Accident

Aircraft Type and Registration:	Rotorsport UK Cavalon, G-CKYT
No & Type of Engines:	1 Rotax 914-UL piston engine
Year of Manufacture:	2018 (Serial no: RSUK/CVLN/027)
Date & Time (UTC):	12 November 2020 at 1250 hrs
Location:	Farmland between Avoch and Munlochy, Black Isle
Type of Flight:	Solo training flight
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Student private pilot
Commander's Age:	67 years
Commander's Flying Experience:	117 hours (of which 46 were on type) Last 90 days - 20 hours Last 28 days - 6 hours
Information Source:	AAIB Field investigation

Synopsis

A solo student pilot was on a local general handling flight when the rotor head of the gyroplane he was flying, separated from the fuselage in flight. The separation was caused by a structural overload failure from exposure to dynamic flight loads, judged to be due to a specific sequence of aircraft manoeuvres.

The gyroplane was found to have been correctly released to service. There were no maintenance issues identified relevant to the accident. A number of operational factors were considered and it was likely that the pilot inadvertently allowed the aircraft to enter a low g flight regime close to, or potentially exceeding, that prohibited by the Cavalon Pilot's Operating Handbook.

The accident highlighted limitations in the design, testing, manufacture and operating limits for the Cavalon and Cavalon Pro gyroplane types. Based on an assessment of the requirements within BCAR Section T, these limitations could be relevant to other gyroplane types certified to this standard. The investigation also highlighted issues with gyroplane training material regarding the awareness of rotor load factor by pilots. Four Safety Recommendations have been made to address these issues.

History of the flight

The student pilot arrived at Inverness Airport at 0850 hrs on the morning of the accident to prepare for a dual check flight with his instructor, followed by a solo flight as part of his PPL training.

The student first completed a 20-minute check flight with his instructor, flying one circuit and a practice aborted takeoff, which the instructor considered were flown well. The instructor then briefed the student for a solo flight in the operator's training area over the Black Isle, 4 nm to the north of Inverness. The instructor reported that he had not given the student specific exercises to fly but had directed him to fly around the training area to gain more experience of handling the gyroplane. The student took a short break while staff from the training school refuelled the gyroplane and added ballast[1]. The student then took off at 1020 hrs, returning to Inverness at 1140 hrs. The flight went without incident and the student was reported as being very pleased with his achievement. The student made no adverse comments about either the flight or the wind conditions encountered. He was scheduled to fly another solo flight on the following day, but the forecast winds were due to be out of limits for solo students. His instructor instead offered him the opportunity to fly a further solo exercise that afternoon as the weather conditions were assessed by him to remain suitable for a student solo.

After a short break, the student reported that he was not fatigued and was ready to fly again. He discussed the content of the sortie with his instructor, which was to repeat the previous flight around the Black Isle. The student then refuelled the gyroplane and booked out with ATC for the flight. The gyroplane took off from Runway 23 at Inverness Airport at 1237 hrs with a clearance to climb not above 2,000 ft until coordinated with radar. At 1240 hrs the student was instructed to contact Inverness Radar, which he did, reporting that he was at Chanonry Point at 1,800 ft and requested a Basic Service (Figure 1).

Footnote

[1] For a description of the ballast, refer to the Weight and Balance section.

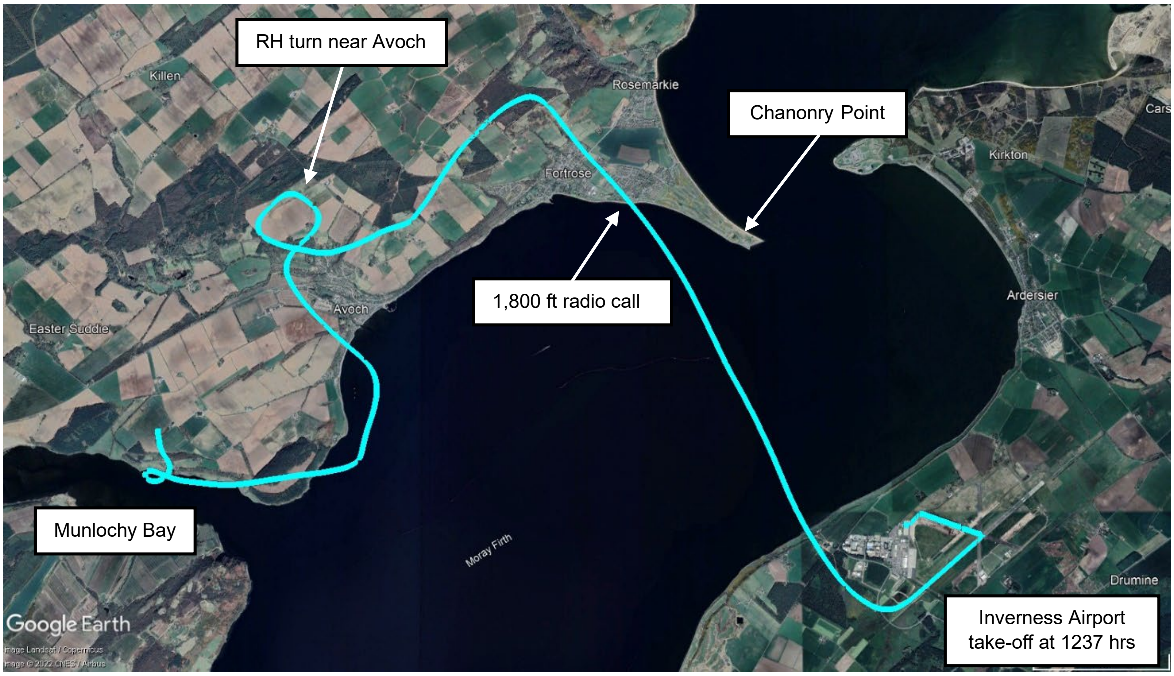


Figure 1

Accident flight track from GNSS

ATC confirmed the request for a Basic Service, informing the student that there were no level restrictions and passed him relevant traffic information. The gyroplane turned onto a westerly track towards Avoch and at 1243 hrs was informed of another aircraft to his west routing from Munlochy Bay to Inverness Airport. The student reported that he was visual with the aircraft.

The gyroplane then completed an orbit to the north of Avoch before routing in a south-easterly direction towards the Moray Firth coastline. The first witness to see the gyroplane in the area (location 1 - Figure 2) described hearing a marked increase in engine noise that prompted him to look up. He reported seeing a gyroplane moving in a south-westerly direction. At approximately the same time, a witness at location 2 reported seeing a gyroplane flying in a similar direction but did not consider there was anything unusual about it. The gyroplane then flew parallel to the Black Isle coastline in a south-westerly direction before turning north-west to follow the Munlochy Bay inlet. Two witnesses in this area (location 3 - Figure 2) reported hearing an engine alternating between high and low revving sounds, and "spluttering", but neither reported seeing an unusual flightpath. As the gyroplane continued on a north-westerly track, witnesses at locations 4 to 8 reported hearing unusual sounds that drew their attention. They variously described the sounds as an engine "roaring as if at full revs" and "spluttering as if an engine was failing". Witnesses at location 8 reported hearing a "very loud mechanical noise, which sounded like a metal crunch", and a "loud mechanical cracking noise".

The eyewitnesses at locations 2 and 3 reported seeing the gyroplane again a few minutes after they had initially seen it, describing it now in a fast, erratic and steep descent. This was a similar description to those given by witnesses 4 to 8 who had looked up at the gyroplane on hearing an unusual sound. One of the witnesses at location 3 reported seeing the rotor blades detach as the aircraft descended. The witnesses at location 8 also reported seeing the main rotor blades spinning off the gyroplane and landing about 30 m from where they were standing. Some of the witnesses then saw the gyroplane hit the ground and catch fire.

At about 1250 hrs, around the time the eyewitnesses reported seeing the gyroplane descending erratically, there was a short open mic transmission[2] on the Inverness approach frequency. At about the same time the controller lost radar contact with the gyroplane. The controller tried to establish radio communication but received no response. He alerted colleagues in the Tower and asked them to look in the direction of the last recorded contact to check if they could see the gyroplane. They reported seeing black smoke rising in the area but could not specifically identify which side of the Moray Firth it was coming from.

Several onlookers made calls to the emergency services, and local community emergency responders arrived on scene at approximately 1305 hrs, quickly followed by paramedics and a doctor. The first responders stated that they could not access the aircraft due to the intensity of the fire which was extinguished shortly afterwards on the arrival of the fire service.

Figure 2

Witness locations in relation to ground track of gyroplane

Footnote

[2] An open mic transmission happens when a press-to-transmit button is held, or the radio transmission unit is stuck on transmit, and no intentional communication is passed.

Accident site

The fuselage was located in a field approximately 150 m west of farm buildings and was surrounded by smaller items, which had been released when the fuselage initially struck the ground. The rotor head and blades had detached from the fuselage together and were located in an adjacent field to the fuselage, some 65 m south-south-east of the same farm buildings. Two ground marks from the leading edge of each blade striking the ground were positioned at an obtuse angle to each other. A trail of small items of wreckage stretched from the location of the detached rotor head east-north-east for approximately 500 m across farmland and into the garden of a private residence (Figure 3). These items of wreckage consisted of sections of the right door of the aircraft, along with the tip of one of the propeller blades.

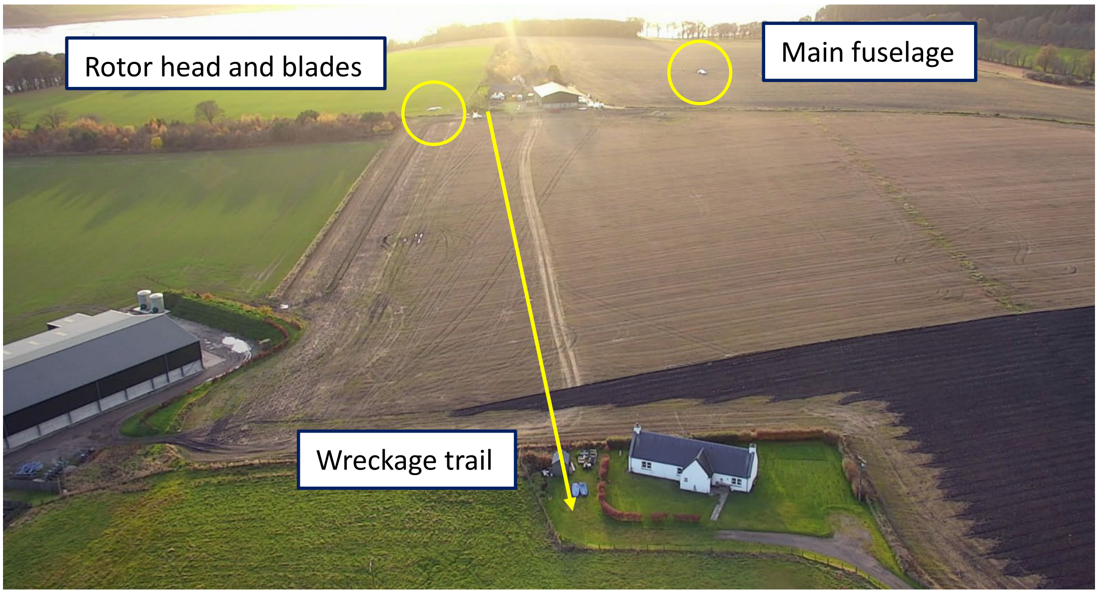


Figure 3

Wreckage location

Recorded information

The aircraft was captured by the Inverness radar head throughout the accident flight, recordings of which were made available by Inverness ATC. ATC also made available recordings of radio transmissions between ATC and the aircraft. The gyroplane was fitted with a transponder capable of transmitting Mode C altitude[3], but this information was not recorded by the radar. Reasons for this could not be established, but it is possible to switch off Mode C altitude on this transponder. A review of the radar data from a previous flight of G-CKYT on 7 November 2020 also confirmed no Mode C altitude had been recorded. The gyroplane was fitted with a number of avionics components but, due to the impact and post-crash fire, they all sustained significant damage. The only onboard device from which data could be recovered was a Garmin GDL 50 portable ADS-B receiver. This device was fitted to receive traffic data via ADS-B which was then transmitted to the cockpit display to allow the pilot to view traffic information on a moving map.

Footnote

[3] Mode C altitude is that sensed by the transponder and transmitted to the nearest 100 ft.

To determine aircraft position, the device included a GNSS receiver and a pressure altitude sensor. This information was recorded to the device as a track log, once per second, which was more accurate and at a higher sampling rate than the recorded radar data. Data in this track log included time, position, altitude, and a derived vertical speed, groundspeed and track. This device was positioned on the coaming above the instrument panel and attached to the aircraft's power supply.

Despite suffering impact damage, the device was successfully downloaded at the AAIB and contained a track log which was from the accident flight. There were no other flights recorded. The data recovered did not contain any GNSS accuracy information such as the number of satellites in view at the time.

G-CKYT previous flight

The flight prior to the accident flight lasted approximately 1 hour 20 minutes. Figure 4 shows the radar ground track of this flight in which the student took off from Inverness then travelled around the Black Isle in an anticlockwise direction.

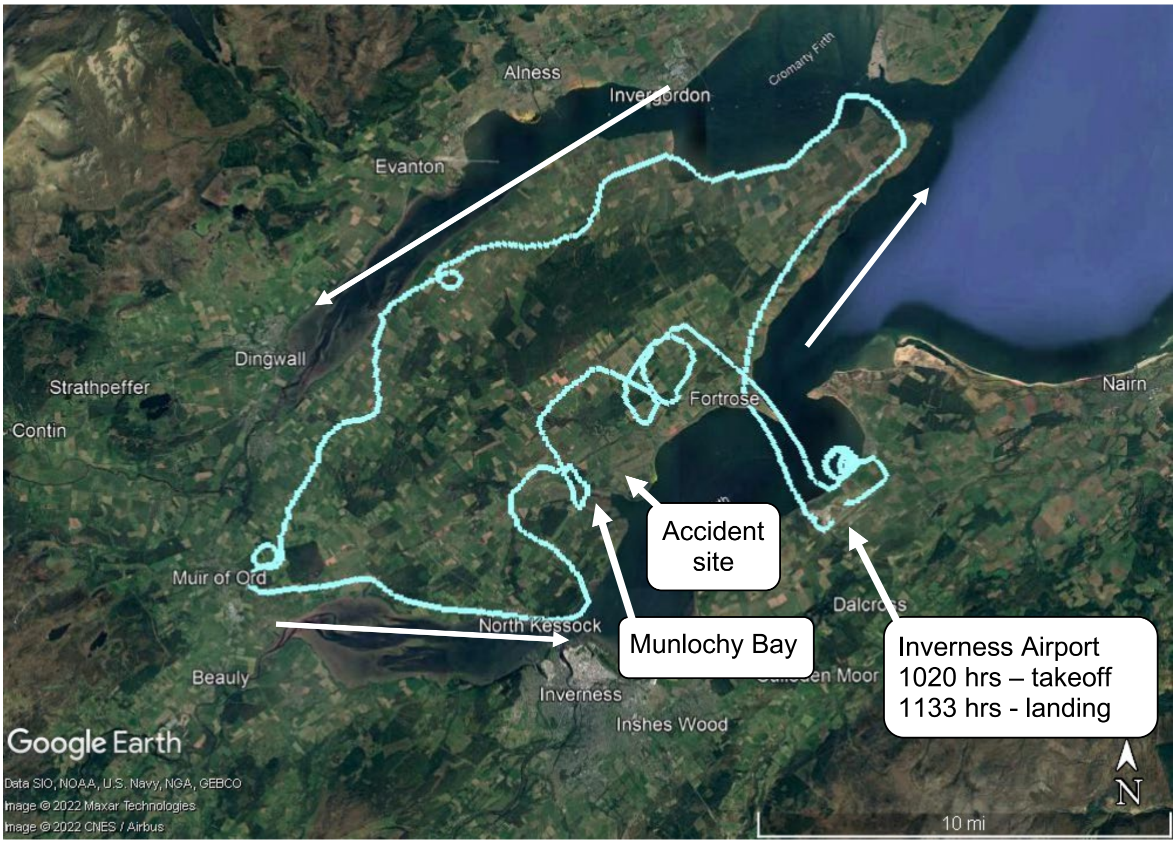


Figure 4

Radar data showing G-CKYT flight track prior to the accident flight

The radar was only recorded every four seconds and has a significantly lower position accuracy than the GNSS data. However, it was possible to show that a number of left and right orbits were performed throughout the flight, including one over Munlochy Bay, two in the region of Avoch and four mid-downwind prior to landing.

Accident flight

The GNSS device only contained one recording which was for the accident flight and provided more detailed flight path information than the radar data. The pressure altitude recorded by this device used a reference pressure of 1013 hPa which was corrected to the Inverness QNH at the time of 1001 hPa. When comparing the recorded altitude to the elevation of the Inverness runway, the recorded pressure altitude was within 20 ft. GNSS altitude was also recorded and was within 30 ft of the airfield elevation. After takeoff, the GNSS altitude was consistently lower than the pressure altitude but within 13-95 ft.

