MAP pressure tapping on the EIS could not be used due to impact damage, so the accuracy of the MAP display could not be assessed.

Analysis

Weather

The meteorological information available before the aircraft left Bembridge was not conducive to a VFR flight to Bidford that backtracked the route flown south the previous day.

The 1350 hrs report for Odiham indicated broken cloud at 800 ft agl and, in order to backtrack the route flown southbound, the aircraft would have to pass over terrain where the elevation was 400 ft higher than that at Odiham. In addition, the forecast for Brize Norton indicated that the aircraft could encounter conditions of 3,000 m visibility with cloud at 400 ft agl in that vicinity.

However, it is possible that the pilot was encouraged by a perceived improvement to the weather on the Isle of Wight and by the 1350 hrs weather report at Southampton where visibility was 8 km, the lowest cloud was at 1,200 ft agl and the main base was at 2,300 ft agl. He may also have noted that airfields near his destination had cloud below 500 ft agl at 1350 hrs but forecast good visibility and no cloud below 1,200 ft agl around his estimated time of arrival.

It was not possible to confirm whether the pilot viewed all the available weather information. If he did not, he may not have appreciated the difficulties there could be in navigating this route while maintaining safe terrain clearance, due to the limited visibility and low cloud. It is also possible, because he possessed an IMC rating, that he was content to fly in weather conditions close to the VFR minima. His aircraft was not certified to fly with sole reference to instruments but he may have felt confident to use the instruments to assist him in poor conditions without a clear horizon.

The freezing level was above 4,000 ft near Gatwick, after the front had passed, so there is no evidence that the aircraft might have been affected by airframe icing.

Departure and initial part of the flight

Based on the limited recorded data, the pilot apparently back-tracked the route taken to Bembridge the previous day but at a slower speed. Before reaching the mainland coast, the transponder and radio settings indicated that the pilot was listening to the Southampton ATC frequency. At no point in the flight was transponder altitude reporting (Mode C) active and no radio calls were received from the aircraft. There was no requirement for the pilot to contact ATC while in Class G airspace.

The Mode A transponder returns ceased in the vicinity of Portsmouth Harbour; later examination of the transponder identified that it was in standby mode and no evidence of a technical fault was found that would have prevented radio communication or transponder Mode A reporting.

In the absence of evidence of a technical fault, it is likely that the pilot set the transponder to standby. This could have been because he had encountered worse weather conditions than anticipated and did not wish to be distracted by ATC while trying to fly and navigate the aircraft clear of cloud. The aircraft's position at this time coincided with the Met Office's assessment of where the band of rain and cloud associated with the weather front was likely to have been. Data from the TCU indicated that it was around this time that the aircraft stopped climbing at about 1,600 ft amsl and started to descend. A diversion or return at this point might have been appropriate. After this, the aircraft altitude varied between 800 ft and 1,300 ft amsl.

Diversion to Popham

The recorded data shows that, approximately 19 minutes after takeoff, the aircraft was climbing through 2,000 ft as the TCU stopped recording. It is not clear why the climb was initiated.

The damage to the wire from the throttle position sensor to the TCU is consistent with it having chafed on an adjacent part of the engine. This would have created a ground on the wire, causing the TCU to drive the wastegate of the turbo fully closed and trigger the orange flashing TCU warning light on the instrument panel. It is also likely that engine manifold pressure and rpm would have increased in response to the turbo becoming active, although with the throttle below the takeoff power position, it is unlikely the engine would have exceeded any operating limitations at this point.

Given the warning notice in the engine Operator's Manual and his familiarisation training, it is likely the pilot's response was to isolate the electrical power to the TCU by pulling the circuit breaker. This would have frozen the servo valve and thus the turbo wastegate in the fully closed position. It would also have prevented the overspeed protection logic and the orange and red warning lights from working, and would have stopped the TCU from recording. In this sequence of events the fault, fault indication and the subsequent electrical isolation of the TCU must have occurred before the next 60 second period of data gathering and recording could be completed.

The pilot may have diverted to Popham to minimise the flight time with a turbo fault or it may have been because the weather was too poor to continue. Popham was near the planned route, he had passed it on the flight south and he was likely to have had it displayed on the navigation app on his tablet. The subsequent descent and track, recorded on radar, are consistent with this. The lack of any radio call to Southampton or to Popham and the fact that the Popham frequency had not been selected, suggest the pilot was fully occupied as he dealt with poor weather, a malfunctioning turbo and diverting to an unfamiliar airfield.

Arrival at Popham

The wind at Popham was reported to favour a landing on Runway 03. It is not clear whether the pilot tried to make a straight-in approach to Runway 26 at Popham and then went around or whether he overflew the airfield before deciding on which runway to land. Witness evidence suggested that the aircraft flew a low-level circuit which ended up on what appeared to be a base leg for Runway 03. However, it is equally possible that the pilot's intention was to position downwind, at low level, for Runway 26. The landing gear was selected down, which indicated an intention to land but evidence from the wreckage indicated that the flaps were retracted when the aircraft crashed.

Power increase

The normal landing configuration for this aircraft type involves the use of full flaps, so at least one stage of flap is likely to be selected when late downwind or on base leg. During the evaluation flight it was noted that the aircraft's performance was poor with gear down and full flap selected.

With the turbo wastegate fully closed, the pilot would have had to limit the throttle position to keep the engine parameters within limits. With the TCU not powered, the only additional warning of an engine exceedence was the rpm display on the EIS turning yellow and then red. However, this display was very small and the pilot may have overlooked it when he was preparing to land at an unfamiliar airfield in poor weather. If the pilot conducted a go-around from an approach to Runway 26, he managed to do so without causing a catastrophic engine exceedence.

However, during the subsequent circuit, when heading east, the engine stopped and the aircraft stalled into trees. It was not possible to determine whether the pilot inadvertently selected too high a throttle position, was unaware of the potential consequences of depowering the TCU or he had no alternative in order to try to maintain airspeed and altitude. However, with the TCU protection logic disabled, there was no limit on the manifold pressure produced by the turbo until it reached its maximum performance. The engine manufacturer confirmed that excessive manifold air pressure could result in misalignment of the engine crankshaft to an extent that the engine would seize. The evidence from the engine strip and the location and lack of damage to the propeller blades, support the conclusion that the engine stopped in-flight for this reason. One witness noticed the engine noise reduce before the aircraft was lost from view.

The stall

The pilot apparently warned the passengers to brace thus indicating that he was conscious immediately before the accident and aware that the aircraft was about to crash. With no engine power available, it is possible that the pilot retracted any flap that had already been extended in an effort to extend the glide and clear the trees. Retracting the flap would have reduced the drag but it would have increased the stall speed and the evidence from the car driver suggests that the aircraft stalled before it struck the trees.

Differences training

Prior to 3 January 2015, the pilot had logged fewer than five flying hours on type, but he had previously flown for 35 hours in the smaller two-seat version of the aircraft. He indicated when he purchased G-CGVO that he had completed appropriate differences training but there is no written record of this being the case. However, he did have experience with a retractable undercarriage and a variable pitch propeller while flying his previous aircraft, so his apparent lack of differences training on these systems is unlikely to be relevant to the accident.

The test pilot who carried out the evaluation flight reported that, in normal circumstances, the turbo on this aircraft did not present a pilot with any special challenges. However this aircraft apparently suffered an unusual turbo malfunction and the pilot would have needed detailed knowledge of this aircraft's specific installation to cope with it. The differences training, required by regulation, could have been achieved on another SEP Class '*variant*' without covering the technical detail specific to this engine installation. Although the pilot had not apparently received formal differences training for turbochargers, he had received familiarisation training specific to this '*variant*' from the individual who had sold him the aircraft.

Aircraft Flight Manual – TCU warnings

The Aircraft Flight Manual has no guidance on the actions to be taken if the orange caution light for the TCU illuminates. The pilot may have been aware of the statement in the engine Operator's Manual which intimates that the servo motor for the wastegate should be turned off. However, the wording is ambiguous and given the specific configuration on this aircraft, it results in removing power from both the TCU and the servo motor. If the pilot did this, by pulling the circuit breaker, there would have been several implications. Firstly, it would have frozen the wastegate in its current position (in this case the ground on the chafed wire would have run it to the fully closed position), even if the ground had been intermittent and the problem was temporary. Secondly, it disabled the manifold pressure exceedence protection, although the ground on the wire would also have had this effect. Thirdly, and perhaps most significantly, it disabled the manifold pressure exceedence red warning light. This information was not provided in any of the operating manuals in a readily accessible way and the pilot may not have been aware of these issues. As a consequence the following Safety Recommendations are made:

Safety Recommendation 2016-027

It is recommended that Alpi Aviation modify the design of the Pioneer 400 to ensure that the manifold pressure exceedence red warning light remains functional, by allowing isolation of electrical power to the turbo wastegate servo control motor without removing power from the Turbo Control Unit.

Safety Recommendation 2016-028

It is recommended that BRP-Powertrain GmbH & Co. KG amends the Rotax 914 engine Operator's Manual, to clarify the actions required by the pilot following activation of the orange Turbo Control Unit warning light, particularly with regard to isolation of the turbo wastegate servo control motor.

Safety Recommendation 2016-029

It is recommended that Alpi Aviation incorporate in the Pioneer 400 aircraft operating manual, the manifold air pressure limits and warnings, and pilot actions described in the Rotax 914 engine Operator's Manual, for red and/or orange Turbo Control Unit warning light activation.

In light of the chafing damage identified on the engine wiring, the following Safety Recommendation is made:

Safety Recommendation 2016-030

It is recommended that BRP-Powertrain GmbH & Co. KG reviews the wiring installation design and guidance for the Rotax 914 engine to optimise the routing and protection for wiring looms to minimise the likelihood of damage from chafing.

Light Aircraft Association review

As a consequence of the issues identified by this investigation, the LAA have advised that they intend to conduct reviews into differences training requirements for pilots operating aircraft with turbocharged engines, and also the minimum requirements for instrumentation and the wastegate control system for this type of engine.

Conclusion

When the pilot reached the mainland coast it was likely that he saw a deterioration in the weather that eroded the safety margins for VFR flight. At this early stage, it would have been prudent to divert to a suitable nearby airfield or to have turned back to Bembridge. Safety Sense leaflet 1e *'Good Airmanship'* advises pilots how to plan VFR flights around the forecast weather and on decision making when the conditions encountered are worse than anticipated.

Whilst a very specific defect occurred on this aircraft, the engine was still capable of being operated safely with an increased level of pilot monitoring and awareness. The engine most likely only stopped as a result of the throttle being moved by the pilot to a setting where a damaging level of manifold pressure was reached. Regardless of this, pilots with an SEP Class rating are trained in the need to anticipate engine failures for any reason and to conduct forced landings when necessary.

The poor weather conditions at Popham meant the pilot, who had limited flying experience, especially on this aircraft type, had to fly below the normal circuit height. This would have increased his workload and reduced the time available in which to make critical decisions. When combined with the additional workload created by the engine fault, this may have led to the circumstances surrounding the failure of the engine and would then have limited the options available when confronted with the need to perform a forced landing.

