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.

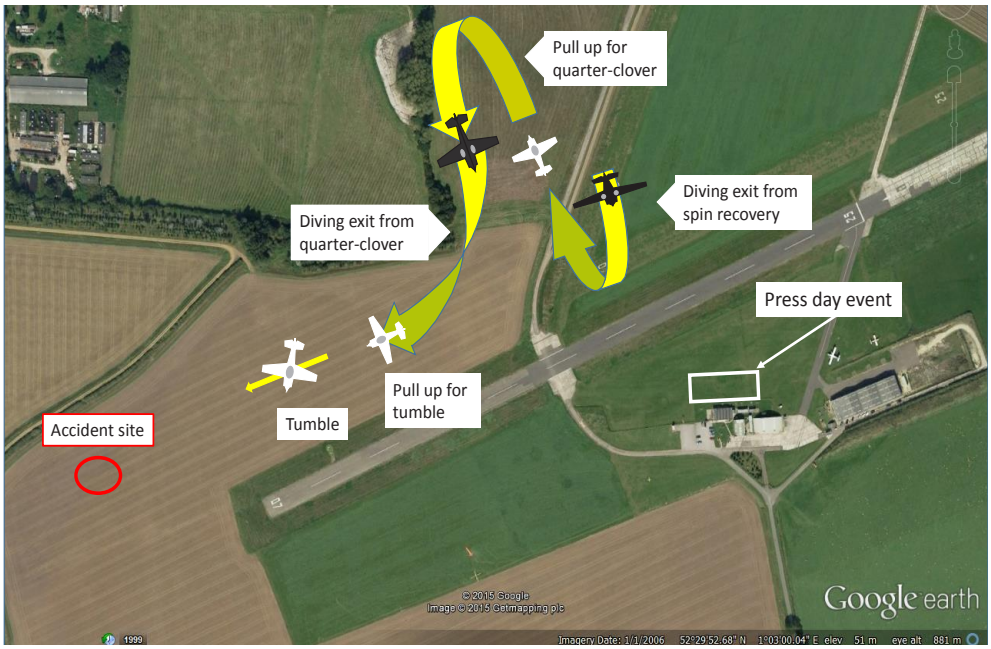

Figure 2

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.