Analysis of the recorded pressure altitude over time revealed that it was not smooth and fluctuated even when the aircraft was in level flight. The GNSS altitude was smoother than the pressure altitude and despite an offset, followed the same trend as the pressure altitude.

Radar data showed the presence of a light aircraft, a Grumman AA-5, transiting through the area of the accident a few minutes prior to G-CKYT. It was enroute to Inverness from the north and, when passing over Munlochy Bay at 1244 hrs, was descending through an altitude of about 1,900 ft.

Derived parameters

An estimate of the airspeed was calculated using surface wind conditions at Inverness Airport and those at 1,000 ft and 2,000 ft amsl (see Meteorology section). The reported wind at 2,000 ft amsl was 30 kt from the south-west which had a notable effect on the difference between ground and airspeed. A simple estimate of bank angle was calculated using aircraft airspeed and rate of turn, assuming a level and coordinated turn.

The vertical speed parameter recorded on the GNSS device correlated well with the rate of change of GNSS altitude. The rate of change of this vertical speed provided an estimate of the vertical acceleration. This is only the acceleration in the vertical direction in m/s^2 which can also be expressed as a fraction of normal gravitational acceleration, or g ($9.81 m/s^2$).

Accident flight data

The recovered GNSS track (Figure 1) was similar to the recorded radar track. Figure 5 shows the GNSS data parameters with respect to time for the whole flight. Takeoff commenced at 1237:15 hrs followed by a right turn. Just over three minutes later, the pilot made a radio transmission to Inverness Radar for a Basic Service, stating he was at 1,800 ft. At the time, the data showed the aircraft climbing through a pressure altitude of 1,700 ft (GNSS altitude 1,624 ft) at an airspeed of 64 mph.

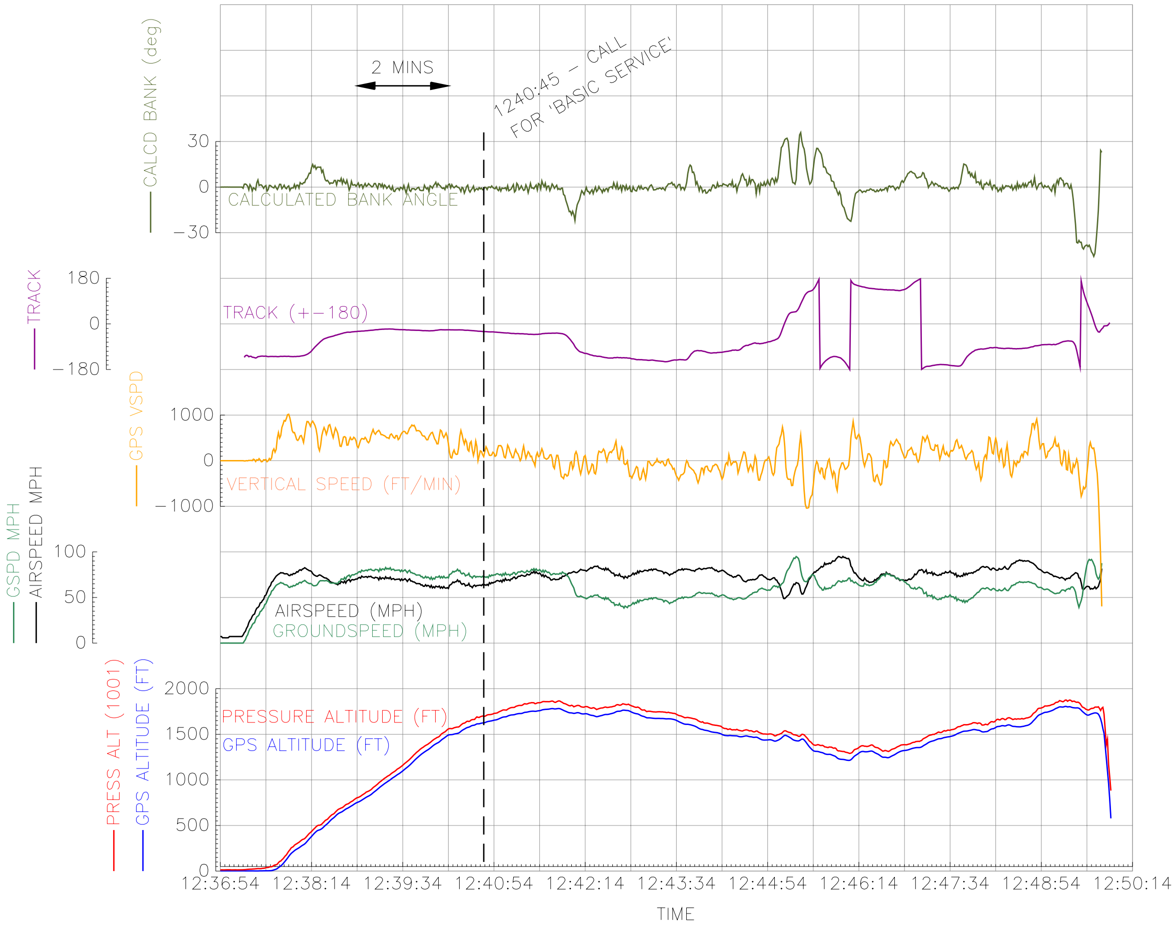


Figure 5

G-CKYT GNSS flight parameters

The aircraft continued towards the Black Isle, climbing to a maximum altitude of 1,860 ft before turning left to towards Avoch. When just under a mile from Avoch, ATC advised G-CKYT of another aircraft routing towards Munlochy Bay, returning to Inverness Airport. The pilot replied that he was "VISUAL WITH THE LIGHT AIRCRAFT".

Turn north of Avoch

One minute later, at 1244:30 hrs, G-CKYT was overhead Avoch and commenced a turn to the right at a pressure altitude of 1,540 ft and approximate airspeed of 73 mph. During the turn, bank angle was estimated at approximately 30° with the pressure altitude fluctuating and progressively decreasing over 1 minute 22 seconds to 1,347 ft at the end of the right turn. Airspeed during the turn reduced to approximately 50 mph before increasing to 92 mph by the end of the turn (a total loss in the turn of 193 ft and increase of 19 mph). Vertical speed fluctuated in the turn, reaching a descent rate of up to 1,000 ft/min and as the turn was completed, the aircraft was descending at approximately 500 ft/min with an increasing airspeed.

The aircraft then turned to the left and tracked towards the coast before turning into Munlochy Bay (Figure 1). Its airspeed reduced and the aircraft climbed progressively to approximately 1,900 ft amsl.

Remainder of the flight

At 1249:20 hrs, when overhead the northern shore of Munlochy Bay, the aircraft commenced a turn to the left (Figure 6).

Figure 6

G-CKYT final ground track (Google Earth)

The turn started at a pressure altitude of 1,870 ft (GNSS altitude 1,799 ft) and airspeed of 73 mph. For the first 16 seconds of the turn, the estimated bank angle increased and remained at between approximately 35-40° to the left. During this time, the vertical speed fluctuated, at one point reaching a descent of 782 ft/min (Points A to B, Figure 7).

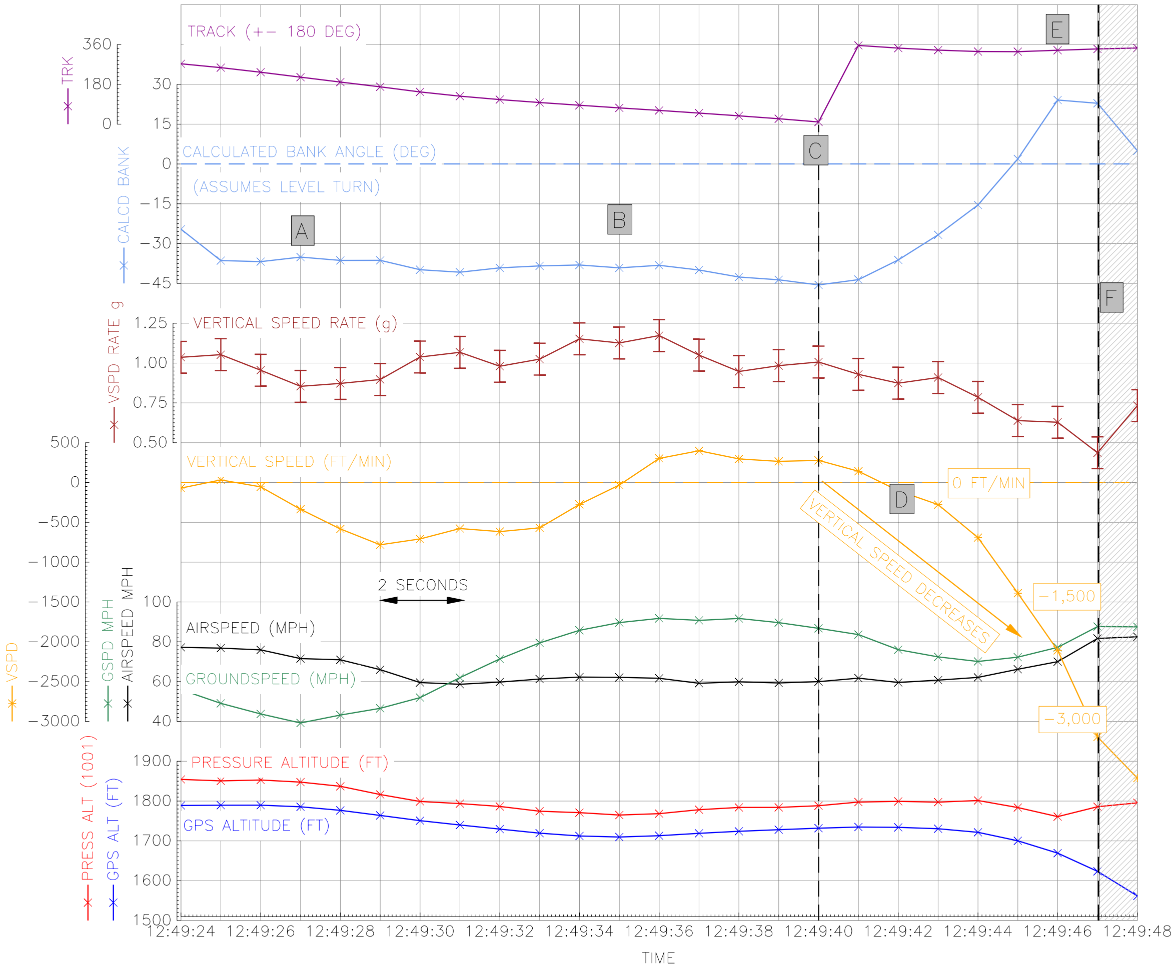


Figure 7

G-CKYT flight parameters

Towards the end of the left turn, at 1249:40 hrs, the estimated bank angle had increased to approximately 45° (point C). At this time, the aircraft was at a pressure altitude of 1,788 ft (GNSS altitude 1,732 ft), an airspeed of 60 mph and climbing at 278 ft/min. After this time, the vertical speed started to reduce. Over the next seven seconds, the vertical speed decreased progressively, from +278 ft/min to -3,195 ft/min.

From 1249:42 hrs (point D), the vertical speed became negative (-102 ft/min), signifying the start of a descent. Three seconds later, the calculated aircraft track showed completion of the left turn while at a pressure altitude of 1,783 ft (GNSS altitude 1,700 ft) and an airspeed of 66 mph, but was then descending at 1,390 ft/min.

At 1249:46 hrs, the calculated aircraft track showed the aircraft then entering a right turn (point E) while still descending, but now at a pressure altitude of 1,761 ft (GNSS altitude 1,669 ft), an airspeed of 70 mph and descending at 2,107 ft/min.

Radio transmission at 1249:46 hrs

At the same time, a transmission was recorded on the Inverness Approach frequency. The source of the transmission could not be confirmed as coming from G-CKYT, but appeared to be a radio transmission which lasted a fraction of a second. There were two further transmissions at 1249:48 hrs and 1249:49 hrs, lasting 0.5 seconds and 7 seconds respectively. The transmissions contained primarily a high-pitched frequency with no intelligible speech. An analysis was performed, comparing these transmissions with those from earlier in the flight. Previous recordings included clear audio signatures of the aircraft propeller, a lower level of background noise and clear speech. The transmissions from 1249:46 hrs differed, with no evidence of the propeller audio signature and a much higher level of background noise. No conclusive information could be drawn from these radio transmissions.

Last part of the recording

The GNSS and pressure altitudes had been similar throughout the flight, apart from GNSS altitude consistently being lower than the pressure altitude. In the final minute, the GNSS altitude was within between 48-92 ft of the pressure altitude with a similar trend.

At 1249:47 hrs (Point F, Figure 7, one second after the first of the radio transmissions), the recorded pressure and GNSS altitudes began to diverge. The derived rate of descent from the GNSS altitude at this time was 3,195 ft/min. The pressure altitude indicated a reversal from descent to climb within one second (a derived vertical speed change of -1,368 ft/min to +1,494 ft/min). Such a change is not possible in this aircraft so the pressure altitude from this point was considered to be inaccurate.

Low confidence in the accuracy of the data beyond this time meant detailed analysis of the recorded data after 1249:47 hrs was not considered reliable. At 1249:49 hrs, the recording of position and GNSS altitude was the same as that for one second later. Potential reasons for this are discussed below but it is indicative of a loss in accuracy of the device.

Despite the loss in accuracy of the device, the recording continued. Position and GNSS altitude data from 1249:47 hrs showed a continued descent towards the location of the aircraft wreckage. The final recorded data point was at 1249:55 hrs.

Vertical Acceleration

Between 1249:40 hrs and 1249:46 hrs, the aircraft vertical speed reduced. The rate at which this reduced is a measure of how fast the aircraft was accelerating vertically, with respect to the recorded GNSS altitude. Figure 7 shows the derived vertical acceleration (g) and that the trend towards the end of the valid data was for a decreasing vertical acceleration. As there were no accuracy metrics in the GNSS download, it is difficult to ascertain a tolerance on the calculated figures. However, using different calculation methods gives a difference of approximately ±0.1 g.

GNSS accuracy

From 1249:47 hrs, inaccuracies were noted in the GNSS device recording. These included a divergence between the pressure and GNSS altitudes, significant reversal of the pressure altitude value and a double recording of position/GNSS altitude recording. There was no GNSS accuracy data recorded by the device which could help explain this.

The accuracy of the device in determining position and GNSS altitude depends on a number of factors. If the GNSS antenna is obscured, the number of satellites in view may be reduced and the accuracy of the recorded position and GNSS altitude will be affected. Sensing of pressure altitude is performed by a pressure sensor in the device which is affected by the location of the device. If there is a sudden pressure change, the pressure sensor reading (and recorded pressure altitude) will be affected.

In previous investigations, the AAIB has encountered erroneous position and altitude data recovered from GNSS devices when aircraft have been in unusual attitudes and, as a result, the aircraft has a shielding effect on the device antenna. Erroneous GNSS data is not unusual during an accident sequence.

For the GNSS device fitted to G-CKYT, if the number of satellites in view reduces, the track log will continue to be recorded, albeit with a lower position and altitude accuracy. This would be seen in the track log as either unusual positions, GNSS altitudes, or both.

If the GNSS signal is lost completely then the device used an algorithm to predict the ongoing position and GNSS altitude for a period of time. This prediction, based on its previous flightpath, allows a continuation of the position reporting and recording in the event of an intermittent signal loss. This predictive tracking is also known as ‘coasting’ and during testing of another Garmin GDL 50, this coasting function was confirmed and occurred for up to 20 seconds. As there were no accuracy measures recorded, the difference between an accurate track, coasted track and one affected by a reduced satellite count could not be distinguished.

Aircraft information

G-CKYT was a Rotorsport UK Cavalon gyroplane. This was a UK imported version of the AutoGyro Cavalon, manufactured in Germany.

The Cavalon is a side-by-side, two seat gyroplane, with an aerodynamically shaped composite fuselage and fully enclosed cockpit. It has a non-retractable, tricycle landing gear and a tailplane attached by a curved tail boom, which provides clearance for the propeller. The tailplane has a horizontal stabiliser and three vertical fins, of which the largest centre fin is equipped with a rudder. The aircraft is powered by a Rotax piston engine, which in the case of G-CKYT was a 914 UL fitted with a turbo. The engine is located at the rear of the fuselage and drives a three-blade composite IVO pusher propeller, which rotates anticlockwise (when viewed from the rear). The gyroplane has an 8.4 m diameter teetering rotor, located at the top of a mast to provide clearance from the propeller. The fuselage mass is approximately 529 kg at maximum weight[4].