ACCIDENT

Aircraft Type and Registration:	McKenzie Edge 360, G-EDGJ
No & Type of Engines:	One Lycoming YIO-390-EXP piston engine
Year of Manufacture:	1991 (Serial No: MCK002)
Date & Time (UTC):	22 April 2015 at 1341 hrs
Location:	Old Buckenham Aerodrome, Norfolk
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	61 years
Commander's Flying Experience:	1,290 hours (of which 265 were on type) Last 90 days - 4 hours estimated Last 28 days - 4 hours estimated
Information Source:	AAIB Field Investigation

Synopsis

The pilot was flying a series of aerobatic manoeuvres at Old Buckenham Airfield when the accident occurred. His aircraft failed to recover correctly from a gyroscopic tumbling manoeuvre and inadvertently entered an spin. The pilot made no apparent attempt to recover from the spin and suffered fatal injuries in the ground impact.

The aerobatic manoeuvre was entered at relatively low speed and height, which may have been due in part to a lack of recent aerobatic practice and the use of a new or improvised aerobatic sequence. The investigation concluded that the aircraft entered the spin as a result of inappropriate control inputs, which also precluded a recovery.

The pilot was found to have been suffering from a serious and previously undiagnosed heart condition, which had the potential to affect his ability to perform the aerobatic manoeuvres safely and which could have produced incapacitating symptoms at a critical stage of the flight.

Background information

The accident occurred as the pilot performed a series of aerobatic manoeuvres at Old Buckenham Airfield where a closed press day was taking place to promote a forthcoming air show. The intention of the press day was for local newspaper and television journalists to meet the air show organisers and some of the display pilots, as well as undertaking local passenger flights. There was no other flying or display element intended or planned. The event was therefore deemed to be neither a *flying display* nor a *special event* as defined by the Civil Aviation Authority (CAA), so was not subject to any specific restrictions.[1] However, the airfield operator had closed the airfield to non-participating traffic and a NOTAM had been issued to that effect.

G-EDGJ was a single seat aerobatic aircraft, shown at Figure 1. Its owner, the accident pilot, was a member of a local formation and aerobatic display team which flew two Pitts Special aircraft and G-EDGJ (the team had a total of four Pitts Specials, the other aircraft being used for additional roles such as providing formation flying experiences). The team's aircraft were based at private airstrips in the local area. The team members had close links with Old Buckenham Airfield and regularly practised there, both collectively and individually. For such practices, the CAA had granted a standing exemption from the low flying regulations of the Air Navigation Order[2].

The team was to display at the forthcoming air show and it had been arranged that the pilots would attend the press day with their aircraft. The two Pitts Specials had arrived ahead of G-EDGJ and their pilots were attending the press event when the accident occurred.

Figure 1
The accident aircraft: McKenzie Edge 360, G-EDGJ

History of the flight

The pilot rose early on the day of the accident and drove to the nearby airstrip where G-EDGJ was kept before making a short flight to RAF Marham near Kings Lynn, landing at 0700 hrs. It had been arranged that he would fly that morning as passenger in an RAF Tornado aircraft; this was not connected with the event at Old Buckenham, but arose through the display team's close links with the airbase, having displayed there on a number of occasions. The two Pitts Specials accompanied G-EDGJ to RAF Marham, with the intention that the team would fly on to Old Buckenham later. The pilot's activities whilst at RAF Marham are detailed later in this report.

Footnote

1 See CAP 403: *Flying displays and special events: A guide to safety and administrative arrangements*
2 UK Air Navigation Order 2009.

The display team leader's original intention had been to fly three Pitts Specials to Old Buckenham and it was planned that the accident pilot would fly one of them. As he had flown his own aircraft to RAF Marham, a revised plan was made whereby he would fly G-EDGJ from RAF Marham to a private airstrip where the third Pitts Special was based before then flying that aircraft to Old Buckenham. Accordingly, once the pilot had landed from his Tornado flight, the two Pitts Specials departed for Old Buckenham, 24 nm to the south-east.

When the pilot departed RAF Marham in G-EDGJ, he seemed to be calm but in good spirits and not suffering any ill-effects from his Tornado flight. Takeoff was at 1329 hrs and recorded radar data showed that the aircraft flew on a direct track to Old Buckenham. Nearing the airfield, the pilot contacted the Air/Ground Radio operator. Having been given the airfield details and informed that there was no other known air traffic in the vicinity, the pilot stated his intention to join from the west and to fly some aerobatic manoeuvres overhead before landing.

The main runway at Old Buckenham was orientated 07/25. The pilot approached the airfield on a track aligned with Runway 07. Trailing white display smoke, the aircraft descended to a height of about 100 ft above the airfield before pitching up to the vertical as it commenced a series of aerobatic manoeuvres. These were flown on the northern side of the runway, away from the clubhouse area where the visitors were gathered, but centred upon them (what would be termed 'crowd centre' for a flying display).

The pilot first flew three vertical manoeuvres[3]. The first comprised a series of aileron rolls both while climbing and descending in the vertical axis. The second was the first part of a loop with 5½ descending flick[4] (or "snap") rolls performed from the highest point. The third was a vertical climb which transitioned into an erect two-turn spin to the left. Recovery from the spin appeared normal and immediate, and left the aircraft diving away from the clubhouse area at an angle of about 90° to the runway. Figure 2 shows a graphical representation of the aircraft's manoeuvring from that point.

After a brief pause, the aircraft pitched up once more into the first part of a loop. As it became inverted at the highest point it began to roll to the left, so that it emerged from the manoeuvre in a diving right hand turn to align once again with the runway, this time in the Runway 25 direction (a manoeuvre known as a quarter-clover). The aircraft descended to a height of about 100 to 150 ft before pitching up to a 45° climb. It then rolled 90° to the right before entering a gyroscopic tumbling manoeuvre to the left (described later in this report). The aircraft failed to complete the manoeuvre successfully and entered an erect spin. It completed about one and a half turns before striking the ground, without any apparent attempt by the pilot to recover from the spin. An intense fire broke out at the crash site immediately on impact.

Footnote

[3] A manoeuvre performed mainly in the vertical, where the aircraft gains a substantial amount of height before descending again. A loop would be an example of a vertical manoeuvre.

[4] A manoeuvre in which one wing is forced to partially stall, leading to a rapid roll rate.

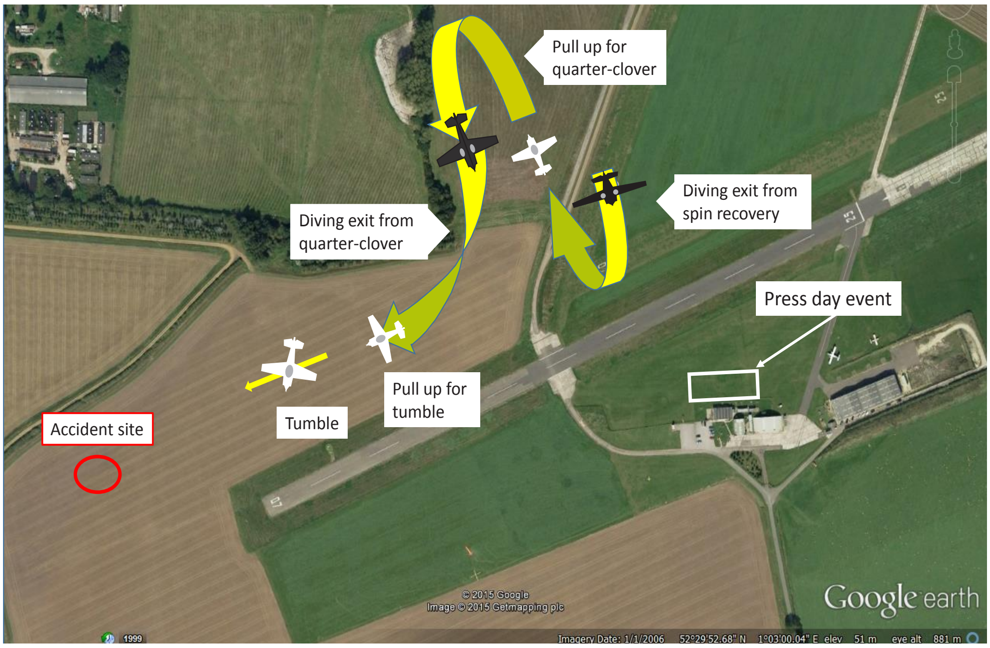

Figure 2

Representation of the aircraft's final manoeuvres

Accident response

Old Buckenham is a licensed airfield but, as notified in the UK Aeronautical Information Publication, usually only has the associated facilities available from Friday to Sunday. At other times, although some facilities such as ATS or RFFS[5] may not be available, the airfield is still available to aircraft not requiring a licensed airfield. On the day of the accident, the Air/Ground Radio station was manned but the RFFS facility was not.

The accident was witnessed by numerous onlookers, many of whom rushed to the scene on foot and in private vehicles. The first to arrive expended several fire extinguishers to bring the fire under control, but it was immediately apparent that the pilot had not survived. The emergency services arrived a short while later, having been notified as part of the airfield's emergency response plan.

Accident site

The aircraft struck the ground in an area of standing crops, about 150 m from the threshold of Runway 07 and about 600 m from the clubhouse area. Although physically close to the runway, the crash site was just outside the airfield boundary. The ground marks and wreckage distribution indicated that the left wing tip struck the ground first with the aircraft in a nose-down attitude on a heading of 110º(M). The aircraft bounced once and rotated anticlockwise before coming to rest upright on a heading of 080º(M). Items from the cockpit area, including parts of the canopy, were found adjacent to the aircraft in an arc extending between the right wing and empennage.

Footnote

5 Air Traffic Service, Rescue and Fire Fighting Service.

Witness information

Among the witnesses attending the press day were a number of experienced aerobatic pilots. Some thought the pilot was flying to a lower base height[6] than usual during his manoeuvres, and wondered afterwards if this could have been due to an incorrect altimeter setting. Witnesses thought that the initial run-in was flown down to a height of about 100 ft, and that the aircraft descended to a similar height between manoeuvres and immediately prior to pitching up to start the final tumble manoeuvre, the entry to which was at an estimated 300 to 400 ft.

Witnesses described seeing the tumble manoeuvre end with the aircraft appearing to enter a flick roll to the left. One thought that the aircraft appeared to lack energy as it went into the final manoeuvre, and that the aircraft's behaviour at the point of recovery might have been unfamiliar to the pilot for that reason. There was general agreement that normal engine noise could be heard throughout the final manoeuvre until the point of impact.

Meteorological information

The weather was settled, with broken cloud over the airfield at an estimated 2,000 ft and a surface wind of 12 kt from 050º. Norwich Airport (14 nm north-east) reported a maximum wind of 10 kt throughout the period, with good visibility and broken cloud at 3,500 ft.

The QNH in the area was 1030 HPa. The difference in elevation between Marham and Old Buckenham was 117 ft. If the pilot had omitted to reset his altimeter to local QFE on arrival at Old Buckenham (the value was passed to him by radio on arrival), it would have over-read by the same amount.

Aircraft information

The Edge 360 is a high-performance single-seat aerobatic aircraft with a Laser Z200 fuselage and wings from Zivko Aeronautics. The wings and empennage are made of composite material and the fuselage is constructed from tubular steel covered in a mixture of Ceconite, aluminium skins and composite material. The fuel is stored in two fuel tanks, one in each wing.

G-EDGJ was equipped with a 210 hp, four-cylinder, fuel-injected piston engine fitted with a two-bladed, constant-speed, wooden propeller. A storage tank for the 'smoke oil' used during aerobatic displays was located on the upper part of the fuselage directly behind the pilot's head.

The aircraft had conventional flying controls with a control column connected to the ailerons and elevators by a series of conventional pushrods, torque tubes and bell cranks. The right elevator was fitted with a cable operated trim tab. Each rudder pedal was connected to a bracket connected to a cross tube running across the floor of the cockpit. A metal footplate

Footnote

[6] Base height: the lowest height being used to start and finish aerobatic manoeuvres. The lowest height permitted will be determined by applicable regulation or specific authorisation. Pilots may nominate and fly to a higher base height than the minimum allowed in the circumstances.

was positioned on the floor in front of each pedal. The rudder was operated by two cables, each of which was connected to the outside of the rudder pedals and routed down the side of the fuselage, through nylon guides, to its respective rudder control horn.

G-EDGJ was fitted with a five-point seat harness. When the aircraft was imported into the UK, each shoulder harness was independently mounted on a frame at the rear of the cockpit. However, the attachment was not compliant with JAR 23.561[7] so a modification was introduced to secure both shoulder harness to a shackle that was attached by two steel cables to a cross tube located one metre behind the pilot's seat. These cables, which were routed over the top of the 'smoke oil' tank, were fitted with 'anti chafe' PVC covers.

An aerobatic sight was mounted on the left wing tip and a mount for a small High Definition camcorder was fitted on the right wing tip, 6 cm aft of the wing leading edge.

Aircraft examination

General

The fuselage aft of the engine bulkhead and the inboard section of both wings had been destroyed by fire. The steel frame immediately aft of the engine bulkhead had distorted and broken leaving the engine aligned 30° to the right of the fuselage. The frame on the left side of the forward part of the fuselage had also distorted. The structural damage was all consistent with the aircraft striking the ground while in a spin to the left.

Engine

The wooden propeller had shattered and the damage on the remaining sections fitted to the hub was consistent with the propeller rotating at impact. The right side of the engine had been damaged by the fire and the lower part by the impact. The colour of the spark plugs was normal and a videoscope inspection of the inside of each cylinder revealed nothing unusual.

Controls

Control continuity was established between the control column and the elevators. The left aileron control rod had failed at the lower screw fitting on the control rod located aft of the pilot's seat. The control rod had bent and the fracture surface was consistent with the rod having failed in an overload condition. The left side of the fuselage frame adjacent to the broken control rod had also distorted in the accident.

The rudder cables were still attached to the pedals and the rudder control horns. The nylon bushes supporting the cables had all melted and the left rudder cable had failed 26 cm aft of where it connected to the rudder pedal. There was no evidence of the cable having been damaged prior to the accident and the failure was consistent with the cable having failed in overload. The rudder pedals were intact, through the right side of the cross tube that they were attached to had distorted causing the right pedal to be displaced outwards.

Footnote

[7] Joint Aviation Requirements JAR-23 contained airworthiness requirements for Normal, Utility, Aerobatic and Commuter Category Aeroplanes.

The rudder and ailerons were free to move. The elevator could not be moved as the control rod for the elevator that passed under the pilot's seat had distorted in the crash and the outboard section of the right tail plane and elevator had bent upwards causing the elevator surface to jam. The trim tab on the right elevator was found in the fully down position (trim nose-up). From the disruption to the wreckage it is likely that the trim moved to this position during the accident sequence.

There was no evidence of any item in the cockpit having jammed the rudder pedals, nor was there any visual evidence of any part of the rudder control system having jammed. The few items which the pilot was known to have been carrying with him on the accident flight were accounted for; there was no evidence that any would have presented a loose article hazard.

Seat harness and parachute

While the seat harness had been destroyed in the fire, the metal fittings remained intact. The steel shoulder harness cables were still attached to the aircraft frame and the shoulder harness fitting. The remainder of the harness fittings were also still attached to their anchor points. The harness buckle was found in the engaged (closed) position. The pilot was wearing a parachute.

Aircraft maintenance

The last flight recorded in the aircraft's logbooks was on 21 December 2014. In January 2015 the aircraft began a period of maintenance during which the propeller and its governor were removed for overhaul.

The following significant maintenance activities were recorded in the aircraft documentation:

- On 15 March 2011, a larger rudder was fitted as a repeat modification and a flight test was carried out on the 19 March 2011 before the documentation was submitted to the Light Aircraft Association (LAA).
- On 7 April 2011, following the flight test, the LAA authorised the modification of the new, larger rudder but noted that it was not a repeat modification as previous installations had been 'dealt with done at import or done at transfer to LAA'.
- On 25 February 2012, at 743 flying hours, the rudder cables were replaced with new items during the annual maintenance.
- On the 16 April 2015, at 838 flying hours, the annual maintenance, inspection and check flight required for the issue of the Permit to Fly, Certificate of Validity was completed. The aircraft work sheets show that the flying wires had been cleaned and coated with silicon, and the seat harness had been replaced. The propeller and its governor had also been refitted following overhaul. The maintenance and inspection of the aircraft was carried out by the owner and supervised by a LAA inspector. The Certificate of Validity was issued by the LAA on 20 April 2015.

Aerobatic and spinning flight test report

The last aerobatic flight test was carried out by the pilot on the 19 March 2011 following fitment of the larger rudder. The test schedule required demonstration that the aircraft perform, and safely recover from, spins of up to three turns in either direction. The pilot recorded that a two-turn spin to the left recovered normally within half a turn following recovery action, while a three turn spin recovered in two thirds of a turn. Recorded recovery action was: right rudder, forward control column (down elevator). Total loss of height for a two-turn spin and recovery was 2,000 ft. The flight test spins were performed with the throttle closed.

In the flight test report, the pilot recorded:

> *'The aerobatic tests showed no areas for concern. The new rudder provides better control at low airspeeds and enhances manoeuvres such as rolling circles. Flick and spin characteristics were unchanged.'*

The check flight carried out by the owner on 16 April 2015, as part of the application for the Permit to Fly Certificate of Validity, was signed as satisfactory. There was no requirement for, and no record of, the aircraft having been spun during this check flight.

Pilot information

General

The pilot, who had no health issues known before the flight, was described by colleagues as a stable individual. It was not unknown for him to fly some aerobatics on arrival at an airfield if the opportunity presented itself, so his decision to do so on the day of the accident, even though there was no brief to do so, was not seen as being out of character by those who knew him.

The pilot spent the evening before the accident at home and retired early. He rose early and had breakfast before leaving the house with a packed lunch and bottle of water. He was not rushed, appeared well rested and was looking forward to his Tornado flight.

Flying and aerobatic experience

The pilot was a very experienced and well regarded aerobatic pilot. He started flying training in 1985 whilst living in the USA and gained a Private Pilot's Licence. He continued flying on his return to the UK, and became a part-owner of a Piper PA-28. In 2003, having developed an interest in aerobatic flying, he purchased a Laser Z200 single-seat aerobatic aircraft. In 2004, the pilot began competition aerobatic flying and in 2009 he purchased G-EDGJ. He became a regular competitor at UK aerobatics competitions and was the British Aerobatics Advanced Champion in 2012 and 2013. He had also been a member of the British team at the European and World Aerobatics Championships.

In 2013 the pilot joined the formation and aerobatic display team with which he was to visit Old Buckenham on the day of the accident. His display role was to fly dynamic solo aerobatic manoeuvres, co-ordinated with the formation flying of the two Pitts Specials. As a separate venture, he also provided solo aerobatics displays for public, corporate and private events.

The pilot held a Display Authorisation (DA), issued by the CAA in accordance with the provisions of the Air Navigation Order. The DA, first issued to the pilot in 2006, authorised him to perform Advanced category aerobatics (including tumble-type manoeuvres) as part of a flying display to a minimum height of 200 ft, with a minimum height of 50 ft for flypasts (ie substantially straight and level, non-aerobatic flight).

Flying and aerobatic currency

The pilot's flying logbooks showed that he typically flew regularly during the summer months and steadily, though much less regularly, during the winter (considered here to be November to March inclusive). He flew nine flights during the winter months of both 2012/13 and 2013/14.

There was evidence that the pilot flew a number of aerobatics practice flights prior to the air show season in both 2013 and 2014. He logged his first seven flights of 2013 (between 3 January and 5 April) as aerobatic practise flights. For six of these flights there was video evidence of him practising aerobatics in his local area using base heights which appeared to be at or above 1,000 ft. He logged eight local flights in early 2014 (between 10 January and 24 April). These were not recorded as aerobatics practices, but there was similar video evidence for three of the flights. Video evidence is discussed fully later in this report.

Winter 2014/15 followed a different pattern. The pilot flew regularly until the end of September 2014, after which he flew twice on a single day in October (but did not fly any aerobatics, according to the aircraft logbook) and again on 21 December 2014, which was a solo aerobatic display at a private function and the last flight to appear in his personal logbook and the aircraft's logbook. There was no formal record of the pilot flying G-EDGJ again until the flight test on 16 April 2015, six days before the accident.

The pilot made three entries, with photographs, on a social media website which indicated that he had flown three aerobatic flights in G-EDGJ in the period 6 December 2014 to 20 January 2015. However, there were no associated entries in his personal logbook or the aircraft's logbooks. The pilot signed a declaration on 16 April 2015, at the time of renewal of the aircraft's Permit to Fly, stating that the recorded hours were accurate. The recorded hours did not include the flights indicated on social media.

On 17 April 2015, the pilot flew G-EDGJ to Old Buckenham where he refuelled it before flying back to his home airstrip. It is not known if he practised any aerobatic manoeuvres in the aircraft on 17 April 2015, and no video evidence was found of him having done so. However, on its return, the aircraft was seen by another pilot there to enter a spin overhead the airstrip. The spin and recovery, which were carried out from an estimated height of 2,000 ft, appeared normal.

According to his entry on a social media website, the pilot flew G-EDGJ on 18 April. There was no other record of this flight or whether it included any aerobatics. The pilot next flew G-EDGJ on 22 April 2015, on the short flight to RAF Marham and on the accident flight itself.

The pilot was reported to have flown three flights in other aircraft between 18 April and 20 April 2015: two in a team Pitts Special (one dual re-familiarisation and formation flying practice, one solo consolidation), and one flight in an Extra aerobatic aircraft (providing instruction/demonstration).

Pilot's visit to RAF Marham

The pilot attended the Station Medical Centre to undergo an examination to ensure his fitness prior to his Tornado flight. The Medical Officer conducting the examination described the pilot as appearing to be a fit and well individual. Nothing adverse was detected during the medical examination and the pilot was passed fit for the flight.

The sortie consisted of medium level transits (FL100 to FL 140) to and from the North Wales area, with general handling at or above 2,000 ft and an instrument approach to an airfield. Before landing back at RAF Marham, some simple aerobatic manoeuvres were flown at the accident pilot's request, which were flown to a maximum of +4 'G'.