Footnote

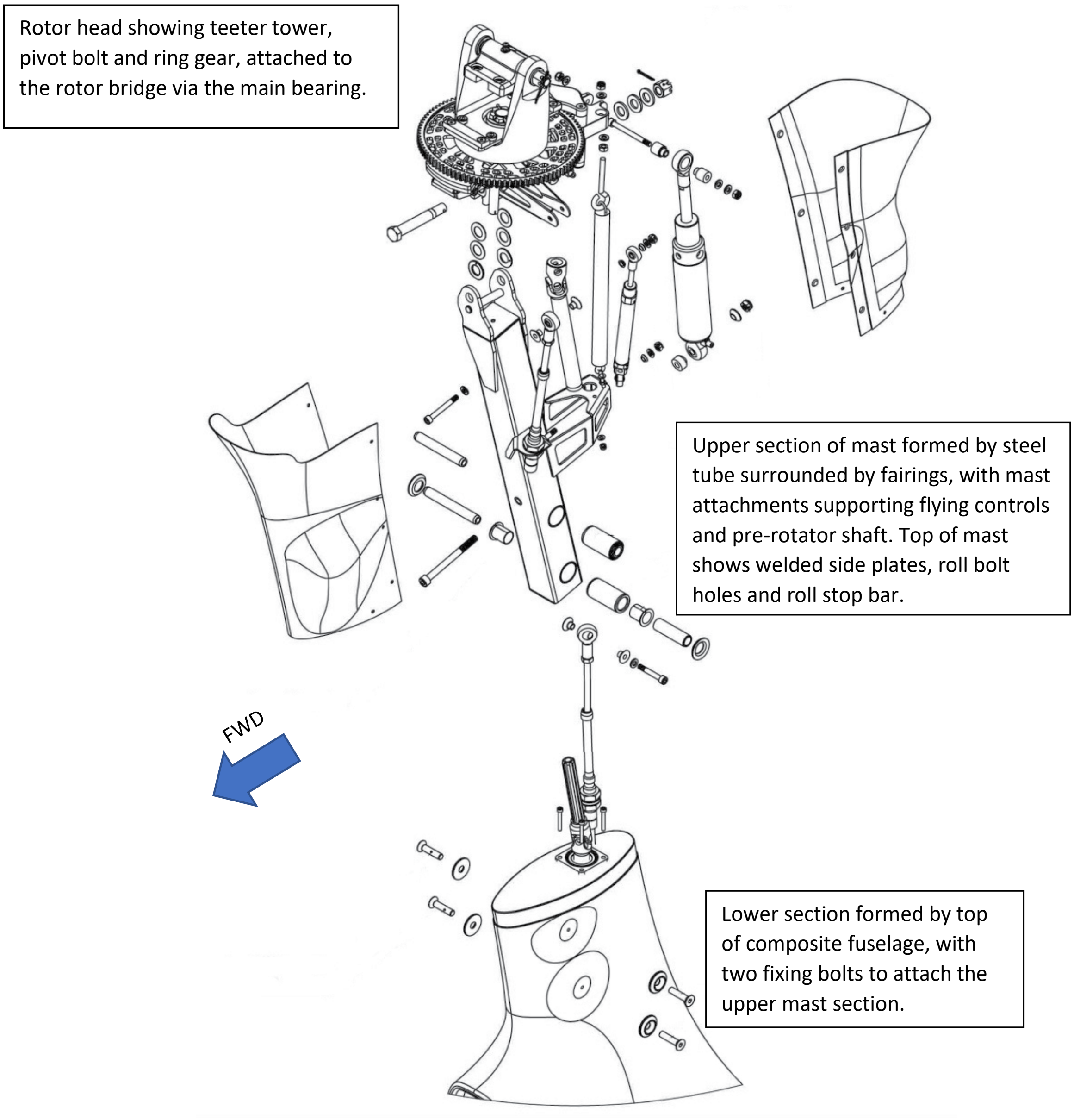
[4] The rotor head and rotor blades together weigh approximately 31 kg.

The top of the fuselage composite structure forms the lower half of the rotor mast. A stainless steel box section tube is bolted to this by two fixing bolts to form the top half of the mast. The steel section also provides the attachments to support the routing of the flying controls and pre-rotor drive shaft, which is then connected to the rotor head. This section of the mast is covered by an aerodynamic fairing (Figure 8).

The rotor head fitted to G-CKYT was a Mark III head (referred to as Rotorkopf III), which was the latest iteration of the design introduced in 2018, and was common to the AutoGyro MTO Sport, Calidus and Cavalon Pro models. The complete rotor head is formed by several individual components attached to an aluminium 'rotor bridge' structure. The rotor bridge locates the main rotor bearing to which the rotating components, namely the pre-rotator ring gear and the aluminium teeter tower and rotor pivot bolt, are fitted, secured by the main rotor bolt. The two rotor blades are joined together by a centre section and attached by the rotor pivot bolt to the teeter tower, with the main mass of the blades hanging below the pivot point formed by the rotor pivot bolt.

Bracket plates bolted on to either side of the rotor bridge are in turn secured to a gimbal block laterally by a single pitch pivot bolt and washers, allowing the rotor head to tilt up and down around the pitch axis, relative to the gimbal block. The gimbal block is bolted longitudinally to side plates welded to the front and back faces of the top of the rotor mast by a roll pivot bolt and washers. This allows the combined rotor bridge and gimbal block to rotate from side to side around the roll axis. Flying control and trim connections attach at the rear of the rotor bridge to control pitch and to a bracket which extends to the left side (viewed from the rear) of the rotor bridge to control roll (Figure 9).

The manufacturer's design drawing designates a 65 mm long, 10 mm diameter stainless steel bar is fitted into locating holes in the side plates on the mast below the roll bolt holes and is welded in place on the exterior surfaces of the plates. The manufacturer confirmed the thickness of these plates should nominally be 5 mm. Only the internal width dimension between the side plates (52.0 + 0.5 mm) is specified on the manufacturer's drawing. With a nominal plate thickness of 5 mm this would result in the bar extending between 1.5 and 1.25 mm beyond the external faces of the side plates on either side, though any variation in the thickness of the side plates could reduce this further. The drawing specifies an all-round fillet weld on the external face only. It does not give a dimension for the throat, but specifies the use of a 2 mm, 1.4576 steel electrode. The weld requirement is the same on both side plates of the mast. When the mast and gimbal block are assembled, the bar on the mast locates in a channel along the bottom of the gimbal block (Figure 10). When the gimbal block rotates in roll around the roll pivot bolt by approximately 8° in either direction, the respective side of the channel contacts the roll stop bar to act as a limit stop. The manufacturer advised this control stop feature was only intended for use on the ground.



Rotor head showing teeter tower, pivot bolt and ring gear, attached to the rotor bridge via the main bearing.

Upper section of mast formed by steel tube surrounded by fairings, with mast attachments supporting flying controls and pre-rotator shaft. Top of mast shows welded side plates, roll bolt holes and roll stop bar.

Lower section formed by top of composite fuselage, with two fixing bolts to attach the upper mast section.

Figure 8

Mast and rotor head arrangement (original image courtesy of manufacturer)

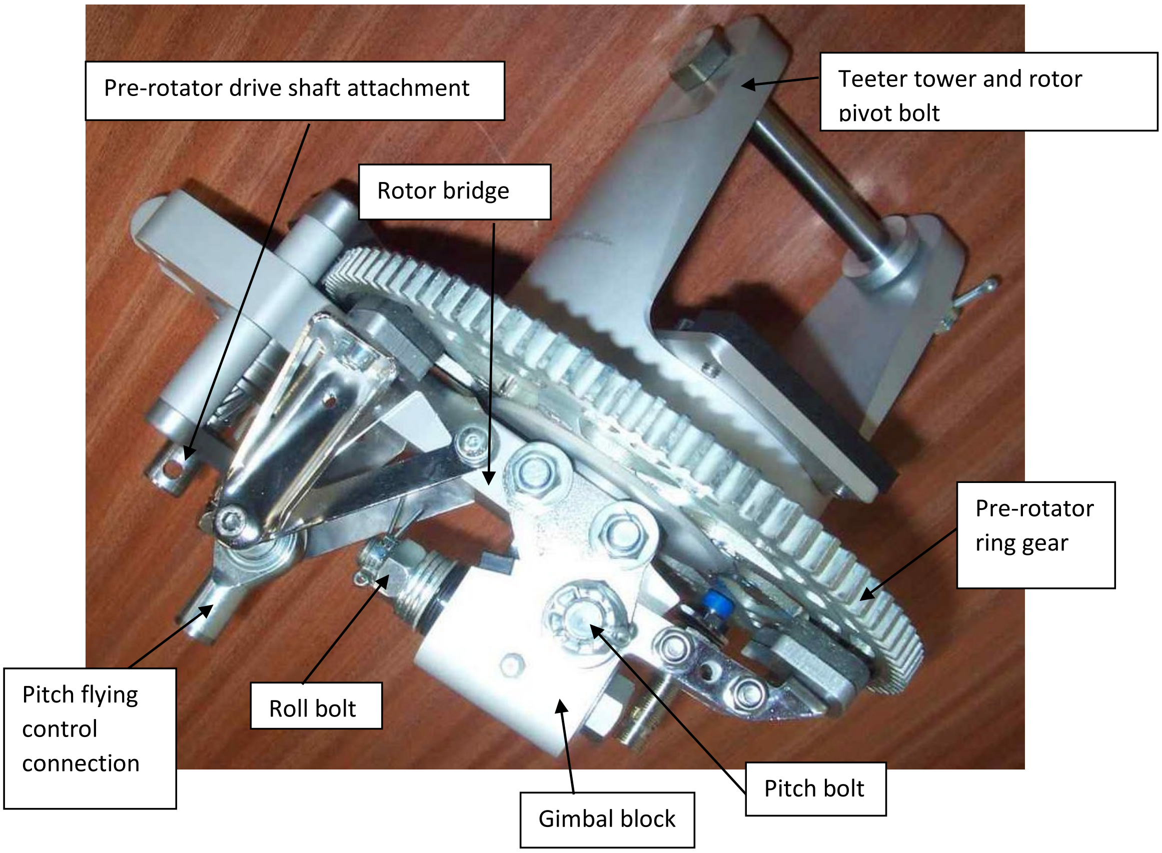


Figure 9

Rotor head components (original image courtesy of manufacturer)

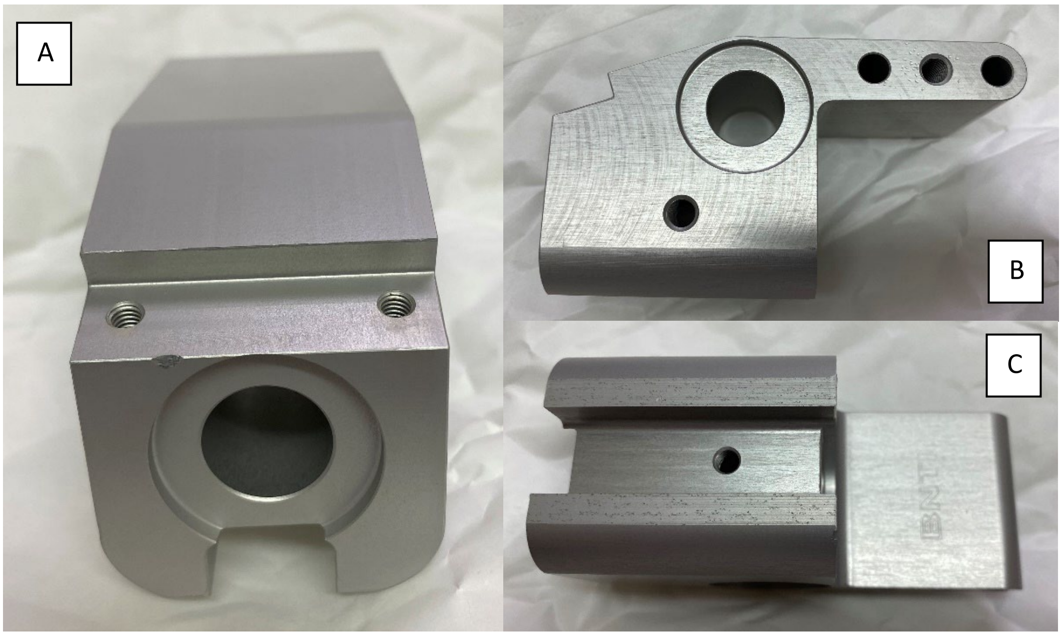


Figure 10

Gimbal block: A – rear, showing roll bolt hole and roll stop channel. B – right side, showing pitch bolt hole. C – bottom, showing roll stop channel and grub screw hole

Gyroplane Operation

A gyroplane achieves lift and directional control through a free turning rotor. The rotor operates in autorotation spinning freely as a result of air flowing up through the blades with the aircraft being propelled by an engine-driven propeller. This is in contrast to a helicopter which relies on an engine to turn the blades and draw air from above. Aerodynamic forces acting on the rotor blades during autorotation keep the rotor turning, as well as creating lift to keep the gyroplane airborne.

The forces acting on a gyroplane in flight are lift, weight, thrust and drag. Lift is derived from the rotor, which also produces a drag force. The lift component of rotor force acts vertically in straight and level flight whilst the drag component acts rearwards. Drag forces also act on the fuselage which, when combined with the rotor drag, give the total drag of the aircraft.

Thrust acts forward and is provided by an engine typically driving a pusher propeller. This acts directly through the airframe, rather than through the rotor system as on a helicopter. Changes in thrust are used to control airspeed and to compensate for changes in the lift and drag components of the rotor force caused by aircraft manoeuvring.

To manoeuvre the gyroplane in pitch and roll, the entire rotor is manually rotated about the pitch and roll pivot bolts respectively, with control connections from the pilot’s control stick to the rotor bridge to enable this. Moving the control stick forwards and backwards rotates the rotor bridge around the pitch pivot bolt. Moving the stick from side to side rotates it around the roll pivot bolt.

In a banked turn, due to the angle of the rotor plane (relative to horizontal) a proportion of the rotor force generated acts horizontally resulting in a turn. The greater the bank angle, the greater the proportion that acts horizontally and the less there is acting vertically. Pulling back on the stick increases the total amount of lift force generated by the rotor, but this also increases drag. Increased drag is countered by the pilot increasing engine power to increase the thrust from the propeller.

During a turn, the pilot must use a combination of backstick and increased thrust to maintain airspeed and altitude. Increasing bank angle requires increasing thrust until a bank angle is potentially reached where all available power is required. Any further increase in bank would then result in either a loss of airspeed or altitude.

As a result of the control arrangement, the entire weight of the fuselage hangs directly from the roll pivot bolt and is free to rotate laterally like a pendulum. This rotation is not damped and there is no artificial control force system to moderate the pilot’s control inputs. In a level turn, the centrifugal force acting horizontally outwards from the centre of the turn causes the fuselage to swing upwards, pivoting around the roll pivot bolt, until the mast is at approximately 90° to the plane of the rotor[5]. Reversing the roll angle, will cause it to rotate around the roll pivot bolt in the opposite direction.

Footnote

[5] This reaction is actually the result of inertia but is perceived to be a force with respect to the fuselage.

Lift forces generated by the rotor disc during dynamic operation of the rotor effectively act through the rotor pivot bolt and teeter tower and down into the rotor head and gimbal block. The rotors do not contact the teeter stops when the rotor rpm remains within the normal operating rpm range. Movement of the rotor head bridge through flying control inputs changes the angle of the rotor disc without stop contact occurring. The roll control input is offset from the rotor bridge by a bracket, to reduce the control force magnitude required to overcome the aerodynamic and gyroscopic forces generated by the rotor in normal flight.

In the air, the lift force opposes the weight of the fuselage. Changes in the balance of these forces dictate whether the gyroplane climbs or descends and the rate at which this vertical speed varies.

Load factor

The load factor (n) is simply defined as lift divided by weight. For a gyroplane, this is the actual load on the rotor head and mast at any point, divided by the normal load or gross weight. When a gyroplane flies in a constant altitude turn, maintaining level flight, the load supported by the rotor blades is greater than the total weight of the gyroplane. The steeper the bank angle is, the greater the load supported by the rotor and the greater the load factor. Load factor is non-dimensional, but is often expressed relative to the perceived force (weight) under normal gravitational acceleration or 1 g. For example, a turn which results in a load factor of 2 might also be described as a 2 g turn.