On landing from the flight, which lasted 1 hour 35 minutes, the pilot was accompanied to the squadron crew room where he drank a large glass of water (he was known to be aware of the adverse effects of dehydration). The Tornado pilot then accompanied him to his aircraft and the two men spoke for a while before the accident pilot started his preparations for departure. The pilot's behaviour appeared normal, with no indication that he was suffering any ill effects from his flight.

Rules applicable to aerobatic currency with regard to flying displays

The event was not classified as a flying display or special event. The pilot's aerobatic sequence, although flown to what appeared to be typical display minima, would therefore be regarded as a practice. CAP 403 (*Flying displays and special events: A guide to safety and administrative arrangements)* stated in Chapter 5 *(Pilot display competency):*

> *'…a Display Pilot is required to meet certain recency requirements before his DA is valid. In the 90 days preceding a demonstration at a flying display for which an Article 162 Permission is required, a minimum of three full display sequences must have been flown or practised, with at least one display sequence flown or practised in the specific type of aircraft to be displayed.'*

And

> *'…It is emphasised that the above requirement should be viewed as a minimum requirement for display recency and that pilots are encouraged, particularly*

during the winter months or pre-season work up, to undertake sufficient practice to ensure that a sufficiently high standard of safety is maintained… If the display sequence has not been practised recently, the pilot should set himself appropriately higher minima, for practice or actual display purposes, until such time as full currency is regained.'

Medical and pathological information

A post-mortem examination established that the pilot died as a result of multiple injuries sustained in the accident. These were consistent with peak deceleration forces beyond the range of human tolerance. Although the post-crash fire took hold immediately after impact, there was no evidence that the pilot was conscious or actively breathing at that time. Toxicological examination showed no evidence of alcohol or drugs.

The examination identified a severe narrowing of the left anterior descending coronary artery (one of the main arteries supplying blood to the muscle of the main pumping chamber of the heart) by atheroma, with the presence of relatively fresh blood clot (thrombus) in the lumen of the vessel, which was confirmed microscopically. The pathologist compiling the post-mortem report acknowledged that the effects of this condition on an individual piloting an aircraft in aerobatic manoeuvres were outside the scope of his report. However, he wrote that:

'if seen in the clinical setting, acute coronary artery thrombosis is considered a serious medical event, requiring immediate intervention.'

The post-mortem examination was attended by a specialist aviation pathologist who provided the AAIB with a report in which he considered the implications of the examination findings for the accident investigation. In his report, the specialist said that it was difficult to be precise about how long the blood clot had been in the coronary artery, but it was likely to have been of the order of hours to a few days. The effect of the blood clot would have been to produce an acute reduction in the blood supply to the area of heart muscle supplied by this coronary artery. This would have had a wide spectrum of possible effects, from being unnoticed through to causing chest pain, shortness of breath, abnormal heart rhythms, infarction of the heart muscle (a myocardial infarction), collapse or sudden death. Acute coronary artery thrombosis is a medical emergency which necessitates rapid treatment, but an individual would only be aware of its presence if it were causing noticeable symptoms. The fact that the pilot undertook his aerobatic flight was strongly suggestive that he would have been unaware of his blood clot beforehand.

In relation to the pre-flight medical examination which the pilot underwent before his Tornado flight, the specialist noted that, unless his blood clot were causing symptoms at rest or producing secondary effects on the functioning of the heart, it would not be detected at a routine medical, and may not have been apparent on an ECG.

The specialist examined video evidence of the accident flight (presented later in this report) and observed that the pilot was conscious throughout the flight, including the final manoeuvre. The video was also viewed by the national medical expert on long-duration acceleration (‘G’), who concurred that it showed no evidence that the pilot was suffering from G-induced loss of consciousness or any other form of G-induced impairment. However, the specialist noted that during the aerobatic sequence the pilot will have been physically exerting himself and his heart rate and the effective work of his heart muscle will have increased during this time. The heart muscle is only effectively perfused during diastole (that period of the cardiac cycle in which the heart muscle is relaxed); as the heart rate increases, this period of diastole reduces, and the muscle becomes more prone to the effects of a compromised coronary circulation.

The specialist considered that it was highly conceivable that the blood clot in the pilot’s coronary arteries may have had an effect on his heart during his aerobatic sequence which had not been evident prior to this. While he clearly had not lost consciousness, it is quite plausible that he may have been suffering from symptoms or effects which would have impaired his performance and his ability to fly what were demanding manoeuvres safely. His report concluded with the following:

> *‘In summary, the pilot of G-EDGJ died of multiple injuries which were sustained in the non-survivable crash of his aircraft. He exhibited evidence of a recent blood clot in one of his coronary arteries. While this has apparently not caused him problems prior to his final flight, it is difficult to ignore its presence, and in the absence of any other demonstrable cause for the accident, it is possible that during the increased physical workload of his aerobatic sequence it has caused some symptoms or effects which may have impaired his ability to perform highly demanding flight manoeuvres.’*

The aerobatic tumble manoeuvre

The pilot was attempting one of a family of extreme aerobatic manoeuvres that use the gyroscopic properties of the rotating propeller to induce a series of tumbles about the lateral (transverse) axis. While the manoeuvre can be highly disorientating for the pilot, it is carried out at a relatively low airspeed and the forces on him are not extreme.

To achieve the tumble, a pilot has to overcome the aircraft’s natural stability for the duration of the manoeuvre and to keep the wing at a zero-lift angle of attack[8]. The entry the pilot used was a recognised one, in which the aircraft is first pitched to a 45º climbing attitude then rolled to 90º right bank to achieve ‘knife edge’ flight. Typical entry actions for a tumble to the left are then: up to full down elevator, full left rudder and some left aileron.

While tumbling, the aircraft requires very precise roll control if its behaviour is to be completely predictable. If the aircraft should roll and the wing start producing lift due to developing significant positive or negative angle of attack, there is a risk that the aircraft may flick, with the possibility of entering an erect or inverted spin (depending on whether

Footnote

8 The angle of attack is the angle between the relative airflow and a line joining the wing’s leading and trailing edges. The angle of attack corresponding to a zero lift condition (ie producing neither positive nor negative lift) will vary with the design of the wing, but will be zero degrees for a wing of symmetrical cross-section.

the wing starts producing positive or negative lift). Provided there is sufficient airflow over the ailerons, they can be used during the tumble to exercise some control over the wing's angle of attack, changes in which may be detected visually or through the forces acting on the aircraft. Application of right aileron during the tumble will tend to reduce a positive angle of attack (or increase a negative angle of attack). If the airspeed drops to the point that the ailerons cease to be effective, a high angle of attack may develop quickly, with the associated risk of an unintentional spin.

Typical recovery actions to return the aircraft to conventional flight are: application of opposite rudder (right rudder in this example) and elevator to neutral. Ailerons are not normally used as a recovery aid. Engine power is typically kept at a high setting during the tumble, as it provides the driving gyroscopic force. If necessary or desired, it can be reduced for recovery in order to lessen the gyroscopic forces, although at low speed this will also reduce the effectiveness of the tail control surfaces by reducing the propeller slipstream effect.

While tumbling, the aircraft continues on a projectile trajectory, which is why tumbles started from lower heights (as in the accident case) need to be entered on a climbing flight path. Provided that it retains sufficient forward progression (whether through entry speed or by entering with a downwards vector if height permits), returning the controls to neutral should allow the aircraft's natural stability to realign it with the relative airflow. However, during the tumble, the aircraft is partly sideways-on to the relative airflow and therefore in a high drag condition. Consequently, when the tumble is entered with an upwards vector, speed can dissipate rapidly to the extent that more positive pilot action may be required to regain conventional control.

Video footage examination

General

The investigation had access to video footage of the accident flight and of earlier flights. Ground based footage was provided by the local television company covering the event and by personnel at Old Buckenham Airfield. The pilot recorded many of his displays and practices with the camcorder mounted at the aircraft's right wing tip; it was in use on the day of the accident and captured the latter stages of the accident flight, including all the aerobatic manoeuvring. Video files stored on the pilot's home computer showed previous flights, including instances of him flying the same tumble manoeuvre. Additionally, some flights had been recorded with an in-cockpit camcorder.

While the ground based footage provided the necessary overview of the accident, the camcorder evidence provided detailed information concerning the tail control surfaces, aileron position and the cockpit area. It included a sound track, but it was not possible to discern large changes in engine noise at higher airspeeds or during dynamic manoeuvres when the airflow near the camcorder was affected by large movement of the right aileron. Unless otherwise stated, all heights given in this section are estimated from the video footage.

Control terminology

This section refers to control surface positions (elevator / rudder / aileron) rather than cockpit control positions. Aileron is described as left or right according to the conventional roll response of the observed position. The aircraft was not always in conventional flight during its aerobatic manoeuvring so control surface position may not always indicate the aircraft's actual response.

Historical footage

A total of 63 video files were identified which contained aerobatic manoeuvring, the great majority being recorded in 2013 and 2014. There was footage of the pilot performing the same tumble manoeuvre on 32 previous occasions: in practice, during solo displays and during team displays.

There was video evidence of the pilot practising aerobatics at or above 1,000 ft base height in the early months of both 2013 (6 flights) and 2014 (3 flights). Further files, covering 22 flights, showed the pilot flying aerobatics at display heights (for this purpose, with a base height of 500 ft or lower). These were mainly during the 2014 season, all but one of which were as part of the team display. Apart from the accident flight, the only footage for 2015 was the short transit flight to RAF Marham. No video record was found of any aerobatic manoeuvres in 2015 prior to the accident flight.

All the manoeuvres flown on the day of the accident (with the exception of the quarter-clover linking manoeuvre) were ones which appeared individually numerous times in the historical footage, although the sequence as flown on the accident day did not. Only once (in September 2014), was the pilot seen to fly part of the accident sequence. On that occasion, he flew the same first three vertical manoeuvres (with minor variations in positioning), although the erect spin was not allowed to develop, recovery being achieved after about three-quarters of a turn.

Minimum heights during actual displays varied with location. At airfield sites the aircraft would typically descend to between 100 and 200 ft between manoeuvres and the pitch-up prior to the start of the tumble manoeuvre was typically made from about 200 ft. On a few occasions it was from lower, down to about 100 ft. At non-airfield sites, this height varied from about 200 ft up to between 400 and 500 ft.

The manoeuvre the pilot normally flew immediately before the tumble manoeuvre (during the 2014 team display) was a loop with two flick rolls at its highest point. This was preceded by a break in the sequence, allowing a diving run-in to gain speed. A limited number of other preceding manoeuvres were identified (mainly during the 2013 season), but these were also relatively high energy vertical manoeuvres, to the extent that some of the early examples involved three rotations in the tumble rather than the two rotations used latterly. There was no video evidence of entering the tumble manoeuvre from a quarter-clover type manoeuvre.

The pilot always entered the tumble manoeuvre after pitching the aircraft to about 45º nose-up. He would then pause before rolling to 90° right bank (occasionally this would be achieved by rolling left through 270º). There would then be a further, shorter, pause before he would initiate the tumble. The initial pause varied between 1.7 and 3.1 seconds, being about 2 seconds on average. Entry to the manoeuvre was initiated with up to full down elevator, followed immediately by up to full left rudder. As these inputs were made, about one quarter to one third left aileron was applied. During the manoeuvre, there would typically be variable amounts of left aileron.

Recovery actions were normally initiated when the aircraft was in a nose-high attitude, completing a further part tumble to adopt a nose-low attitude at exit. Initial recovery actions were: elevator neutral and ailerons neutral. As the tumble ceased, he would gradually centralise the rudder and apply aileron as required to align the aircraft with the desired exit heading. The aircraft was then recovered from the ensuing dive. On two occasions, a significant amount of up elevator was applied for a brief period, but this appeared to be in order to limit the nose-down pitch angle once the tumble ceased.

Display smoke was frequently used. The aircraft always appeared to have sufficient energy that its trajectory took it away from the smoke throughout the manoeuvre and recovery. The smoke trail tended to indicate that the aircraft's sideways motion during the tumble was not excessive (it can be flown successfully with the nose yawed only about 45º from the direction of travel).

The pilot only introduced the erect spin into his team display routine in July 2014. It was always entered from a vertical climb (as seen on the accident flight), such that the aircraft transitioned from the climb directly into the spin. On no occasion was a spin of more than one turn recorded, most being considerably less. On no occasion did a spinning manoeuvre precede the tumble manoeuvre.

In-cockpit footage

There were six occasions when the pilot also filmed the tumble manoeuvre with an in-cockpit camcorder. Five were solo practice flights but the last, recorded in June 2014, was a team display. Although some allowance had to be made for instrument errors during the highly dynamic manoeuvres, there was a close and consistent correlation between the observed speed and altitude values.

Height gained prior to the tumble manoeuvre was a direct product of the speed at pull-up (variable between 190 to 215 kt) and the length of pause before initiating the tumble. The average height gained in the initial pitch up to 45° was 180 ft, while the overall height gained to the point where the tumble was started varied between 500 and 900 ft. Actual heights for initiating the tumble varied between 1,300 ft (during a team display) and 1,700 ft. The minimum height seen for the aircraft to recover from the nose-down attitude at the end of the tumble was 300 ft.

Accident flight footage

The footage started 3 minutes 35 seconds before the accident, with the aircraft in straight and level flight about 4.2 nm from Old Buckenham Airfield. The aircraft dived to arrive overhead the airfield at low height and trailing display smoke before entering the first of the series of manoeuvres as described earlier in this report. Between manoeuvres, the aircraft descended to heights estimated from the footage to be between about 100 and 150 ft.

The manoeuvres included a two-turn spin to the left. It appeared in the sequence immediately before the quarter-clover manoeuvre which linked it to the final tumble. The spin stabilised with full left rudder applied, full up elevator and a small amount of right aileron, consistent with earlier intentional spins. Rotation rate stabilised at about 120º/sec. Spin recovery actions taken by the pilot were: right rudder and moderate down elevator. The amount of right rudder applied could not be determined accurately due to obscuration by smoke, but the spin recovery appeared prompt and normal. The aircraft recovered from the ensuing dive and, after a pause in level flight, pitched up into the quarter-clover.

The aircraft exited the quarter-clover manoeuvre in a diving right turn while descending to a height assessed as between 100 and 150 ft, which was consistent with witness accounts. Without pause, it continued to pitch up for the tumble manoeuvre. Immediately on reaching about 45º pitch attitude, the aircraft rolled to 90º right bank, followed immediately by initiation of the tumble. There were no pauses between these elements, so the aircraft entered the tumble at a noticeably lower height than on earlier occasions. Control inputs to enter the tumble and in the early stages were consistent with those seen on earlier footage.

As the tumble developed, changes in the smoke trail indicated that the aircraft adopted a more sideways attitude than usually seen and that the wing started to develop a significant positive angle of attack. About half right aileron was applied late in the manoeuvre but before recovery action was taken.

Recovery actions appeared to be initiated at the normal point, but the control positions were not typical: the elevator moved briefly to neutral but continued to move to become marked up elevator. Rudder was approximately centred at the same time as the elevator moved, but a small amount of left rudder remained applied. Variable amounts of right aileron remained applied throughout the attempted recovery phase. The aircraft had very low forward motion at this stage, such that it became enveloped in the display smoke for a time.

At about this point, with a very high angle of attack, right aileron, up elevator and residual left yaw, the aircraft entered a flick roll to the left. The elevator briefly moved towards a neutral position, but as the aircraft adopted a steep nose-down attitude, there was a further upwards movement, placing the aircraft in an incipient spin condition[9] with controls in a position conducive to spin entry.

Footnote

[9] A dynamic transition period on spin entry where the conditions for the spin are present but the spin has not yet stabilised.

The aircraft descended in a spin with full up elevator, between neutral and very slightly right rudder and full right aileron. The spin stabilised at about 120º/sec. Ground impact occurred about 5 seconds after spin entry. The control inputs remained substantially unchanged until impact and were such that they would have continued to drive the spin.

Throughout the manoeuvres, the pilot's appearance (including head position) was similar to that seen on historical footage. There was no video evidence that he had struck his head on the airframe, lost consciousness at any stage or experienced any difficulty in the cockpit with, for instance, a loose article or with his harness restraint.

Earlier event

On one occasion (in September 2013) historical footage showed a tumble manoeuvre which contained significant differences to others but had similarities with the accident footage. On this occasion too, the smoke trail suggested that the aircraft's sideways motion had developed to a greater extent than was usual. Right aileron was applied shortly before recovery, rudder was returned to neutral much earlier than usual and elevator moved to a modest up position.

The significant differences between this manoeuvre and the accident manoeuvre were that the entry conditions were normal and the aircraft retained some forward momentum, not appearing to develop a high positive angle of attack or becoming enveloped in smoke as seen on the accident footage. Additionally, the up elevator and right aileron inputs were not as exaggerated nor held for as long.

Analysis

Preliminary note

The investigation was assisted by pilots expert in flying the type of advanced aerobatics manoeuvres involved in this accident. They provided much of the specialist explanatory material contained earlier in this report as well as contributing to the analysis of the video footage.

General

The pilot, who was skilled and experienced in advanced aerobatic manoeuvres, had been unable to prevent his aircraft from entering a spin from the failed tumble manoeuvre or to attempt recovery actions once the spin became established. This analysis therefore concentrates on the aircraft technical examination, the failure of the tumble manoeuvre and the spin itself. It also considers other aspects of the pilot's performance on the day of the accident and finally the implications of the post-mortem examination findings.

Technical investigation

The ground marks and damage to the aircraft were consistent with video and witness evidence that it impacted the ground while in an erect spin to the left. It was established that the propeller was rotating under engine power at impact, which was also consistent with witness accounts that the engine was running during the final seconds of flight. The forces involved in the accident were not survivable.

Consideration was given to the possibility of a control failure or restriction occurring that may have prevented the pilot from taking spin recovery action. During the recent annual inspection, the control system was inspected and the cables cleaned and coated with silicon grease. There was no evidence to suggest that the pilot had experienced any problems with the flight control system subsequent to this and prior to the accident flight. There was ample video evidence to indicate that the flight controls were performing normally in the last minutes before the accident, along with evidence of a successful spin recovery immediately beforehand.

Following the accident, the elevator control system was found to be intact with no evidence of a control restriction. The failure of the left rudder cable occurred as a result of overload and can be explained by the distortion of the structure as a result of crashing while in a spin to the left. Nevertheless, failure of the left rudder cable in-flight should not have prevented the pilot from applying full right rudder. The few items which the pilot was known to have been carrying with him on the accident flight were accounted for and nothing was found in the vicinity of the rudder pedals that might have restricted their movement. It was therefore concluded that the failure to recover from the spin was not caused by a control failure or restriction.

There was no requirement or expectation that the pilot fly any aerobatics on the day of the accident, so he could have discontinued the sequence at any stage had he felt that the aircraft was not performing as expected. The technical investigation concluded that the accident was not caused by a mechanical defect, failure or malfunction.

Failure of the tumble manoeuvre and entry to the spin

Both video and witness evidence indicated that the aircraft became very slow during the tumble manoeuvre and lost forward momentum. With the amount of historical footage available, and obvious differences occurring on the accident flight, the investigation was able to establish two likely reasons for the loss of energy: slower than normal speed on entry and a greater than normal sideways motion developing during the manoeuvre.

Without exception, all the historical footage showed significant pauses after the pull up for the tumble manoeuvre, which would have occurred as the pilot waited for the speed to drop to the required range for entry to the tumble. At the same time, the aircraft would be gaining height. On this occasion, there were no pauses, indicating that the aircraft had already reached the pilot's normal entry speed, or even dropped below it.

The lack of entry speed is probably attributable to the sequence of manoeuvres beforehand. The two-turn spin would have entailed a considerable loss of energy which the pilot would have found difficult to regain in the short quarter-clover link manoeuvre, particularly as he was already using a low base height and therefore unable to convert excess height to speed.

Coupled with the lack of speed was a lack of height. The initial pitch-up for the tumble was started from a low height and the immediate initiation of the tumble on reaching 45º meant that the aircraft was still relatively low at this point. Witness estimates placed the aircraft at 300 to 400 ft at commencement of the tumble, which is consistent with the performance values seen in the in-cockpit footage. This height should be compared with the minimum height seen on the in-cockpit video of 1,300 ft, recorded during a team display the previous season.

As the tumble manoeuvre progressed, the aircraft quickly lost more energy. The video evidence showed that it adopted a more sideways attitude than usual, which would have caused it to lose energy more rapidly. A similar situation was seen on one previous occasion, in September 2013. As on that occasion, rudder was returned to near centre whilst in the tumble, which was not otherwise seen, suggesting that the pilot was aware of the developing situation on both occasions and responding to it. On the flight in September 2013 the entry speed and height were normal, whereas on the accident flight they were not.

The pilot routinely recovered from the tumble manoeuvre with some left rudder still applied until a late stage, relying in part on the aircraft's residual natural stability rather than using right rudder to eliminate the yaw at an earlier stage, which is the more usual technique. Although this had proved a workable method of recovery for the pilot, it would not be the quickest nor most efficient. It is possible that the pilot's habitual lack of right rudder for recovery may have been a factor in his not recognising the need for it on this occasion. Recovery from the tumble may have been successful had right rudder been applied earlier.

As the aircraft lost forward momentum, maintaining control would have become increasingly difficult and the aircraft's ability to recover through its own natural stability would rapidly diminish. During the second tumble rotation, the dynamic of the manoeuvre changed as the aircraft rolled to the left. This caused the wing's angle of attack to increase markedly and it started to produce lift. In this situation, with significant aileron deflection, up elevator input and residual left yaw, the aircraft flicked to the left and entered autorotation[10].

The control inputs at this stage cannot be explained easily, particularly considering the pilot's experience. They could be accounted for had the aircraft exited the manoeuvre as it normally did, insofar as the pilot would want to limit the nose-down pitch with elevator and stop the left roll with right aileron. It is therefore possible that he did not realise the aircraft was still at a high angle of attack and had not regained conventional flight. Alternatively, the control inputs (particularly elevator) may have been an instinctive reaction as the aircraft pitched nose-down and the low height available became immediately apparent to the pilot.