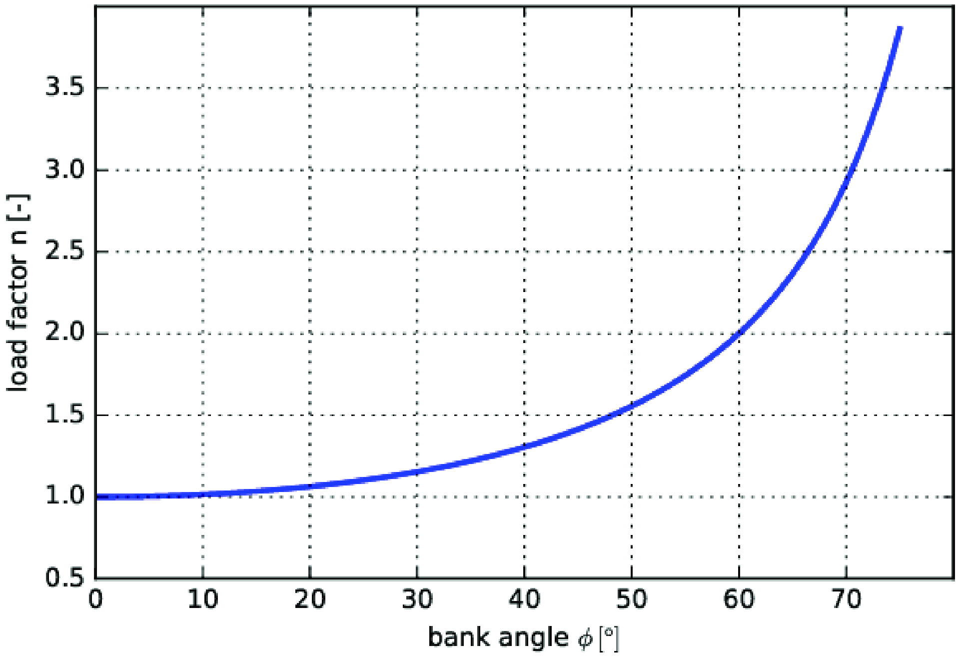


Figure 11

Load factor increase with bank angle

To overcome this additional load factor, the gyroplane must produce more lift by increasing the airflow through the rotor. If additional engine power is not available to achieve this, the gyroplane will descend. The load factor change is relatively small in turns up to 30° but increases more rapidly as the bank angle increases above this (Figure 11).

Load factor is also affected by the gyroplane climbing and descending. An increase in vertical acceleration results in a load factor greater than 1. Conversely if the vertical acceleration of the aircraft reduces below that normally experienced due to gravity, this can result in the load factor reducing below 1, reaching zero or even becoming negative (Figure 12). This reduction results in the gyroplane's rotor 'unloading' or creating a reduced force compared to normal flight at or above 1 g.

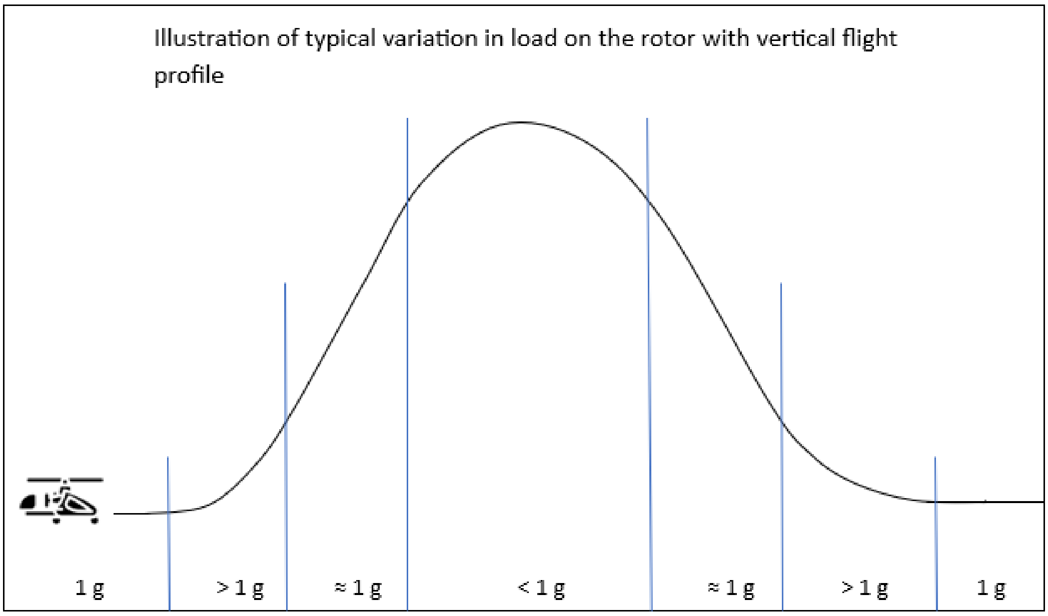


Figure 12

Load variation with vertical flight profile compared to 1 g flight

Reduction in rotor loading can result in a reduction in rotor rpm, altitude and directional control. With a teetering rotor head, if rotor rpm drops too low it can also cause the blade flap angle to increase to a level where the blades contact the teeter limit stops. The adverse effects of unloading the rotor become more pronounced the closer the load factor is to zero, when they can become catastrophic.

When calculating load factor, the flight profile of the gyroplane must be considered in all three dimensions as, for example, the load may reduce in the vertical plane due to a reduction in vertical acceleration but increase in the horizontal plane while flying a turn.

Footnote

[6] Zero g or below is commonly referred to as 'weightlessness'.

Engine torque induced fuselage rotation (Torque Roll)

The force generated by an operating engine to turn the drive shaft and propeller also produces an equal and opposite force. If the engine and propeller rotate anticlockwise (viewed from the rear) this produces a clockwise torque on the engine body in operation. As the engine is fixed in the airframe on a gyroplane, this results in the fuselage rotating clockwise around the roll pivot bolt, which is perceived by the pilot as a right roll, even though the rotor may be horizontal and the control stick is initially centred. The engine manufacturer quotes the torque produced by the engine at various power settings. Typically, the highest torque is generated when the engine is at maximum power and rpm. This is the case for the Rotax engines fitted in the Cavalon. In normal operation the pilot can counter the induced rotation with an opposite roll control input.

Aircraft certification

The accident aircraft was a Cavalon model, approved as a Permit to Fly aircraft by the CAA. Permit annual checks and continued airworthiness were overseen by the Light Aircraft Association, under delegation from the CAA.

The Cavalon design was originally approved by the UK CAA as compliant with British Civil Airworthiness Requirements (BCAR) Section T (CAP643), issue 4. BCAR Section T, covering light gyroplanes, was introduced in 1995 and originally based on Section S (microlight design), with various amendments to address issues specific to gyroplanes. As such, it is a less complex set of requirements compared to those intended to support a full Type Design and Certificate of Airworthiness level of certification. Given the limited total operating hours and relatively small number of aircraft designed to BCAR Section T requirements, compared to other design regulations, they have not been revised as frequently or as extensively.

The CAA advised the investigation that BCAR Section T had been developed as a response to the very high accident rate seen on early gyroplane designs. They stated that it had continued to evolve since the original issue, drawing on other codes such as EASA CS-VLA, CS-VLR and CS-27. They highlighted that it was the first gyroplane design code in the world and is generally considered as the definitive standard for certification. The foreword for Section T states that gyroplanes which have been shown to comply with BCAR Section T will only be eligible for a Permit to Fly.

The manufacturer went on to develop the Cavalon Pro for use in a commercial capacity which required the individual aircraft to have a Certificate of Airworthiness. This was agreed by the CAA based on the original certification work for the Permit to Fly Cavalon, along with the demonstration of compliance to changes in issue 5 of Section T, and additional requirements detailed in Certification Review Item (CRI) E-01. Demonstration of compliance by the manufacturer with the additional requirements was subsequently confirmed by the CAA. This allows a Certificate of Airworthiness to be issued for individual aircraft, permitting them to be used for commercial aerial work in the UK. The manufacturer marketed the Cavalon Pro as being '*compliant with CAA requirements for a UK Standard Category Certificate of Airworthiness*', with which '*the aircraft is permitted to undertake any paid aerial* *work for which it is equipped and approved, and where a Certificate of Airworthiness is required, especially in Europe. Examples of such work include air taxi, carriage of goods, surveying, police and fire service duties, and much more.'* The manufacturer then elected to comply with issue 5 and CRI E-01 for all Cavalon models to standardise manufacture.

BCAR Section T has several requirements regarding structural strength. These include T305, T307, T337, T339 and T547b. The wording of requirement T337 was amended by CRI E-01 to reduce the static strength requirements to:

> *'The gyroplane must be designed such that-*
>
> *a) i) The gyroplane's rotor must be designed for a positive limit manoeuvring load factor of +3.0, at all forward speeds from zero to the Maximum Design Speed VD.*
>
> *ii) The rest of the gyroplane must be designed for positive and negative limit manoeuvring load factors of +3.0 and –0·5, respectively, at all forward speeds from zero to the Maximum Design Speed VD'.*

The means of compliance stated in the manufacturer's Certification Report for T337 was Calculation/Analysis and Laboratory Test. Along with compliance statements, this was the same for all the structural strength regulations. The laboratory test carried out to demonstrate compliance to T337 was a ground-based flight load simulation test, which statically loaded the airframe vertically to simulate the effective weight of the aircraft at 560 kg MTOW and +3[7] load factor. For practical reasons the test did not simulate the negative part of the requirement. It was argued by the manufacturer that, as the structural strength of the components was the same in either direction, the positive load factor test adequately addressed a load factor of -0.5 as well. This was accepted by the CAA who agreed that the test demonstrated compliance with both parts of the regulation.

No flight test activity was conducted to formally demonstrate compliance with T337 or any of the other structural regulations[8]. Some flight testing was done to determine the highest g load likely to be achieved in operation by flying tight, steeply banked turns. This only explored the positive g load part of the envelope. Given the inherent risks associated with prolonged low to negative g flight, this area of the operating envelope was not intentionally explored during any of the general handling flight tests. The manufacturer advised that during the assessment of minimum airspeed for level flight (V_{min}), the gyroplane can momentarily experience less than 1 g as the gyroplane drops below V_{min} and descends. The actual g load, if measured, during this test was not provided to the investigation. The section of the Cavalon Certification Flight Test Summary report relating to general controllability requirements (T143) noted that in normal [≥1 g] flight *'the turbo engine produces some limited torque roll if suddenly engaged.'*

Footnote

[7] The test was done to demonstrate the earlier requirement standard of 500 kg at +3.5 g which was a more severe test.

[8] As stated in RSUK0405 Iss. 1 Cavalon Revised Certification Report.

[9] The Rotax 914 and 915 engines are fitted with a turbo and are both engine options on the Cavalon.

Requirement T675 addresses the need for control system stops and states:

> *'a) Each control system must have stops that positively limit the range of motion of the pilot's controls.*
> *…*
>
> *Each stop must be able to withstand any loads corresponding to the design conditions for the control system.'*

The Type Approval Data Sheet (TADS) issued by the CAA for the Cavalon identifies several prohibited manoeuvres for the gyroplane, it states:

> *'(G) Prohibited Manoeuvres: Aerobatic manoeuvres are prohibited.*
> *Manoeuvres involving a deliberate reduction in normal 'g' shall be avoided.*
> *Flight in icing conditions is prohibited (not placarded).*
> *Flight in strong gusty winds or wind velocities of more than 45 mph (40 kt) is prohibited (not placarded)'.*

Product conformity and airworthiness

An aircraft design is defined by a set of controlled design drawings for every component or assembly which is bespoke to that aircraft. Collectively these represent the baseline standard which has been approved by the certification process of the overall aircraft. To maintain the same standard of airworthiness in production aircraft, each component or assembly manufactured must conform to its drawing for it to be installed on an operational aircraft. Minor quality lapses and variations can be accepted, providing these have been assessed as acceptable from a safety and functionality perspective and this is documented by an approved quality exemption.

If the components are fitted to a new aircraft on the manufacturer's assembly line, then a statement of conformity is issued to the customer for the aircraft as a whole, indicating that each of the individual components and assemblies making up the overall aircraft conform to their respective design drawings. For non-EASA or non-Part 21 aircraft in the UK, components must be supplied with a UK CAA Approved Certificate, which contains a statement of conformity by the manufacturer, that the part conforms to the approved design drawing or details any exemptions or variations. The maintenance provider must confirm this documentation is present before they can fit the component and declare the aircraft serviceable again.

Aircraft examination

A post-impact fire in the fuselage section resulted in severe fire damage to the structure, with only peripheral sections and components made from high melting point metals surviving. These items included most of the engine, the majority of the propeller blades, parts of the landing gear, the rotor mast and some of the flying control cables and connections. Loose ballast material and the remains of a ballast container were found in the main wreckage, however, the level of damage meant it was not possible to determine the position of the ballast at impact. The nose gear wheel and various small items of structure, such as broken plexiglass, were thrown clear of the fuselage and were not affected by the fire.

The rotor head and blades were located separately from the fuselage. One of the blades had been heavily bent and deformed at the blade root where it was bolted to the centre joining section. There were other small marks and distortions along the length of both blades. The most significant of these was a small puncture hole just over a centimetre long. The edges of the hole were pushed inwards from the outside surface of the blade. Adjacent to this, in a diagonal pattern between the hole and the blade leading edge, were many small marks with red and black colour transfer consistent with the paint on the propeller blades. The centre section exhibited impact marks on both sides from contact with the teeter stops (Figure 13). The mark was more significant on one side than the other, but both were superficial and there was no plastic deformation of the blade surface material or the stops.

On the rotor head itself, all the connections to the flying controls had failed at the ‘eye end’ connectors. The pre-rotator drive shaft was disconnected at a join in the drive shaft. The bracket connecting the roll controls to the rotor head was bent backwards and had failed along most of the weld line between the body of the bracket and its mounting plate.

The gimbal block had failed where two cracks joined. One ran vertically through the roll bolt hole and down the length of the block. The other fracture surface ran horizontally through the centre of the pitch bolt hole for half the width of the gimbal block until it met the vertical fracture surface. The pitch bolt was retained in place and secured the largest section of the gimbal block to the rotor head (Figure 13). The other smaller section of gimbal block was missing and despite an extensive search, could not be located on the accident site or the surrounding fields.

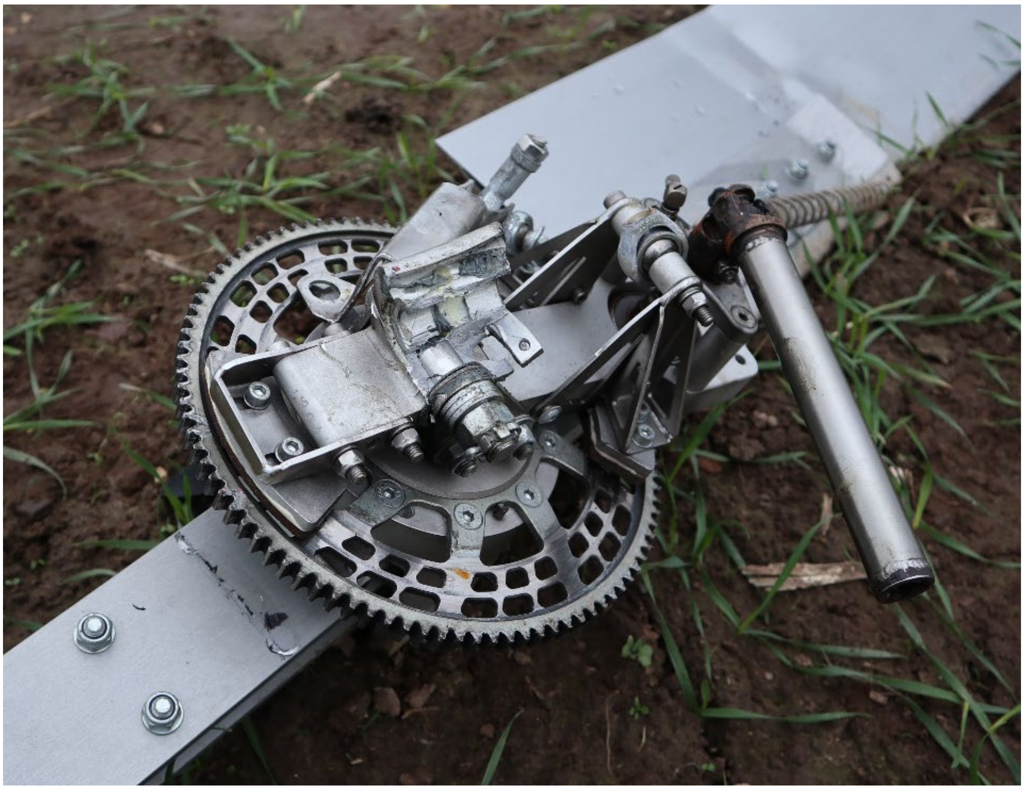


Figure 13

Rotor head showing gimbal block failure, rotor blade deformation and teeter stop contact mark

The roll bolt remained fitted to the top of the mast section. The roll stop bar in the mast had deformed to become curved, rather than straight (Figure 14).