Failure to recover from the spin

Even if recovery from a spin had been possible in the height available, prompt action would have been required to achieve it. Full right rudder to eliminate the yaw was required, together with down elevator (control column forward) to reduce the angle of attack and un-stall the wings. Instead, the rudder remained approximately central and the elevator moved fully up,

Footnote

10 In this context, a situation where the aircraft's wings are at grossly asymmetric values of lift and drag, creating a rolling-yawing motion which can lead to a fully developed spin.

along with right aileron. These control positions not only prevented recovery, but ensured that the aircraft entered and remained in the spin.

Possible contributory factors

There were a number of aspects to the accident flight which, given the pilot's experience, may be regarded as anomalies. These may, together or individually, have contributed to the accident and may indicate the pilot's health or state of mind at the time.

The accident occurred early in the season following a winter in which the pilot had done limited flying. There was no evidence (and limited opportunity) for recent aerobatic practice in G-EDGJ, yet in previous years he had flown aerobatic practices at a reasonable height early in the year to prepare himself for the demands of low level display aerobatics. As the pilot frequently used his camcorder to record displays and practices, the absence of any footage for the flights on 17 and 18 April 2015 suggests that these were not intended to be aerobatic practice flights, even though he may well have flown aerobatics during them. The last occasion on which he had flown aerobatics at his lowest authorised height would have been several months earlier, almost certainly in September 2014.

Although the sequence the pilot flew had some common elements with earlier displays seen on video, there were significant differences. The spin was held for substantially longer than seen previously and it immediately preceded the quarter-clover which linked it with the final tumble manoeuvre. The duration of the spin and its position in the sequence are likely to be the reasons why the aircraft started the tumble with less speed than usual. The quarter-clover itself is not one the pilot used in either his solo or team displays. Its use, together with the extended spin, suggests that the sequence flown on the day of the accident was improvised, either in its entirety or to the extent that the decision to fly the tumble manoeuvre was made in flight.

The low heights between manoeuvres were clear from the video evidence and were remarked upon by witnesses. (Had the pilot not set his altimeter to the local QFE, it would have over-read by around 100 ft. However, given the opportunity to halt the sequence if he felt he was consistently and inexplicably too low, it is thought unlikely that this was a factor.) Although the heights were typical of the pilot's usual in-season displays, the fact that he chose to fly to such low height so early in the season when there was no need to do so, following minimal practice and using a sequence which differed from his usual, was a departure from his normal routine and contrary to established guidance.

Based on the video evidence, the aircraft would take up to 300 ft to recover to level flight from the tumble manoeuvre, so the pilot must have been aware that the low entry height would leave little margin for error, even when entered at the correct speed. As there was no need to fly the tumble, the pilot could have discontinued the sequence at that point, or substituted a less ambitious manoeuvre such as a series of climbing aileron rolls (which he frequently used to end elements of a sequence). Alternatively, he could have chosen to fly a single tumble rotation from the outset, rather than his usual two. Thus, his decision to fly the tumble and to attempt two rotations from a low entry speed and height represents a further anomaly.

The Tornado flight, occurring shortly before the accident, is an unusual aspect of the overall accident scenario and thus represents a potential contributory factor. There was no indication that the pilot suffered any ill effects from the flight, or that he embarked on the accident flight in a euphoric state of mind. Nevertheless, considered with the other aspects mentioned above, the possibility that the pilot's judgement and risk awareness were influenced in some way cannot be ruled out.

Medical aspects

According to expert opinion, it is possible that the pilot became subject to incapacitating effects of his undiagnosed heart condition, which could offer an explanation for his failure to take appropriate action to prevent the aircraft entering the spin and subsequently to recover from it. Although the video evidence ruled out a total collapse, the circumstances indicate that the pilot may have become incapacitated in such a way that he was unable to recognise the situation or respond correctly to it.

It is unlikely that the pilot felt unwell earlier in the sequence, since he could have discontinued it at almost any point. The video evidence showed that he entered the tumble manoeuvre normally (notwithstanding the relatively low speed and height) and that he initially reacted to the higher sideways motion and increasing angle of attack with rudder and aileron in the same manner as he had done in the past. It was therefore concluded that, had the pilot been subject to incapacitating effects of his condition, their onset must have been rapid and probably occurred during the tumble manoeuvre itself.

In isolation, the decision to fly an improvised sequence at low height and with little or no recent practice appears ill-advised, as does the decision to continue with entry to the tumble and to attempt two rotations when speed and height were questionable. Considering the pilot's experience and established reputation, it is therefore possible that his medical condition may have subtly affected his judgement without presenting more obvious physical symptoms.

Conclusions

The pilot lost control of his aircraft whilst carrying out an advanced aerobatic tumbling manoeuvre. The aircraft entered a spin at relatively low height which continued until ground impact without any apparent attempt at recovery. The investigation concluded that the aircraft had entered the spin as a result of inappropriate control inputs, which also precluded recovery from it.

The technical investigation found no mechanical defect, failure or malfunction which could have caused or contributed to the accident.

A number of other factors were identified which could have contributed to the failed aerobatic manoeuvre, including limited recent aerobatic practice and the use of a new or improvised aerobatic sequence. The pilot entered the manoeuvre at a lower height and speed than usual, which not only contributed to the failure of the manoeuvre but also greatly reduced the time and height available for any possible recovery.

The pilot was found to have been suffering from a serious and previously undiagnosed heart condition which had the potential to produce incapacitating symptoms which may have affected his judgement and decision making during the flight. The investigation was able to rule out a total collapse, but it is possible that the pilot became incapacitated at a critical stage of the flight to the extent that he was unable to recognise the rapidly deteriorating situation or respond correctly to it.

AAIB Correspondence Reports

These are reports on accidents and incidents which were not subject to a Field Investigation.

They are wholly, or largely, based on information provided by the aircraft commander in an Aircraft Accident Report Form (AARF) and in some cases additional information from other sources.

The accuracy of the information provided cannot be assured.

ACCIDENT

Aircraft Type and Registration:	Vickers Armstrongs Ltd. Spitfire IX, G-BRRA
No & Type of Engines:	1 Rolls-Royce Merlin 70 piston engine
Year of Manufacture:	1944 (Serial no: CBAF 8185)
Date & Time (UTC):	1 August 2015 at 1300 hrs
Location:	Biggin Hill Airport, Kent
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Minor) Passengers - N/A
Nature of Damage:	Right wing detached, extensive damage to fuselage and propeller
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	52 years
Commander's Flying Experience:	7,710 hours (of which 294 were on type) Last 90 days - 145 hours Last 28 days - 52 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional enquiries by the AAIB

Synopsis

The aircraft had just taken off when the pilot heard the engine 'cough', followed shortly afterwards by a substantial loss of power. He force-landed the aircraft back within the airfield perimeter but it was badly damaged when it struck a line of trees. The engine has not been fully examined although a defect involving an engine inlet valve was noted.

History of the flight

The aircraft took off from Runway 29 at Biggin Hill Airport. The pilot retracted the landing gear and reduced power to 2,400 rpm and +4 boost but, one or two seconds later, he heard the engine 'cough'. This caused him some concern, so he turned the aircraft back towards the airfield, intending to climb overhead to investigate before proceeding en-route. A few seconds later, the engine lost power and the pilot could see flames coming from the right-hand exhaust pipes.

He closed the throttle but realised that he did not have enough total energy to return to the airfield. He therefore increased throttle, finding that only some 10-20% power was achievable, but this, combined with a reduction in airspeed, was just sufficient to reach the airfield. However, it was not enough to reach a runway so, by the time the airfield boundary was crossed, the pilot levelled the wings and landed straight ahead since he feared that the aircraft might stall. The aircraft touched down on its main landing gear on waste ground to the eastern side of the airfield (Figure 1). It was heading towards a line of trees and the pilot attempted to steer towards a small gap between them but the right wing was detached at the root when it struck a tree. The aircraft spun round and ran backwards up a bank before coming to rest on its right side. The pilot was taken to hospital as a precaution but had suffered only minor injuries.

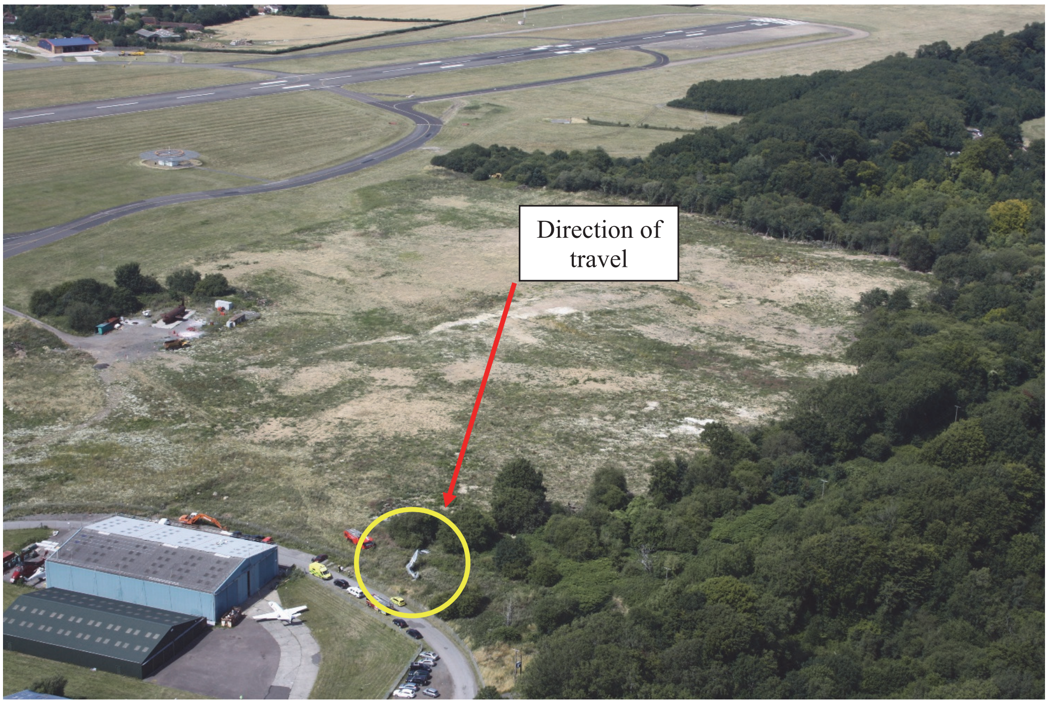

Figure 1

Aerial view of the accident site with G-BRRA circled.
Note that Runway 21/03 visible at the top of the picture was not the one used for takeoff.
(Photo courtesy National Police Air Service)

A limited examination of the engine after the accident suggested that a cylinder in the right bank had a broken inlet valve spring with a penetration of the associated induction flame trap. It is unclear whether this on its own would account for the substantial power loss and it is intended that the engine will be further examined during the recovery and repair process. However at the time of writing, there is no definite timescale for when this examination will take place.

ACCIDENT

Aircraft Type and Registration:	Cessna 210D Centurion, G-OWAN	
No & Type of Engines:	1 Continental Motors Corp IO-520-A piston engine	
Year of Manufacture:	1964 (Serial no: 210-58321)	
Date & Time (UTC):	5 September 2015 at 16:30 hrs	
Location:	Tosside Airstrip, Lancashire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Left wing strut bent, right wingtip, rear fuselage, and fin damaged	
Commander's Licence:	Commercial Pilot's Licence	
Commander's Age:	68 years	
Commander's Flying Experience:	6,623 hours (of which 100 were on type) Last 90 days - 151 hours Last 28 days - 51 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Accident description

The pilot had delayed his intended departure for approximately eight hours, following overnight rain, to allow the sun to dry the grass runway surface. The runway was then walked to assess its condition. The takeoff was downhill, commencing at the beginning of the strip orientated in a 170° direction. A tailwind of approximately 5 kt was reported. The initial part of the takeoff run appeared normal to the pilot, but as the aircraft became light, it veered left and, despite full right rudder and brake, it left the runway onto the adjacent field. It then began to decelerate and, even with full power, the nosewheel contacted the ground. The pilot closed the throttle and mixture, but despite full back pressure on the control column, the aircraft came to a rapid stop and became inverted. The pilot turned off the ignition, fuel and electrical power, released his harness and vacated the aircraft by the left door.

The pilot considered that a small patch of soft earth had caused the initial swing and, as the aircraft was nearly airborne, the brake had little effect.

ACCIDENT

Aircraft Type and Registration:	Cessna F172H Skyhawk, G-BGIU
No & Type of Engines:	1 Continental Motors Corp O-300-D piston engine
Year of Manufacture:	1969 (Serial no: 620)
Date & Time (UTC):	30 July 2015 at 1000 hrs
Location:	Perranporth Airfield, Cornwall
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Footwell floor damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	79 years
Commander's Flying Experience:	651 hours (of which 153 were on type) Last 90 days - 3 hours Last 28 days - 1 hour
Information Source:	Aircraft Accident Report Form submitted by the pilot

After a local flight the pilot positioned the aircraft for a left-hand circuit for Runway 05 at Perranporth Airfield, with 20° of flap selected and the elevator trim set for 70 kt. Whilst the aircraft was on final approach, the pilot realised that he was overshooting and was also too fast. He lowered the nose, before then rounding out too high. The aircraft lost flying speed before making a bounced landing, following which the pilot lowered the nose too far, causing the nosweheel to strike the runway. Subsequent inspection of the aircraft revealed rippling damage to the fuselage footwell floor.

ACCIDENT

Aircraft Type and Registration:	Europa, G-BWJH
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	1996 (Serial no: PFA 247-12643)
Date & Time (UTC):	17 November 2015 at 1234 hrs
Location:	Perth (Scone) Airfield
Type of Flight:	Training
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Nose landing gear collapsed, propeller strike and abrasion to the underside of fuselage, left wingtip and aileron
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	64 years
Commander's Flying Experience:	650 hours (of which 53 were on type) Last 90 days - 1 hour Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The pilot was carrying out practice circuits with an instructor to regain currency and requalify. After completing a couple of approaches leading to go-arounds, his instructor took control and demonstrated the correct technique. The pilot then flew a normal approach but the aircraft bounced twice on landing. He selected full power to go around but, despite the application of aileron, the left wing dropped and the wingtip contacted the runway. The aircraft came to rest on the grass at the edge of the runway having sustained significant damage. The pilot and instructor were uninjured. The pilot considered the cause of accident to be his lack of currency leading to a mishandled landing.

History of the flight

The pilot was carrying out a series of practice circuits with an instructor in preparation for his requalification competence test. He had carried out two approaches both of which he considered too high and carried out go-arounds. His instructor took control, demonstrated a correct approach and after a touch-and-go handed control back to the pilot who then continued to fly a satisfactory circuit and approach. The aircraft was in the correct landing configuration but on touchdown the aircraft bounced twice and the pilot applied full power to carry out another go-around. At this point the left wing dropped and, despite full aileron, the wingtip contacted the runway. The aircraft slewed to the left and came to rest on soft grass at the edge of the runway, during which the nose landing gear collapsed. The aircraft was made safe and pilot and instructor vacated the aircraft uninjured. Inspection of the aircraft found it to have sustained significant damage to the wingtip and aileron, the propeller and the underside of the fuselage.

Discussion

The pilot is clear in his opinion that the difficulties on his approaches and the bounced landing resulted directly from his lack of currency. It is noted that although the pilot had nearly 650 hours on all types, he had only flown 1 hour 10 minutes in the last 90 days and only a few minutes in the last 28 days.

In the instructor's opinion, a go-around could not be executed despite the application of power because the left wing had stalled after the second bounce.

ACCIDENT

Aircraft Type and Registration:	Europa Trigear, G-BXGG
No & Type of Engines:	1 Rotax 912 ULS piston engine
Year of Manufacture:	1998 (Serial no: PFA 247-12803)
Date & Time (UTC):	6 September 2015 at 0805 hrs
Location:	Abbots Bromley Airfield, Staffordshire
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Propeller damaged and main landing gear legs bent
Commander's Licence:	Private Pilot's Licence
Commander's Age:	57 years
Commander's Flying Experience:	296 hours (of which 86 were on type) Last 90 days - 5 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During the takeoff roll the aircraft's pitch trim system commanded full nose-up trim, for reasons that were not determined. The pilot abandoned the takeoff but as the aircraft decelerated it departed the runway to the left, into standing crop, causing damage to the propeller and main landing gear legs.

History of the flight

The aircraft was departing Abbots Bromley Airfield on a flight to Sywell Aerodrome, a flight that the pilot had completed two days previously in G-BXGG without incident. Following normal pre-flight and pre-departure checks, during which the pilot set the all-flying tailplane trim tab to the takeoff position, the aircraft started its takeoff roll on Runway 05. The pilot estimated the wind during the takeoff to be northerly at 8 kt.

The pilot reported that during the takeoff roll he had to apply increasing forward pressure on the control column to maintain pitch control, until the pressure was sufficient that he had to use both hands. The pilot noted that the cockpit-mounted pitch trim indicator was displaying full nose-up trim and that it had changed from the position set prior to commencing the takeoff roll.

The pilot closed the throttle and applied the brakes, but as the aircraft decelerated it weathercocked into the crosswind and departed the runway to the left, coming to rest in a crop of standing wheat approximately 30-40 m from the runway edge. The aircraft's propeller and main landing gear legs were damaged in the accident. The pilot shut the engine down and both occupants, who were uninjured, departed the aircraft without further incident. The pilot confirmed that the tailplane trim tab was in the full nose-up position.

A post-accident check of the electrically-actuated pitch trim system showed that it operated normally, and the cause of the pitch trim runaway on the accident flight was not identified. The pilot reported that having considered his actions during the accident, he regretted not closing the throttle earlier during the takeoff roll, once the pitch mis-trim became apparent, as this may have reduced the severity of the subsequent runway excursion.

ACCIDENT

Aircraft Type and Registration:	Chevvron 2-32C, G-MZDP
No & Type of Engines:	1 Konig SD 570 piston engine
Year of Manufacture:	1990 (Serial no: 20)
Date & Time (UTC):	31 October 2015 at 1245 hrs
Location:	Watnall Airfield, Nottinghamshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Nosewheel detached, structural damage to fuselage and propeller damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	58 years
Commander's Flying Experience:	215 hours (of which 1 was on type) Last 90 days - 3 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

The pilot was flying the aircraft solo for the first time and was completing his third circuit with the intention of stopping. He considered his final approach was stable but had to apply additional power to continue the landing after encountering what he described to be "a drop in lift". The nose gear struck the ground before the flare and immediately collapsed. The aircraft slid to a halt and the uninjured pilot vacated the aircraft normally.

The pilot was unable to explain the cause of the sink but he was using Runway 15 and the wind was forecast to be from 330º at 7 kt. He reported that the windsock showed no wind when he took off approximately 15 minutes before the accident and the sink occurred shortly after passing over a line of trees. The pilot considered that he may have misjudged the height during the attempted recovery and in hindsight considered that an early decision to go-around would have been more appropriate.

ACCIDENT

Aircraft Type and Registration:	Flight Design CTSW, G-CETF
No & Type of Engines:	1 Rotax 912ULS piston engine
Year of Manufacture:	2007 (Serial no: 8318)
Date & Time (UTC):	2 August 2015 at 1530 hrs
Location:	Near Boston, Lincolnshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damage to landing gear, propeller, engine covers, tailplane, rudder, plus extensive airframe damage
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	65 years
Commander's Flying Experience:	161 hours (of which 62 were on type) Last 90 days - 32 hours Last 28 days - 9 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Summary

Whilst on final approach the engine suddenly lost power and the pilot was forced to land in a field short of the runway threshold. The aircraft nosed over and came to rest inverted. The investigation was inconclusive concerning the engine power loss, although fuel starvation was a possible cause.

Accident details

Following an uneventful flight to Cromer, Norfolk, the aircraft was returning to the pilot's home airfield at Boston Aerodrome, Lincolnshire. After joining overhead at 2,000 ft, the pilot descended on the 'dead side' of the airfield and joined the circuit at 1,000 ft agl for Runway 09. On the downwind leg he checked the engine temperatures and pressures, and noted that fuel was visible in the sight tubes in the wing roots (there are no conventional fuel gauges on this aircraft type). 30° flap was selected on turning onto base leg. After turning onto final approach, the aircraft experienced sink, so the pilot applied more power. As he did so the engine suddenly stopped; he attempted a restart but was unsuccessful. There was insufficient height to glide to the runway and the pilot was forced to land the aircraft in a field of unharvested corn short of the 09 threshold. The aircraft nosed over and came to rest inverted; however both occupants were uninjured and escaped unaided.

Description of aircraft fuel system

The CTSW is a high-wing aircraft with integral fuel tanks in the inboard sections of the wings. Each tank has a capacity of 65 litres and a circular plug in each wing root incorporates a fuel contents sight tube.

The wings have a 1.5° dihedral angle, which, in balanced flight, tends to assist in keeping the fuel towards the inboard ends of the tanks. According to the aircraft manufacturer's Aircraft Operating Manual, the unusable fuel is 3 litres per tank. The same manual gives the fuel consumption as 25 litres/hour at maximum continuous power (5,500 rpm) and 18.5 litres/hour at 75% power, a typical cruise setting.

The fuel off-take is located close to the sight tube, towards the rear of the tank, and consists of an inlet strainer attached to a short length of rigid tube that holds the strainer close to the tank floor; there is no sump in the floor that would keep the inlet strainer immersed in fuel. The outlets of the left and right tanks are joined together in the fuselage, immediately upstream of a simple ON/OFF fuel selector. Thus, an ON selection will result in fuel being drawn simultaneously from both tanks. This arrangement, which applied to UK registered aircraft only, superseded an earlier design in which the fuel was selectable from either the left or right tank only, not both. The modified design was implemented by means of Service Bulletin (SB) CT125 and was mandated by the UK Civil Aviation Authority (CAA). Information in the SB noted that: *'after the modification, the fuel should feed reasonably evenly from both tanks. Imbalance in flight can be corrected by flying with a little sideslip for a while.'*

The investigation

The pilot later reported that, with assistance, he was able to return the aircraft back onto its wheels, although damage to the right main landing gear resulted in a right-wing-low attitude. The aircraft was recovered a couple of days later, by which time virtually all the fuel had transferred into the right tank. The pilot stated that he drained the fuel from the aircraft and obtained 22 litres, all but a couple of litres from the right tank. He was confident that no fuel had escaped whilst the aircraft lay in its inverted attitude.