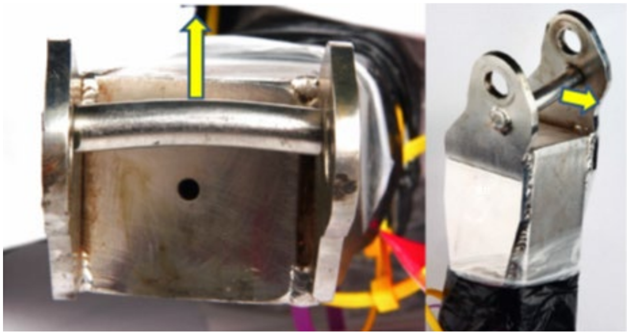
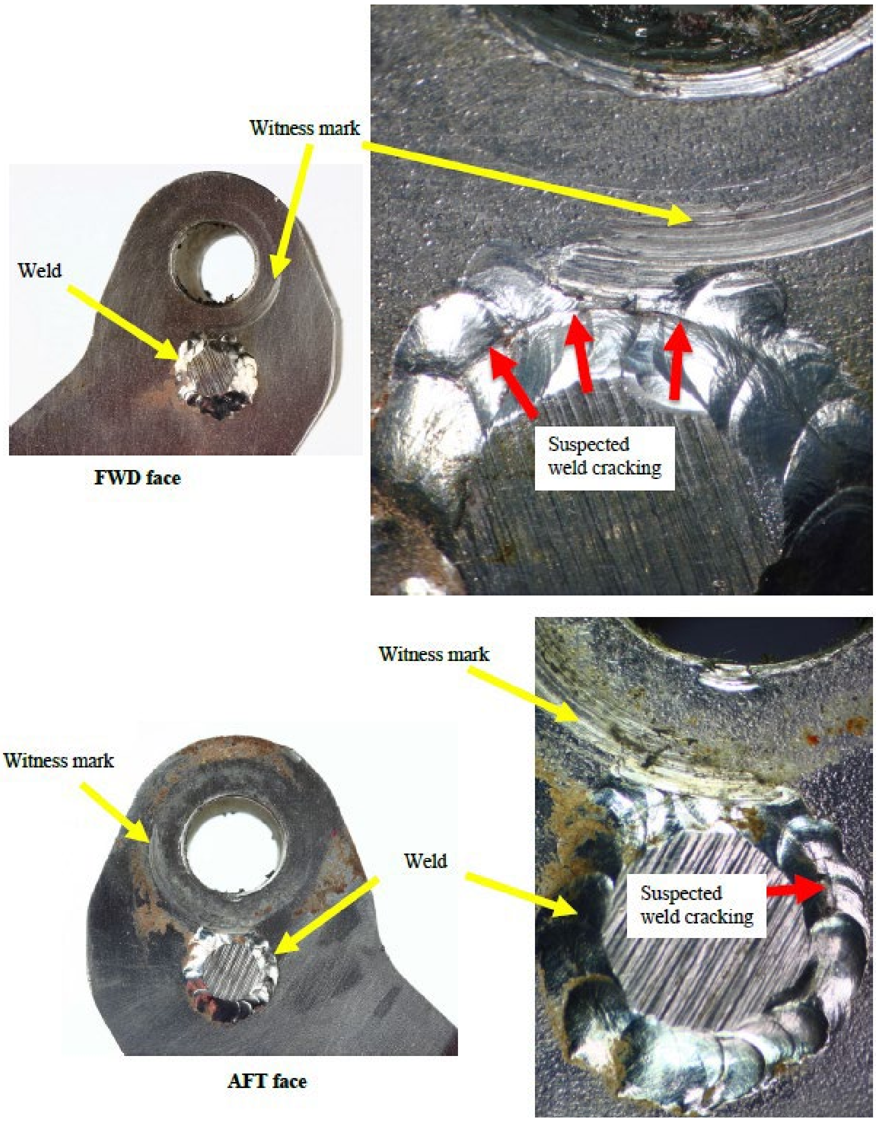


Figure 14

Deformation of mast roll stop bar (with roll pivot bolt removed)



FWD face

AFT face

Figure 15

Detailed inspection of the roll stop bar end welds

Detailed inspection of the mast welds showed witness marks on both external faces of the mast. The manufacturer subsequently stated that these were machining marks, where a flat surface was machined during manufacture to accommodate the washers used in the assembly of the pivot bolt. The inspection also indicated that cracks were present in the weld on both sides (Figure 15).

Laboratory inspection

The rotor bridge, gimbal block and mast were removed from the wreckage and sent for metallurgical analysis. Detailed inspection of the gimbal block showed evidence of additional cracks at one end of the block. There was also a curved indentation in the side wall at each end of the channel that acted as a roll stop (Figure 16). The extent of the missing material is shown in Figure 17.

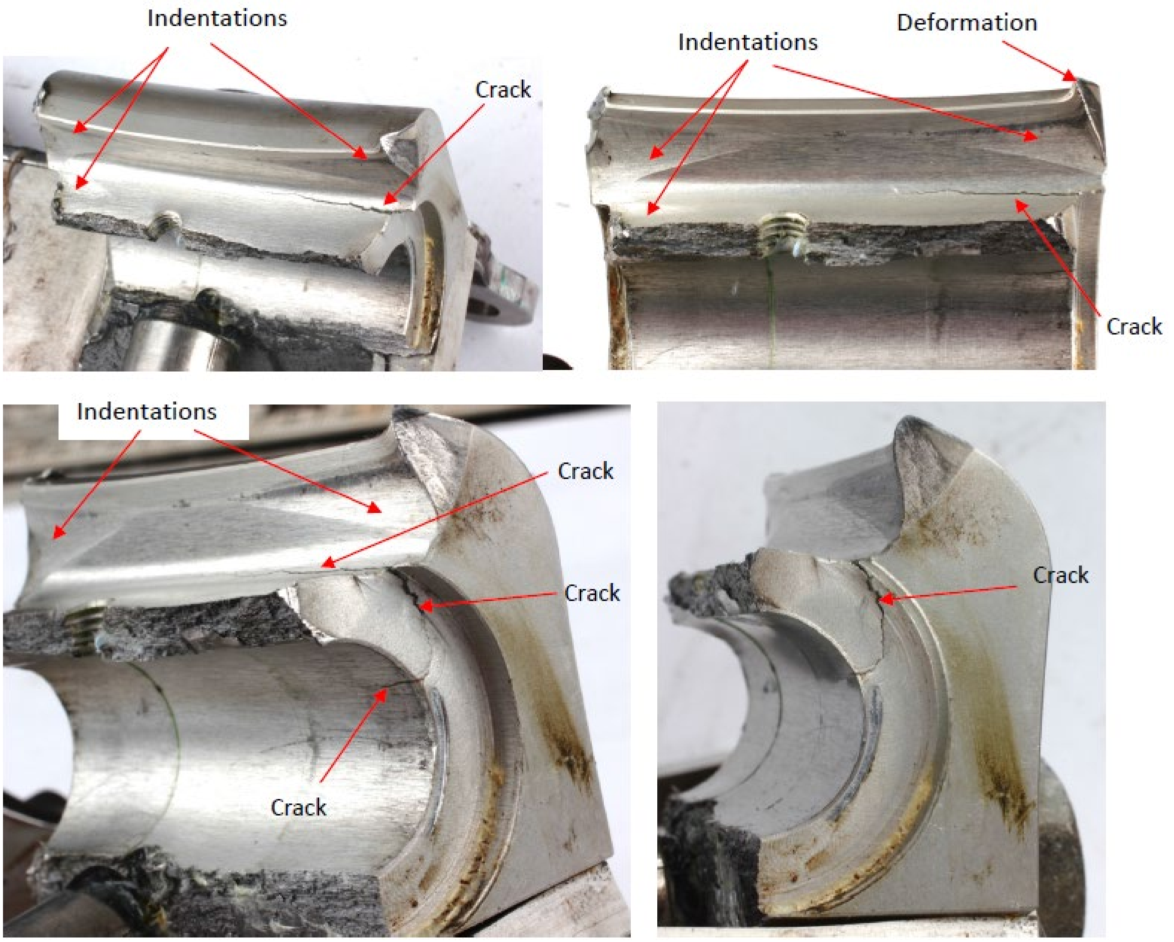


Figure 16

Additional cracks and deformation of the gimbal block

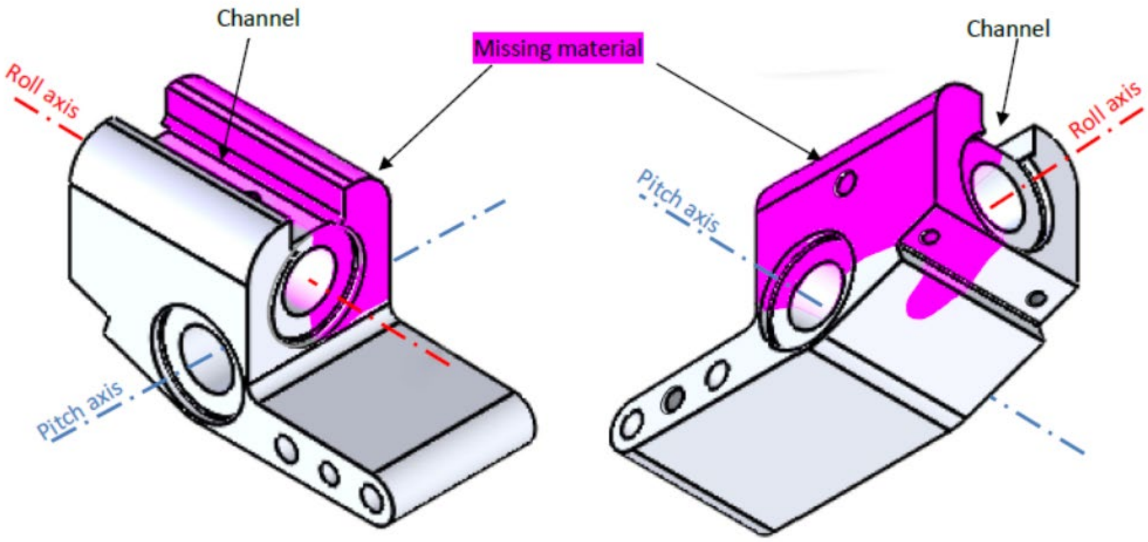


Figure 17

Extent of missing material from the gimbal block
(shown inverted relative to its installed orientation)

Analysis of the gimbal block material properties confirmed that it was machined from extruded T4 aluminium alloy, as specified by the component drawing. The direction of extrusion of the original material was along the roll axis (Figure 17), which was demonstrated by the elongated shape of the grains in this direction. Hardness testing conducted in a number of positions on the block all gave values consistent with the specification for this material. EDX spectrum analysis[10] was carried out, which also confirmed that the alloy composition was within the tolerances of the specification.

Visual analysis of the fracture surfaces showed that the vertical fracture was the primary crack as it extended past the point where it was joined by the horizontal fracture surface (Figure 18). Inspection using a Scanning Electron Microscope (SEM) confirmed that all the fracture surfaces were the result of a single continuous overload, with no evidence of fatigue present. Analysis of the failed flight control attachments confirmed they had also failed in overload.

Footnote

[10] Use of x-rays to determine which chemical elements are present and to what extent within the test sample.

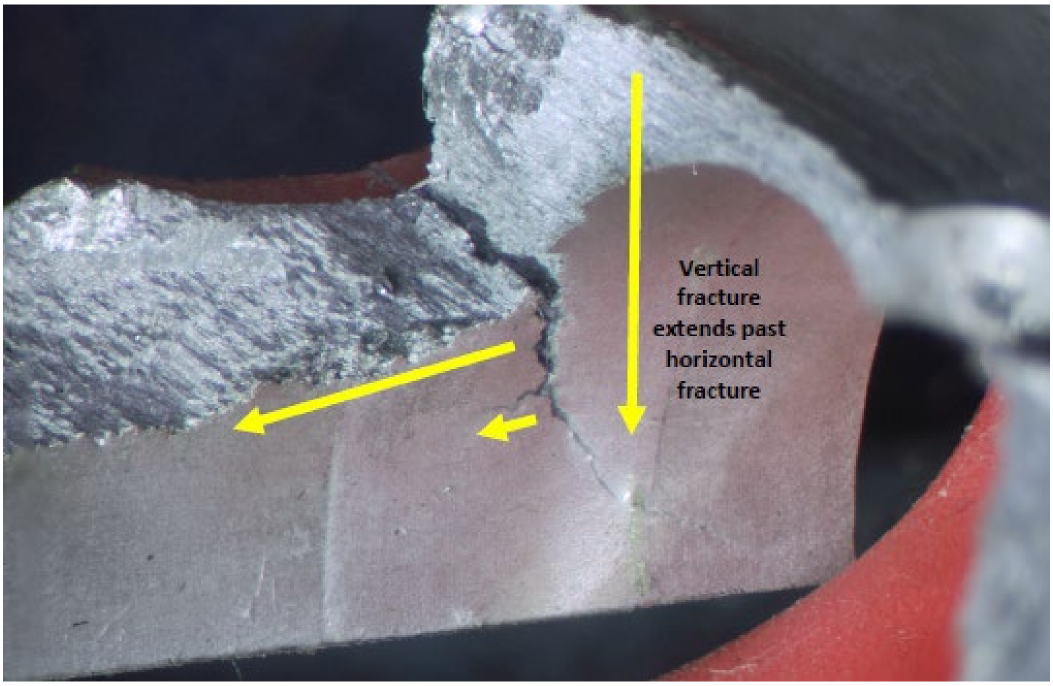


Figure 18

Image showing the vertical fracture surface extending past the horizontal fracture

The side plates which attached the gimbal block to the rotor bridge on both sides were significantly distorted and the bolt holes were elongated. The bolts and bracket attaching the front brake pad assembly to the gimbal block were also distorted, indicating a rotational force on the gimbal block (Figure 19).

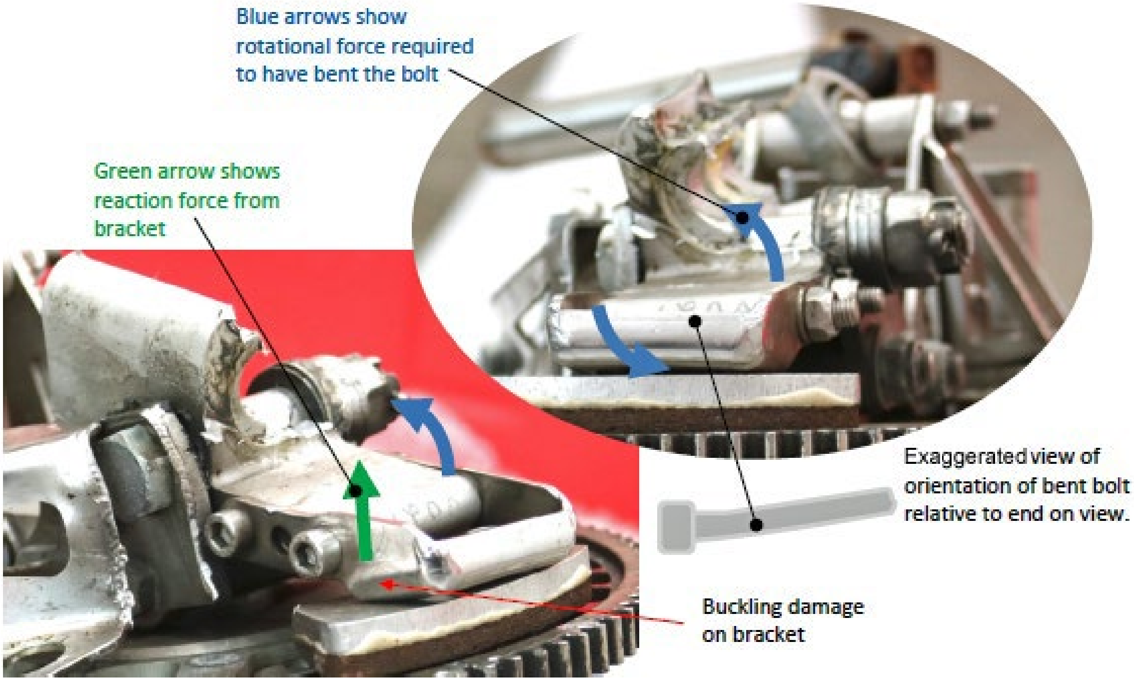


Figure 19

Images of the distorted brake pad bracket and bolts indicating a rotational force

A CT[11] scan was carried out on the mast, which confirmed the extent of the roll stop bar distortion and the distortion from vertical of the side plates which supported the bar and the roll pivot bolt. The orientation of the bend in the bar was consistent with the indent marks on the gimbal block. It also showed that the end welds fixing the roll stop bar in the side plates were surface welds on the exterior of the plates, with very little penetration into the plate material. The welds on both sides of the plate had failed or on one side the weld may not have extended across the hole in the plate originally (Figure 20).

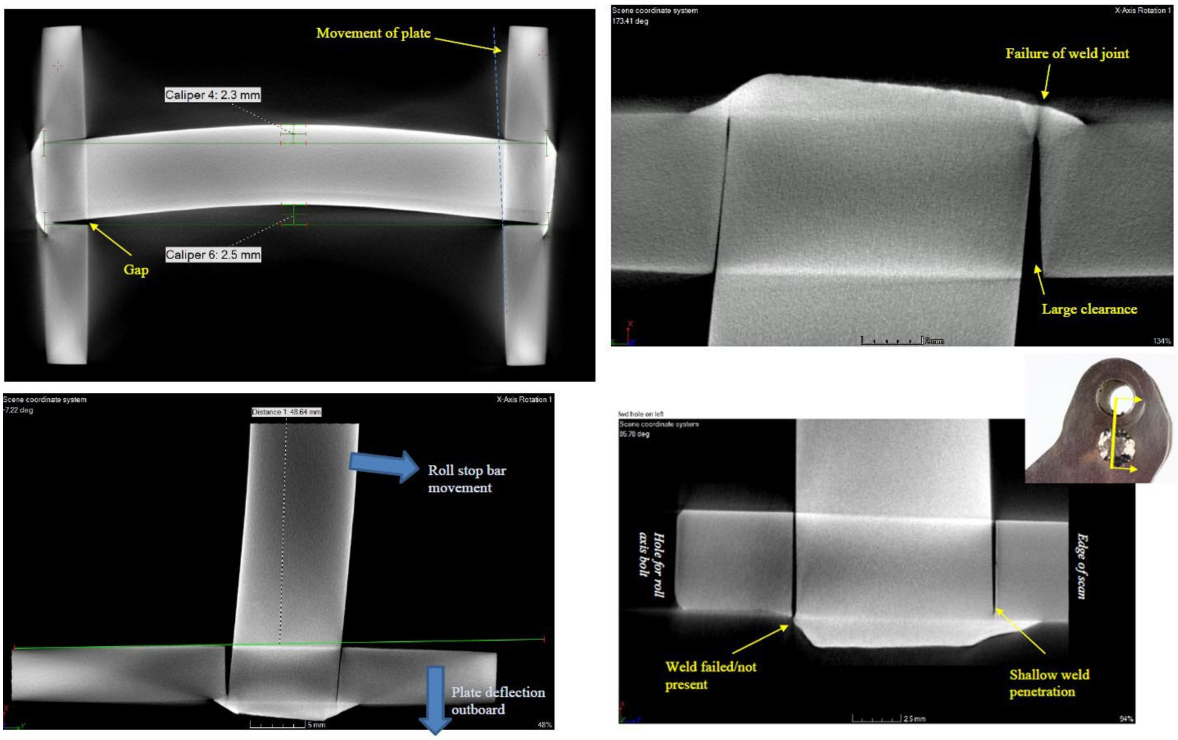


Figure 20

CT scan showing the distortion of the bar and side plates, the shallow weld size and weld failure on both sides

CT scans of the mast also showed the extent that the roll stop bar extended beyond the external face of the mast side plates. This was confirmed as 1.5 mm on the forward side and 1.3 mm on the aft (Figure 21).

Footnote

[11] Computerised Tomography combines multiple x-ray image ‘slices’ through a component to create a 3-D model of the interior of the structure.

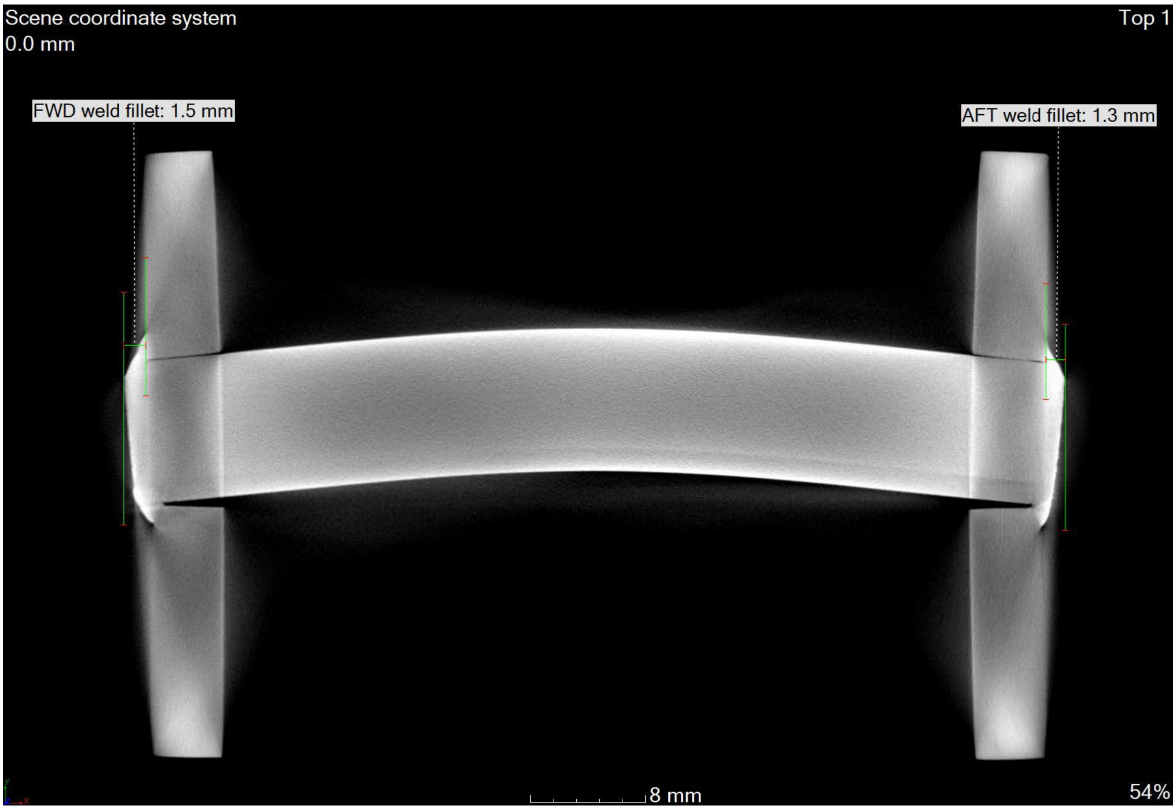


Figure 21

CT scan measurement of roll stop bar extension beyond the mast side plates

Previous incidents

The manufacturer confirmed that the distinctive conical indentations present on the side of the roll stop channel of the accident gimbal block and bending of the roll stop bar had been seen previously. The manufacturer provided samples of gimbal blocks from reported ground-based accidents which had resulted in similar deformation, but not the cracking or complete failure of the block. The manufacturer was not able to provide details of the gyroplanes from which these gimbal blocks had been removed, so it was not possible to determine if the accidents had been independently investigated or the specific circumstances of the incidents which caused the damage. However, as the manufacturer stated that they were ground-based events, it is most likely the damage had resulted from either dynamic rollover of the fuselage or low rotor rpm blade sailing issues during the takeoff roll.

Fuel

After the first flight of the day a member of the operator's staff refuelled G-CKYT with 40 l of motor gasoline, bringing the total to 60 l, providing an endurance of 3 hours of flight. Following the second flight of the day the student refuelled the gyroplane with a further 20 l. Based on the known history of the flights it is estimated that there were 50 l[12] of fuel onboard at departure for the accident flight. This was sufficient for an endurance of 2.5 hours.

Footnote

[12] 36kg at a specific gravity of 0.72 kg/m^3.

Weight and balance

The Pilot’s Operating Handbook (POH) contained the following note about the use of ballast:

> *‘Pilots in the right hand seat weighing less than 65 kg must carry corresponding ballast during solo operation (which may be located in the baggage compartment, around the occupant in a form such as sheet lead under the seat cushion, or securely restrained on the second seat).’*

The student weighed more than 65 kg, but the training school routinely used ballast to minimise the lateral attitude change of the aircraft when the left seat was not occupied on solo student flights.

Ballast was added to the gyroplane for both solo flights undertaken by the student on the day of the accident. This was described as a jerrycan filled with sand weighing 35 kg strapped onto the front left seat, and a sandbag weighing 15 kg, also filled with sand, placed on the cockpit floor in the space behind the left seat.

G-CKYT had a recorded basic empty mass of 326 kg. The calculated take off mass, including the mass of the pilot, fuel and ballast, was approximately 512 kg. The MTOM permitted is 560 kg.

The distribution of weight in the gyroplane was within the limits defined in the POH for weight and balance calculations.

Aircraft limitations

The Cavalon POH contains the following limitations:

Air Speed	Marking		
V_{NE} Never Exceed Speed	Red radial	🟥	**195km/h (120mph)**
V_B 130km/h (max design speed for strong gusty conditions)	Yellow arc	🟨	130 – 195 km/h (80-120mph)
Recommended manoeuvring speed range	Green arc	🟩	30 - **130 km/h (20-80mph)**
	Yellow arc	🟨	0 – 30 km/h (0-20mph)

Figure 22

Cavalon POH - Section 2.4 - Airspeed Limitations and Instrument Markings

In addition, the structural load factors were defined as:

> ***‘2.7.3 Demonstrated Structural Load Factors***
>
> *Demonstrated positive load factor (500 kg).. + 3.5 g*

> *Demonstrated negative load factor (500 kg) – structural limit...................... - 1 g*
>
> *Demonstrated positive load factor (560 kg).. + 3.0 g*
>
> *Demonstrated negative load factor (560 kg) – structural limit.................. - 0.5 g*
>
> ***Important note**: the indication of a demonstrated negative load factor represents a structural limit only. In flight, the limitations (see 2.9) have to be respected at all times.'*

The POH provides the following notes and warnings for manoeuvres:

> ***'Section 2 - Limitations***
>
> ***2.1 General***

> *WARNING*
>
> *Positive G load on the rotor must be maintained during all flight manoeuvres. Do not perform any manoeuvres resulting in the sensation of feeling light or near weightless.*

> *2.9 Kinds of Operation*
>
> *Aerobatic flight is prohibited!*

> *NOTE*
>
> *Manoeuvres involving bank angles of more than 60° are considered to be aerobatic flight.*

> *Low-G manoeuvres are prohibited!*

> *WARNING*
>
> *Any manoeuvre resulting in a low-G (near weightless) condition can result in a catastrophic loss of lateral/roll control in conjunction with rapid main rotor RPM decrease. Always maintain adequate load on the rotor and avoid aggressive forward control input performed from level flight or following a pull up.'*

In a later section entitled '*Safety Tips*', the following advice is provided:

> ***'Low-G Avoidance***
>
> *Never push the control stick forward to descend or to terminate a pull-up (as you would in an airplane). This may produce a low-G (near weightless) condition which can result in a situation with reduced or lost lateral roll control and significant loss of main rotor RPM. Always reduce power to initiate a descent.'*

The manufacturer and the CAA were requested to clarify what specific ‘g’ represented a limit beyond which operation of the gyroplane was explicitly prohibited. They stated it was not possible to provide a specific figure.

Identifying low g

Despite these warnings in the POH describing the need to avoid situations where the rotor head becomes significantly unloaded, there was no qualifying information on what these terms represented. A number of phrases were used to describe this including ‘*low g*’, ‘*near weightless*’ and ‘*sensation of feeling light or near weightless*’. It also describes the need to maintain ‘*adequate load*’ on the rotor.

Enquiries were made with the Royal Air Force Centre of Aviation Medicine (RAFCAM) about a pilot’s ability to perceive low g. This revealed it is likely that a pilot could detect a change from + 1 g to + 0.5 g, and probably even a change from + 1 g to + 0.8 g. However, RAFCAM stated that there is no trial evidence to support this and there is no evidence in medical literature of studies having been conducted in this area. It was further suggested that if the change was from greater than 1 g, or occurring in turbulent conditions, then it is likely that it would be more difficult for a pilot to identify the transition point to less than 1 g.

Typical values of vertical acceleration during climbing and descending were not available from the aircraft flight tests.

Meteorology

On the morning of the accident, the forecast wind speed aloft was 20 kt at 1,000 ft and 30 kt at 2,000 ft from the south-west. The METARs at Inverness Airport recorded at 1020 hrs and 1250 hrs reported the surface wind as 220° at 8 kt and 230° at 7 kt respectively. Between these observations the maximum windspeed recorded was 11 kt. The TAF published at 1100 hrs reported that between 1200 hrs and 2100 hrs the surface wind would be from 220° at 12 kt, with a 30% probability from 1500 hrs of a temporary increase to 17 kt, gusting 27 kt.

With only light winds down the runway, the instructor assessed the weather to be suitable to send his student on solo sorties and regarded the wind speeds of 20 to 30 kt at height as acceptable and ‘*not challenging*’. The wind strength was below the Environmental Limitation in the POH of a maximum wind speed or gust intensity of 40 kt.

An aftercast of the area provided by the Met Office showed Inverness and the surrounding area to be in benign conditions between frontal systems at the time of the accident. From local observations, the wind conditions were shown to be as or lighter than those forecast. Local wind reports were of south to south-westerly with varying wind speeds from 4 to 11 kt at Inverness, 11 to 15 kt at Lossiemouth (46 km north-east) and 11 to 20 kt at Tain (30 km north). There was satellite evidence of mountain wave activity from the Grampian Hills with modest activity at 6,000 ft above the surface. Given the terrain and the forecast mountain wave activity, varying wind speeds were expected. There was no rainfall and visibility was good. Between the surface and 5,000 ft there were only FEW amounts of cloud, with any broken layers above 5,000 ft.

The pilot of the Grumman AA-5 flying in the area shortly before the time of accident reported that there were no gusts or turbulence when he transited the Black Isle and described the weather as '*suitable for normal flying'*.

Gyroplane licensing and training regulation

Responsibility for gyroplane operations had historically been delegated by the CAA to the British Rotorcraft Association (BRA). In 2012 the CAA appointed their first Flight Operations Inspector with specific responsibility for gyroplane operations. This was in response to a recognised lack of relevant in-house experience of gyroplane operations within the CAA.

In 2013 the CAA formed the gyroplane Panel of Examiners, consisting of established industry experts, taking over responsibility for gyroplane operations from the BRA. This included establishing the minimum skill levels for all aspects of PPL gyroplane training and ongoing training standardisation. It comprised three senior gyroplane flying instructors and examiners, meeting biannually chaired by the CAA. Additionally, the group hosted an annual conference of gyroplane instructors to discuss training standards.

Standards set by the Panel are reviewed by the CAA before approval is granted and they are included in CAA Standards Document 44: *Gyroplane Licensing.* This defines the standards to be applied for the training of UK licensed gyroplane pilots after 01 July 2012.

To obtain a Private Pilot's Licence for gyroplanes, PPL(G), a pilot must complete a training course with a CAA certified flight instructor entitled to instruct on gyroplanes. Training must follow the gyroplane syllabus published by the CAA in Standards Document 44.

Instructor information

The instructor gained his instructor's qualification, FI(G), with restricted privileges[13] in 2015 and achieved an unrestricted status in April 2017. He had delivered over 1,000 hrs of dual instruction and became qualified to deliver training to flight instructors in August 2020.

He operated from a flying school, which was an Approved Training Organisation (ATO) for the delivery of fixed wing training, as the sole qualified gyroplane instructor. Oversight of his gyroplane training standards was achieved through the triennial revalidation of the instructor's training qualification, conducted by an examiner who sat on the Panel of Examiners.

The instructor managed and documented the progress of students by an online application. In the '*Pilot's Logbook'* section, students could view the objective of each lesson, including a list of key topics covered by the instructor. It also contained comments from instructors and provided an option for students to add their own comments.

Footnote

[13] An instructor holding a FI(G) with restrictions requires the supervision of an individual holding an FI(G) without restriction.

Student pilot information

The student started training towards a PPL (aeroplane) in August 2014. He achieved 71 hours flying experience but in January 2018 stopped flying for medical reasons. He then decided to gain a PPL on a gyroplane and started his flying training in September 2019, undertaking all his instruction on G-CKYT.

The student was assessed as a confident, diligent, and able student, who presented no supervisory concerns to his instructor. He demonstrated transferable knowledge from his previous fixed wing experience which conferred benefits in the initial phase of the course. However, when developing the skills for takeoff and landing his progress was reported to be of a standard expected for most students. This was attributed to the significant differences in the flying techniques used in gyroplanes and fixed wing aircraft.

Following a period of consolidation of these gyroplane techniques, he undertook his first solo flight on 6 November 2020, six days prior to the accident, which was conducted without incident. He did not undertake any further flights until the day of the accident.

Gyroplane training syllabus

CAA Standards Document 44 included a training syllabus largely developed independently by one of the members of the Panel of Examiners and approved by the CAA. This was used by the operator in training the student and comprised 38 lessons arranged into eight phases.

The syllabus differs from fixed wing training in that the gyroplane student is not expected to be ready to fly solo until after lesson 31. This is attributed to the level of difficulty of gaining proficiency in the techniques for takeoff and landing. The licensing requirement for gyroplanes is a minimum of 40 hours of instruction of which 10 must be supervised solo. Up to the accident flight, the student had achieved 45 hours dual instruction and 1 hour 45 minutes solo.

Lesson 23: Higher bank angle level turns and turning in relation to ground reference features

The objective of this lesson was to teach a student how to maintain airspeed, height and balanced flight during turns using up to 45° angle of bank, and how to turn around a point on the ground maintaining a constant distance from it. The angle of bank is assessed visually by reference to a horizon reference line taped onto the windscreen. The manoeuvre requires the application of significant back pressure on the control stick to prevent the gyroplane's nose from dropping and up to near full power to maintain airspeed. For turns around a point on the ground, in order to maintain a constant distance from the point, the student has to compensate for drift caused by the wind. This is achieved by varying the angle of bank during the turn.