Examination of the aircraft, by both an insurance loss adjustor and a potential repair organisation, found no fault that could explain the power loss. In particular, no mechanical failure had occurred within the engine.

The pilot subsequently commented that, in his experience with this aircraft, the left tank always emptied before the right. This accords with other pilots' experiences of sometimes considerable fuel imbalances occurring in flight, as discussed on internet forums for this aircraft type. The pilot of the subject aircraft noted that his "overhead join" and circuit entry involved five turns to the left, with the power loss occurring after he applied a little right bank, as he aligned the aircraft with the runway. He considered that it may have been possible that his manoeuvres resulted in one of the fuel off-takes to have become temporarily uncovered, such that air was ingested into the fuel system. It is worth noting that flap selection tends to cause the aircraft to pitch down, which would tend to cause the fuel to move forward in the tanks, away from the off-takes. Nevertheless, during the downwind checks, fuel was observed in both sight tubes, which suggested adequate quantities were available to the engine at that stage, although it was not possible to determine how the approximately 22 litres of fuel were distributed between the tanks.

Other reasons for the power loss could include carburettor icing, although the pilot observed that aircraft equipped with the same engine type were operating from the airfield that day, without apparent problems.

Thus, from the available information it was not possible to arrive at a conclusion as to the cause of the engine power loss.

Miscellaneous

This section contains Addenda, Corrections and a list of the ten most recent Aircraft Accident ('Formal') Reports published by the AAIB.

The complete reports can be downloaded from the AAIB website (www.aaib.gov.uk).

BULLETIN CORRECTION

Aircraft Type and Registration:	Agusta Bell 206B Jet Ranger II, G-SUEX
Date & Time (UTC):	16 September 2014 at 1241 hrs
Location:	Flamborough Head, Yorkshire
Information Source:	AAIB Field Investigation

AAIB Bulletin No 1/2016, page 55 refers

The report published in AAIB Bulletin 1/2016 included a graphical display of the main and tail rotor rpm decay, based on the frequency analysis of the witness audio recording (see Figure 5 on page 55). Figure 5 was incorrectly labelled. Reference to the tail rotor should have been to the main rotor, and vice versa. The time axis labels and harmonic references were also incorrect. However, the supporting text, analysis and conclusions were unaffected by these labelling errors. Figure 5 should have appeared, as follows:

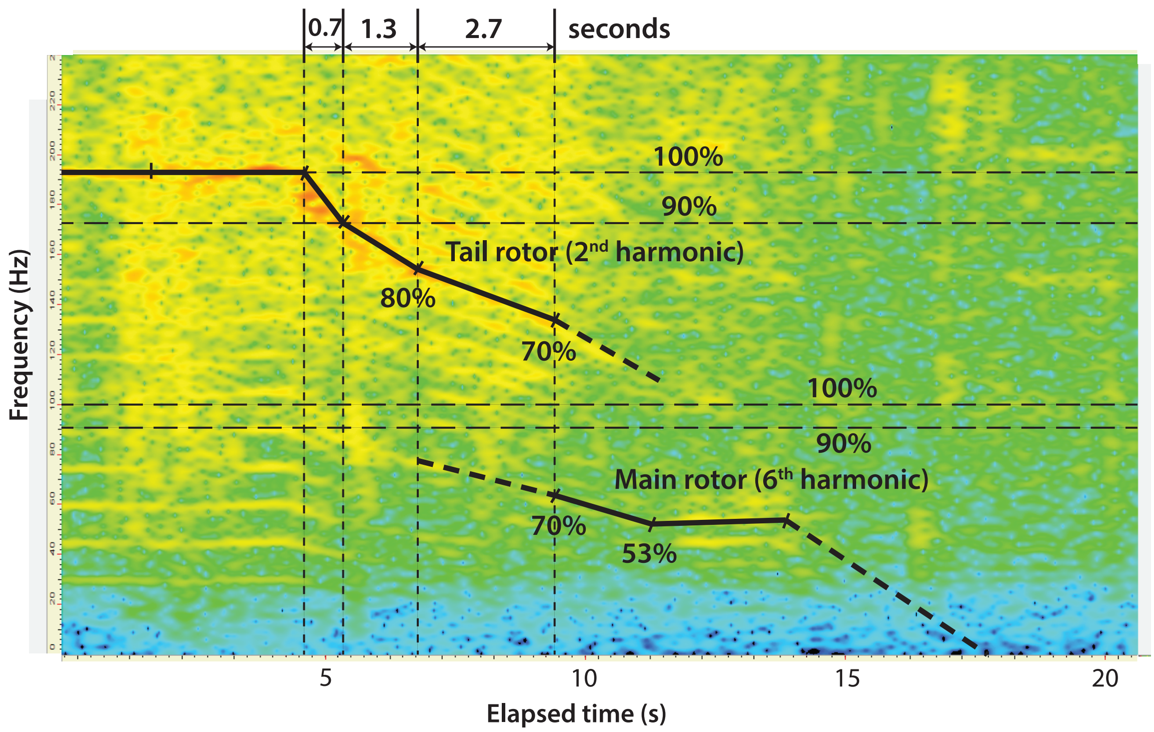

Figure 5

Frequency analysis of witness audio recording showing main and tail rotor rpm decay

The online version of the report was corrected on 29 January 2016.

BULLETIN CORRECTION

Aircraft Type and Registration:	Pitts S-1S, G-EEPJ
Date & Time (UTC):	10 August 2013 at 0710 hrs
Location:	Leicester Airport
Information Source:	Aircraft Accident Report Form

AAIB Bulletin No 11/2013, page 33 refers

The version of this report published in AAIB Bulletin No 11/2013 had the pilot's '28 day' flying experience recency as 1 hour. This figure should have been **15.4** hours, which the pilot noted, and communicated to the AAIB, shortly after publication.

The online version of the report has now been amended.

TEN MOST RECENTLY PUBLISHED FORMAL REPORTS ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

7/2010 Aerospatiale (Eurocopter) AS 332L Super Puma, G-PUMI at Aberdeen Airport, Scotland on 13 October 2006.
Published November 2010.

8/2010 Cessna 402C, G-EYES and Rand KR-2, G-BOLZ near Coventry Airport on 17 August 2008.
Published December 2010.

1/2011 Eurocopter EC225 LP Super Puma, G-REDU near the Eastern Trough Area Project Central Production Facility Platform in the North Sea on 18 February 2009.
Published September 2011.

2/2011 Aerospatiale (Eurocopter) AS332 L2 Super Puma, G-REDL 11 nm NE of Peterhead, Scotland on 1 April 2009.
Published November 2011.

1/2014 Airbus A330-343, G-VSXY at London Gatwick Airport on 16 April 2012.
Published February 2014.

2/2014 Eurocopter EC225 LP Super Puma G-REDW, 34 nm east of Aberdeen, Scotland on 10 May 2012 and G-CHCN, 32 nm south-west of Sumburgh, Shetland Islands on 22 October 2012.
Published June 2014.

3/2014 Agusta A109E, G-CRST Near Vauxhall Bridge, Central London on 16 January 2013.
Published September 2014.

1/2015 Airbus A319-131, G-EUOE London Heathrow Airport on 24 May 2013.
Published July 2015.

2/2015 Boeing B787-8, ET-AOP London Heathrow Airport on 12 July 2013.
Published August 2015.

3/2015 Eurocopter (Deutschland) EC135 T2+, G-SPAO Glasgow City Centre, Scotland on 29 November 2013.
Published October 2015.

Unabridged versions of all AAIB Formal Reports, published back to and including 1971, are available in full on the AAIB Website

http://www.aaib.gov.uk

GLOSSARY OF ABBREVIATIONS

aal	above airfield level
ACAS	Airborne Collision Avoidance System
ACARS	Automatic Communications And Reporting System
ADF	Automatic Direction Finding equipment
AFIS(O)	Aerodrome Flight Information Service (Officer)
agl	above ground level
AIC	Aeronautical Information Circular
amsl	above mean sea level
AOM	Aerodrome Operating Minima
APU	Auxiliary Power Unit
ASI	airspeed indicator
ATC(C)(O)	Air Traffic Control (Centre)(Officer)
ATIS	Automatic Terminal Information System
ATPL	Airline Transport Pilot's Licence
BMAA	British Microlight Aircraft Association
BGA	British Gliding Association
BBAC	British Balloon and Airship Club
BHPA	British Hang Gliding & Paragliding Association
CAA	Civil Aviation Authority
CAVOK	Ceiling And Visibility OK (for VFR flight)
CAS	calibrated airspeed
cc	cubic centimetres
CG	Centre of Gravity
cm	centimetre(s)
CPL	Commercial Pilot's Licence
°C,F,M,T	Celsius, Fahrenheit, magnetic, true
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
EAS	equivalent airspeed
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
EGPWS	Enhanced GPWS
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
EPR	Engine Pressure Ratio
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
FAA	Federal Aviation Administration (USA)
FIR	Flight Information Region
FL	Flight Level
ft	feet
ft/min	feet per minute
g	acceleration due to Earth's gravity
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
hrs	hours (clock time as in 1200 hrs)
HP	high pressure
hPa	hectopascal (equivalent unit to mb)
IAS	indicated airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Intermediate Pressure
IR	Instrument Rating
ISA	International Standard Atmosphere
kg	kilogram(s)
KCAS	knots calibrated airspeed
KIAS	knots indicated airspeed
KTAS	knots true airspeed
km	kilometre(s)
kt	knot(s)
lb	pound(s)
LP	low pressure
LAA	Light Aircraft Association
LDA	Landing Distance Available
LPC	Licence Proficiency Check
m	metre(s)
mb	millibar(s)
MDA	Minimum Descent Altitude
METAR	a timed aerodrome meteorological report
min	minutes
mm	millimetre(s)
mph	miles per hour
MTWA	Maximum Total Weight Authorised
N	Newtons
N_R	Main rotor rotation speed (rotorcraft)
N_g	Gas generator rotation speed (rotorcraft)
N_1	engine fan or LP compressor speed
NDB	Non-Directional radio Beacon
nm	nautical mile(s)
NOTAM	Notice to Airmen
OAT	Outside Air Temperature
OPC	Operator Proficiency Check
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PIC	Pilot in Command
PNF	Pilot Not Flying
POH	Pilot's Operating Handbook
PPL	Private Pilot's Licence
psi	pounds per square inch
QFE	altimeter pressure setting to indicate height above aerodrome
QNH	altimeter pressure setting to indicate elevation amsl
RA	Resolution Advisory
RFFS	Rescue and Fire Fighting Service
rpm	revolutions per minute
RTF	radiotelephony
RVR	Runway Visual Range
SAR	Search and Rescue
SB	Service Bulletin
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TAF	Terminal Aerodrome Forecast
TAS	true airspeed
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Collision Avoidance System
TGT	Turbine Gas Temperature
TODA	Takeoff Distance Available
UHF	Ultra High Frequency
USG	US gallons
UTC	Co-ordinated Universal Time (GMT)
V	Volt(s)
V_1	Takeoff decision speed
V_2	Takeoff safety speed
V_R	Rotation speed
V_{REF}	Reference airspeed (approach)
V_{NE}	Never Exceed airspeed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional radio Range

Air Accidents Investigation Branch