The student's instructor stated that in his experience bank angles of 45° or greater required '*application of full throttle (5,600 rpm) and significant back pressure on the control stick*'. He stated that in comparison to this, initiating a turn using approximately 30° angle of bank at 60 to 70 mph with 4,800 rpm set, would require an increase in engine power of approximately 200 rpm during the turn and some back pressure on the control stick to maintain height and speed.

The student conducted lesson 23 on 29 July 2020 and consolidated the technique on 5 November 2020 during pre-solo practice with his instructor. The instructor noted in the student's training record after the flight on 29 July that the student required *'more focus on the horizon reference line during the exercise, and less focus on the point we are turning around*' and cautioned him, '*Don't go too far on the high bank turns'.* The student added the comment: '*fun high bank turns, but easy to go too far*'. The training record contained no further entries regarding high bank angle turns.

The instructor reported that while turns using up to 45° angle of bank should be well within the skills of a pilot by solo stage, students would normally be expected to use a maximum of 30° angle of bank when flying solo unless specifically briefed.

The instructor reported that he had not given the student specific exercises to fly but had directed him to fly around the training area to gain more experience of handling the gyroplane. His expectation was that the student would not use more than 30° angle of bank, but this was not explicitly briefed to the student.

Lesson 24: avoiding, recognising and recovery from unusual attitudes

During this lesson students were taught to be able to understand why unusual attitudes[14] occur, how to recognise them and how to safely recover the gyroplane back to controlled flight. A particular manoeuvre taught was the recovery from a descending steep banked turn, also referred to as a 'spiral dive'. This was taught by the operator in two forms: a 'slow' spiral dive at a manoeuvre entry speed of approximately 40 mph, and a 'fast' spiral dive at approximately 70 mph.

The instructor would place students into the manoeuvre using up to 30° angle of bank, with the student following through on the controls, then hand over control to the student to recover to straight and level flight using the following technique:

- Reduce power.
- Select a level attitude in the order of roll, pitch then yaw.
- Maintain a level attitude until the rotor rpm reduces back to the normal level for cruise conditions.
- Once rotor rpm is stable, increase power to a cruise setting and continue flight.

The student received training in this technique on 13 March 2020 and again on 29 July 2020. On both occasions they were flown over Munlochy Bay. The instructor informed the AAIB that students were not permitted to practise this technique when flying solo before they gained their pilot's licence.

The instructor stated that he would not expect the descent rate to exceed about 1,000 ft/min when a student properly recognised and recovered from the unusual attitude as taught, before it developed into a spiral dive.

Footnote

[14] An unusual attitude is an unintentional, unanticipated, or extreme aircraft attitude.

The instructor further commented that as part of the lesson on climbing and descending turns, the bank angle is incrementally increased which can result in a significant increase in descent rate up to 1,500 ft/min. He stated descent rates above 1,500 ft/min were in any case unusual in normal gyroplane operations but descent rates of up to about 2,000 ft/min may be achievable in a spiral dive if the nose is lowered to increase airspeed as part of the manoeuvre. He stated that 2,000 ft/min was considered safe and within the ability of most instructors but is '*pretty extreme'* and '*not something that would ever be performed by a student'.*

NPPL skills test accuracy

The instructor stated that for the NPPL skills test the relevant tolerances for flying accuracy during normal manoeuvres were:

- Airspeed: ±5 kt.
- Altitude or height: ±100 ft.

Training for avoiding low g

Standards Document 44

Standards Document 44 contains the syllabuses for all gyroplane licences, including instructors and examiners. In the section on the General Flying Test for the award of a PPL(G), it states:

> *'The syllabus lists all the items which should be covered during training and which may be examined during the Flight Test. The applicant will be required to demonstrate a satisfactory standard of knowledge and handing in all items included in the Flight Test.'*

However, there was no guidance provided on the need to teach or examine recognising and avoiding low and negative g flight profiles.

In contrast, the awareness of the hazards of low g is included in the syllabus of theoretical knowledge for a PPL(H)[15] and in the UK CAA *Helicopter Flight Examiner Manual*[16].

The instructor

The instructor reported that he discussed the subject of low and negative g throughout the PPL(G) course, including reference to video footage of historic gyroplane accidents. Documentary evidence provided to the AAIB indicated that the emphasis during training was placed on avoiding pushing the control stick forward too quickly or abruptly during manoeuvres, and the avoidance of over-controlling. This reflected warnings and advice contained in the manufacturer's POH.

Footnote

[15] CAP1340: Alternative Means of compliance 1 FCL210; FCL215 Syllabus of theoretical knowledge for the PPL(H), October 2015.

[16] UK CAA Helicopter Flight Examiner Manual, Version 1, 23/04/2021.

Neither source covered the potential for a transient reduction in the load factor below 1, hence unloading of the rotor, during a turn-reversal manoeuvre.

Medical information

While undergoing training on aeroplanes, the student held an EASA Class Two medical. His last EASA Class Two medical examination was on 30 December 2016, at which he had an Operational Safety Pilot (OSL) restriction[17] added due to a medical condition. This medical condition subsequently caused him to stop flying.

Medical records indicated that the student then received successful treatment for his condition. On 1 September 2020, on the commencement of his gyroplane training, the student presented a Pilot Medical Declaration of fitness to fly signed by his General Practitioner (GP) and dated 12 December 2019.

The Pilot Medical Declaration is appropriate for pilots flying an aircraft less than 2,000 kg MTOM. The student provided this declaration on CAA Form SRG 1204, although this went out of use after 25 August 2016 being replaced by an online declaration which does not require a doctor's countersignature. However, the declaration and GP's countersignature affirmed that the student met an appropriate medical fitness standard that was acceptable to the CAA.

Post-mortem examination did not reveal any evidence of medical incapacitation. The impact forces were assessed as not survivable.

Assessment of point of failure from the wreckage trail

The recorded GNSS path up to 1249:47 hrs, wreckage location and estimated wind conditions were used to help estimate the approximate point of the rotor head failure (Figure 23). The gyroplane had sufficient height that the lightweight, low inertia debris released during the failure sequence was blown downwind to form a long wreckage trail roughly half a kilometre long. The wind direction at 2,000 ft was estimated by the Met Office but corresponds well to the direction of the wreckage trail. The gyroplane had a groundspeed of at least 70 mph during this period, so the debris would have travelled diagonally forward[18] from the point of release. This gives some indication of when the failure must have occurred and is consistent with the period immediately before the data became unreliable.

Once the rotor had departed the fuselage, physical evidence from the wreckage shows a rotor blade contacted the propeller, stopping the engine; there was now no other means of influencing the flight trajectory and the fuselage would have fallen ballistically. Given its significant weight and inertia compared to the small debris released at the same time as the rotor head, although it would have been affected by the prevailing wind, it would have maintained its forward speed and fallen faster, reducing the extent of the change in direction and distance it travelled.

Footnote

[17] This limitation is added to a medical certificate when a pilot is considered to be at increased risk of incapacitation compared to his/her peer group. The holder of the medical certificate must always fly with a safety pilot.

[18] Forward relative to the approximate direction of travel at the point of failure.

Figure 23

Image showing wreckage trail and prevailing wind direction relative to the GNSS flightpath

Tests and research

DLR gyroplane flight performance modelling

The German national aeronautics and space research centre (DLR) were contacted to assist the investigation based on their extensive knowledge of gyroplane performance modelling and flight testing.

The DLR have created an accurate data model of gyroplane flight characteristics, which has been validated by flight testing with an instrumented airframe. The gyroplane on which they based the model and which was subsequently used for flight test validation of the data was an AutoGyro Cavalon.

The DLR model was used to simulate a period of reduced g during a turn. This included a number of assumptions which were not taken from the accident flight data but considered a similar typical scenario.

The simulation used assumed parameters of an engine torque of 100 Nm (approximately 75% power), a rotor head roll control angle increasing above 4° and a reducing vertical acceleration (n_z) below 1 g. This resulted in a fuselage angle at the rotor head roll pivot bolt (xi_RH) that reaches the maximum available (-8°) in the geometry of the rotor head control system at around 0.3 g. Practically this would result in the roll stop bar on the mast coming into contact with the left side of the gimbal block channel.

The time taken for the fuselage angle to reach the maximum available is proportional to the rate at which the vertical acceleration reduces and will vary with increased engine torque, as shown by the top graphs in Figure 24. A faster reduction in vertical acceleration, or a greater torque figure, would result in a faster response at the roll pivot bolt. The torque and rate of vertical acceleration change chosen for the modelling were arbitrary and not taken from the accident flight data, as was the resulting time of 8 secs to reach -8° limit.

The bottom left graph shows that although the rotor rpm reduces as the vertical acceleration reduces, it remains within the normal operating limits for the gyroplane, as stated in the POH, of 200-550 rpm.

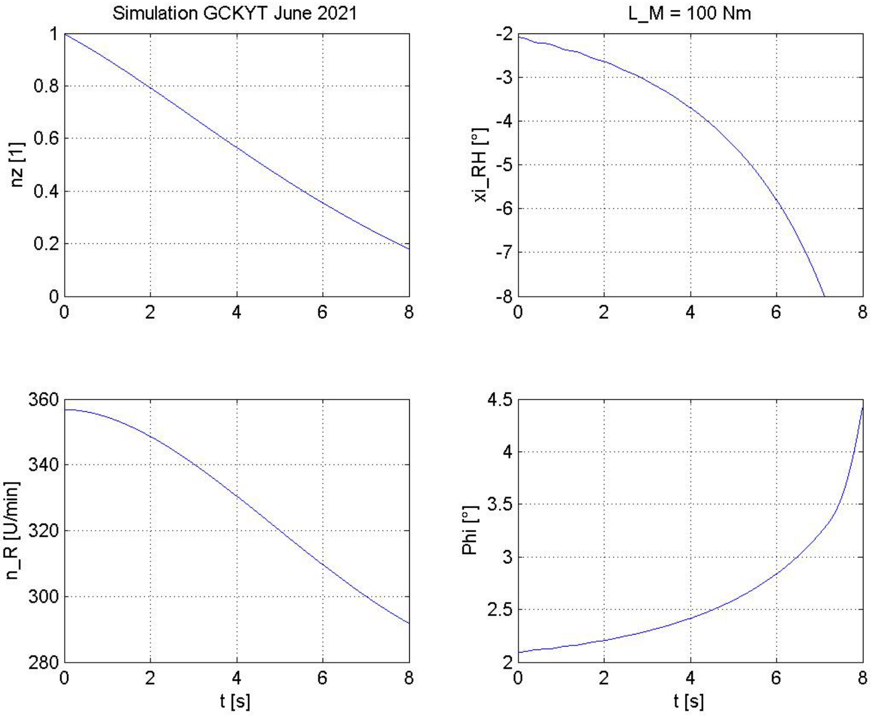


Figure 24

DLR modelling predicting an induced roll angle of the fuselage due to engine torque during flight conditions below 1 g

The DLR also provided a static calculation tool for the Cavalon. This allows an assessment, under static conditions, of approximately how much roll control angle input is required at the roll pivot bolt to counter the engine torque induced rotation. In normal 1 g or above flight, where the vertical acceleration results in a force acting against that induced by the engine torque, this requires only a small amount of counter control input. However, as the vertical acceleration reduces, the effects of engine torque can become significant and result in the fuselage rotating clockwise (viewed from the rear) about the roll pivot bolt in the gimbal block.

Based on the calculation tool, for a Cavalon configured to the same assumed weight and balance as G-CKYT and the engine operating at full power, if the vertical acceleration drops to approximately 0.5 g, then the maximum available opposite roll input may be required to counter the torque of the engine, resulting in possible contact between the mast roll stop bar and the gimbal block. If the vertical acceleration drops below 0.5 g, there would be insufficient control authority to counter the induced rotation without increasing the contact force on the gimbal block.

In dynamic operation, if the fuselage is already rotating clockwise about the pivot bolt, reducing the clearance between the gimbal block and the roll stop bar, this could in theory lead to contact occurring at vertical accelerations above 0.5 g. For example, at 0.6 g, if just over one degree of fuselage rotation past the neutral position is present, the required control input to counter the engine torque may result in contact.

The DLR modelling and calculation tool only provide an approximate indicator of the likelihood of contact between the gimbal block and roll stop bar but highlight the significance of vertical acceleration, engine power and whether the aircraft is manoeuvring. The DLR calculations confirm that the vertical acceleration can theoretically be above the subjective POH limitations of *'near weightless'* or *'low g'* when contact with the roll stop bar occurs. However, the recorded data from the accident flight did not have sufficient parameters to allow the exact circumstances resulting in contact during the accident flight to be confirmed.

Mast interface

In order to assess the geometry of the mast interface found on G-CKYT, a new production mast was purchased directly from the manufacturer for comparison. This mast had not been used in operation. It was CT scanned to determine the interface dimensions and weld penetration on the roll stop bar. Figure 25 shows that the internal distance between the side plates is 52.2 mm, which was within the drawing tolerance. It also confirmed that the side plates were flat and aligned at 90° to the roll stop bar, which was straight, but the bar measured 62.5 mm, rather than the specified 65 mm.

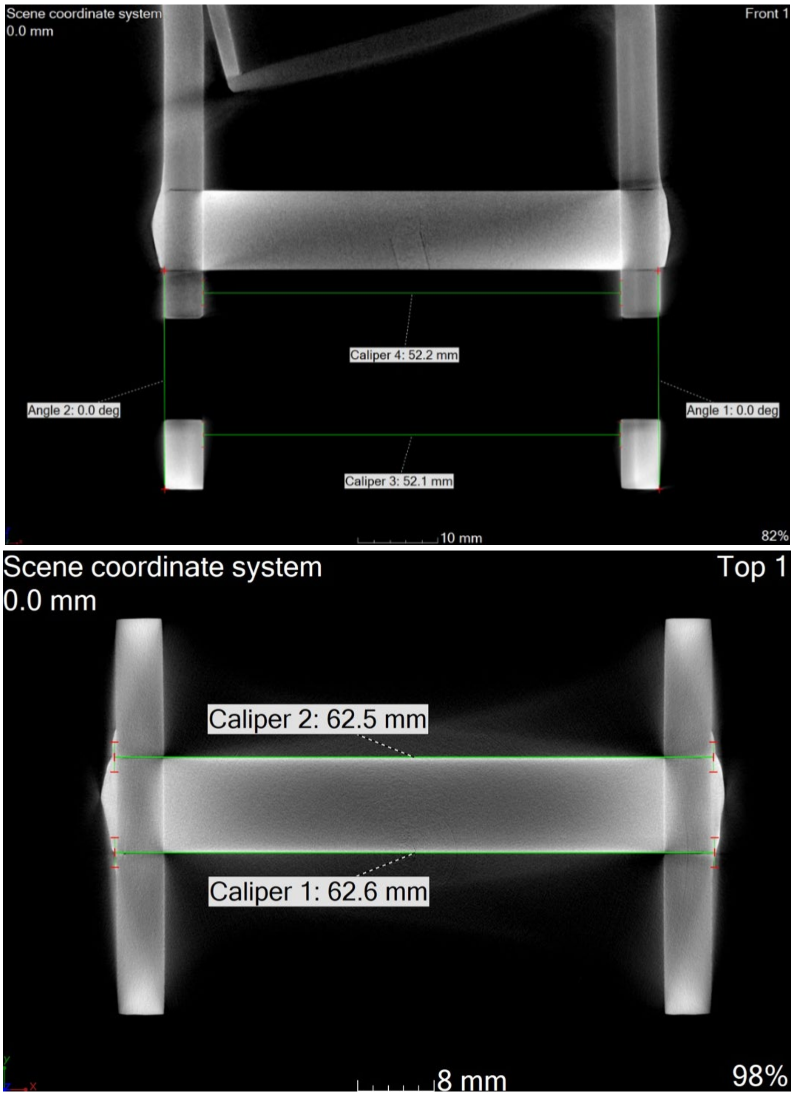
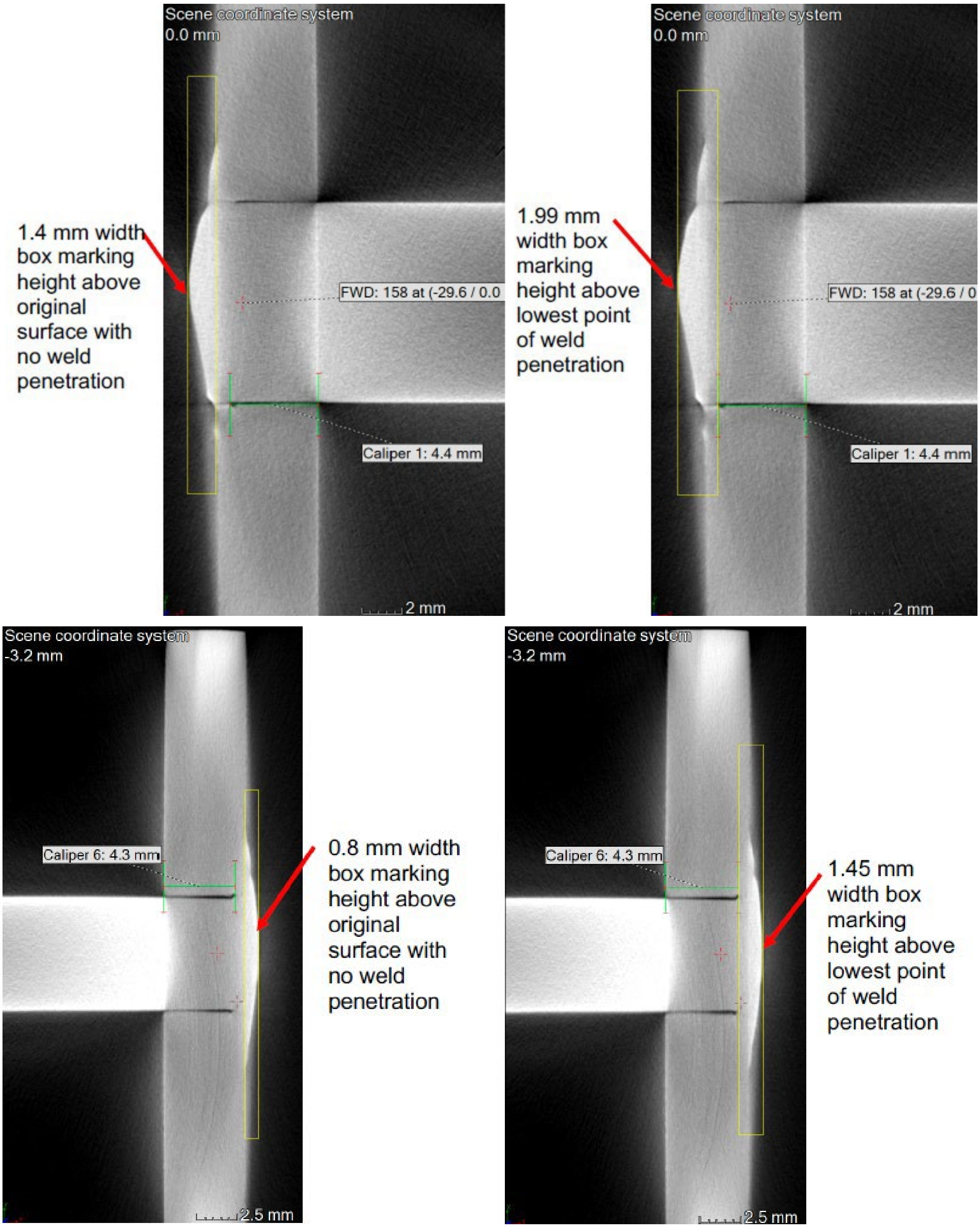


Figure 25

CT scan of new production mast top

Measurements taken from the scan showed that the roll stop bar at its highest points extended beyond the external face of the side plates by 1.4 mm on the aft side and 0.8 mm on the forward side, although the measurement dropped significantly away from the peak. The weld depth at its deepest penetration was 1.99 mm and 1.45 mm respectively on each side, but this also varied significantly across its diameter (Figure 26).



1.4 mm width box marking height above original surface with no weld penetration

1.99 mm width box marking height above lowest point of weld penetration

0.8 mm width box marking height above original surface with no weld penetration

1.45 mm width box marking height above lowest point of weld penetration

Figure 26

CT scan of new production mast top showing the roll stop bar weld (aft side - top images, forward side - bottom images)

According to the design drawing dimensions, for a nominal plate width of 5 mm, the roll stop bar should extend between 1.5 mm and 1.25 mm, depending on manufacturing tolerances.

The mast arrived with an existing witness mark on the side plates. The manufacturer confirmed that these were machine marks, where the faces and weld had been machined flat during manufacture to accommodate the washers fitted during assembly of the roll pivot bolt. (Figure 27).

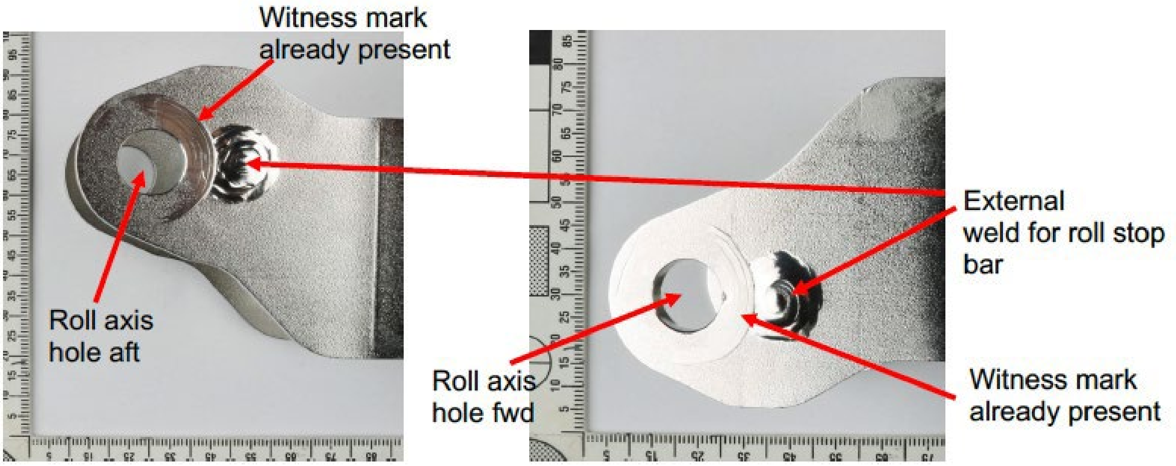


Figure 27

As received part showing damage to weld

Assessment of the roll stop bar welds

The strength of a fillet weld is based on the throat size (a), shown in Figure 28 as the distance between the two red arrows on the left. The strength can be increased by using a deep penetration weld shown on the right of Figure 28, which increases the size of the throat (a).

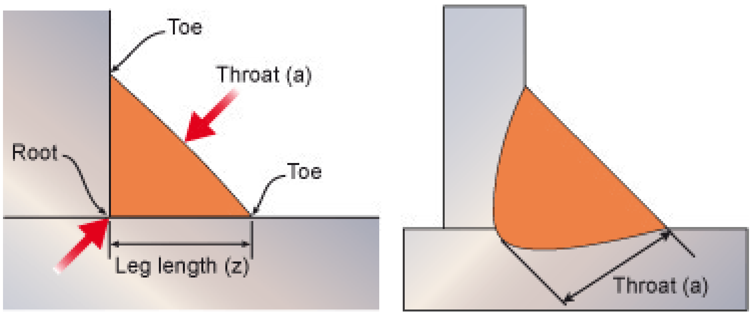


Figure 28

Weld definitions

The throat dimension can’t be easily measured on a finished weld, but it can be estimated using the leg length (z) shown in Figure 28. For an isosceles triangle (equal leg lengths), the throat is approximately 0.7 of the leg length ($a \approx 0.7z$). European welding standards EN ISO15614-1 state that where the drawing doesn’t specify weld size, for plate material between 3 and 30 mm thick, the minimum throat size should be 0.5t (where t = minimum plate material thickness) or at least 3 mm to achieve a full strength weld.

For the roll stop bar and side plate of thickness 5 mm this would give a minimum leg size of 4.3 mm. In order to measure this, the roll stop bar would need to extend at least 4.3 mm from the external face of the side plates. The CT scans show that on one side of the new production mast the bar only extended 0.8 mm at its highest point, this would give a theoretical best-case throat thickness of 0.6 mm. In reality, the height was not consistent across the width of the bar, tapering to less than half this height at the edges of the bar. The CT scans showed that the penetration of the weld reached 0.7 mm at its greatest, but as the extension height tapered across the radius of the bar, it did not significantly improve the throat size. As such, the weld was less than a third of the recommended size. The welds could, therefore, only be considered as ‘tack’ welds used to hold the bar in position, rather than full strength welds designed to carry load. As the mast on G-CKYT was the same, this was considered a consistent feature of production rather than a single quality lapse.

The manufacturer was requested to confirm whether they considered that the accident mast and the production mast supplied for testing conformed to the approved design drawing for the component and whether there was any intention to change the manufacturing process to address the findings of the investigation. In response, the manufacturer stated that the gimbal block channel was not expected to contact the roll stop bar in flight and was only intended to act as a control stop on the ground. As such, the welded joint was not anticipated to carry significant load and did not need to be a full strength weld. They considered that there was a lack of evidence, based on their experience gained from the large number of other aircraft currently in service, that a change was required. They did however state they will review the entire mast welding process as part of their product improvement programme.

Gimbal block testing to failure

A rig test of an assembled mast and gimbal block was commissioned using nC^2 engineering consultants at the University of Southampton. The test was designed to apply a load to the side of the gimbal block roll channel, by rotating the mast until the roll stop bar on the mast made contact with the block, then continuing to move the mast to increase the load until the gimbal block failed.

To achieve this a test rig was designed to attach the gimbal block to a high load hydraulic press, with a roller cradle to hold the mast and keep the point of load approximately in the same place as it moved (Figure 29). The new production, unused mast and gimbal block were configured with accessory components to be as representative to normal operation as possible. To understand how the loads were transferred through the gimbal block and mast assembly and how the structure responded, four rosette strain gauges were applied on the mast along the box section and two on either side of both of the side plates. One gauge was placed on the roll stop bar, thirteen were fitted to the gimbal block, including the roll channel. One rosette gauge was fitted to each of the brackets attaching the gimbal block to the test fixture. The output of these gauges was logged and also displayed on a screen in real time to identify when the various components started to deform and ultimately fail during the test. The applied force data from the hydraulic test machine was also recorded.

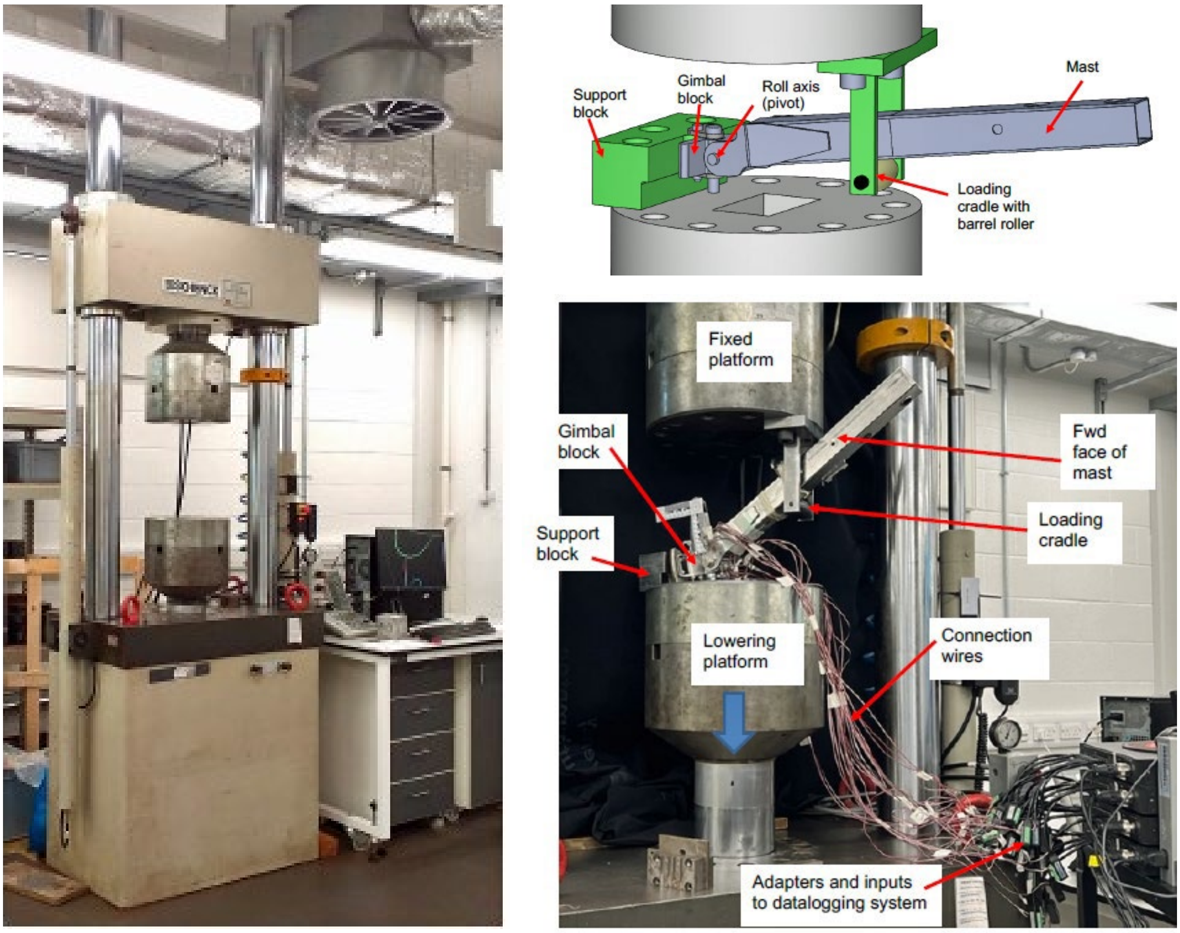


Figure 29

Images of the test machine, test configuration and installed test piece with instrumentation

Test conduct

Below explosive/ballistic levels, the speed at which the load is applied does not significantly change the way the material reacts. Whilst significantly slower than a flight manoeuvre would have occurred, a speed of 5 mm per minute was chosen to allow time to assess the response of the block and mast assembly during the test and stop if necessary. The force being applied by the hydraulic press was continuously monitored during the test to ensure the test was progressing to plan. At one point in the test, one of the side brackets on the mast (not associated with the test) came into contact with the loading cradle. The test was stopped while the mast was repositioned and then restarted at the same point. Further into the test a loud crack indicated that the gimbal block had started to fail and eventually the load dropped off significantly indicating that load shedding had occurred.

As the mast rotated around the roll bolt pivot continuously through the test, the vertical force readings from the test machine were resolved into a load and moment applied at the point of contact between the roll stop bar and the gimbal block. This raw data is shown in Figure 30.

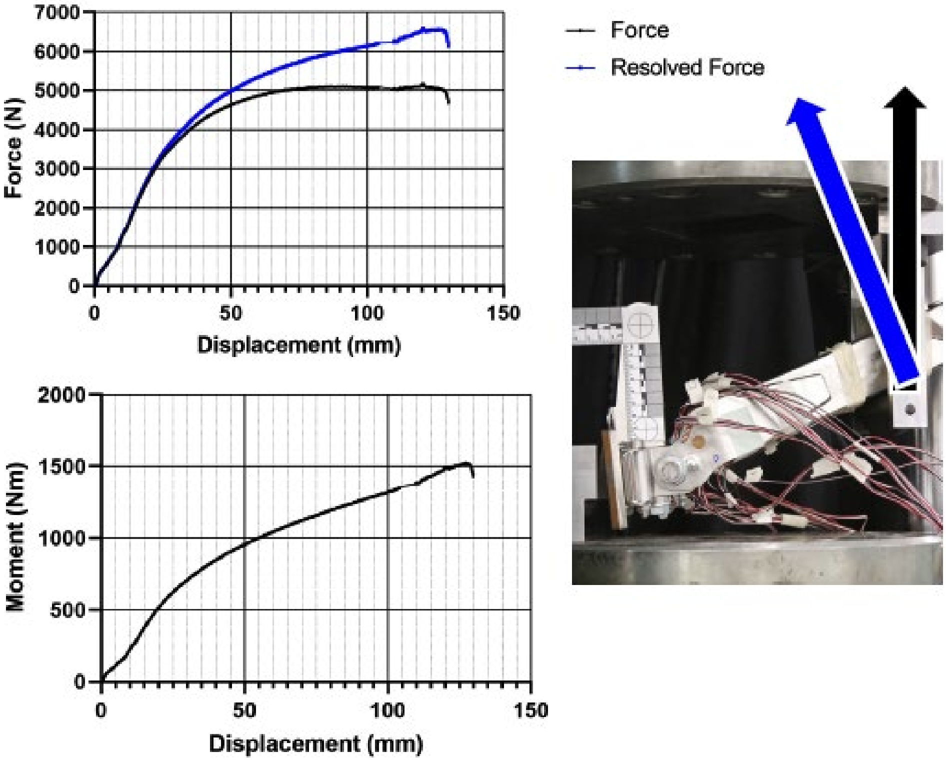


Figure 30

Raw data test results showing the resolved force (blue) and moment acting on the gimbal block (black)

The test showed that the gimbal block failed under a moment of 1,500 Nm.

Post-test inspection

Inspection of the components following the test showed that the roll stop bar had plastically deformed, matching the profile seen on the accident mast.

CT scans of the mast following the test confirmed that the bar had deformed slightly more than the accident mast, with the displacement from straight at the centre measuring 3.3 mm compared to 2.5 mm on the accident mast. The side plates were deformed outwards similar to the accident mast and the roll stop bar welds had failed on both sides, producing the same large gaps between the bar and the plate locating hole on the concave side of the bar (Figure 31).

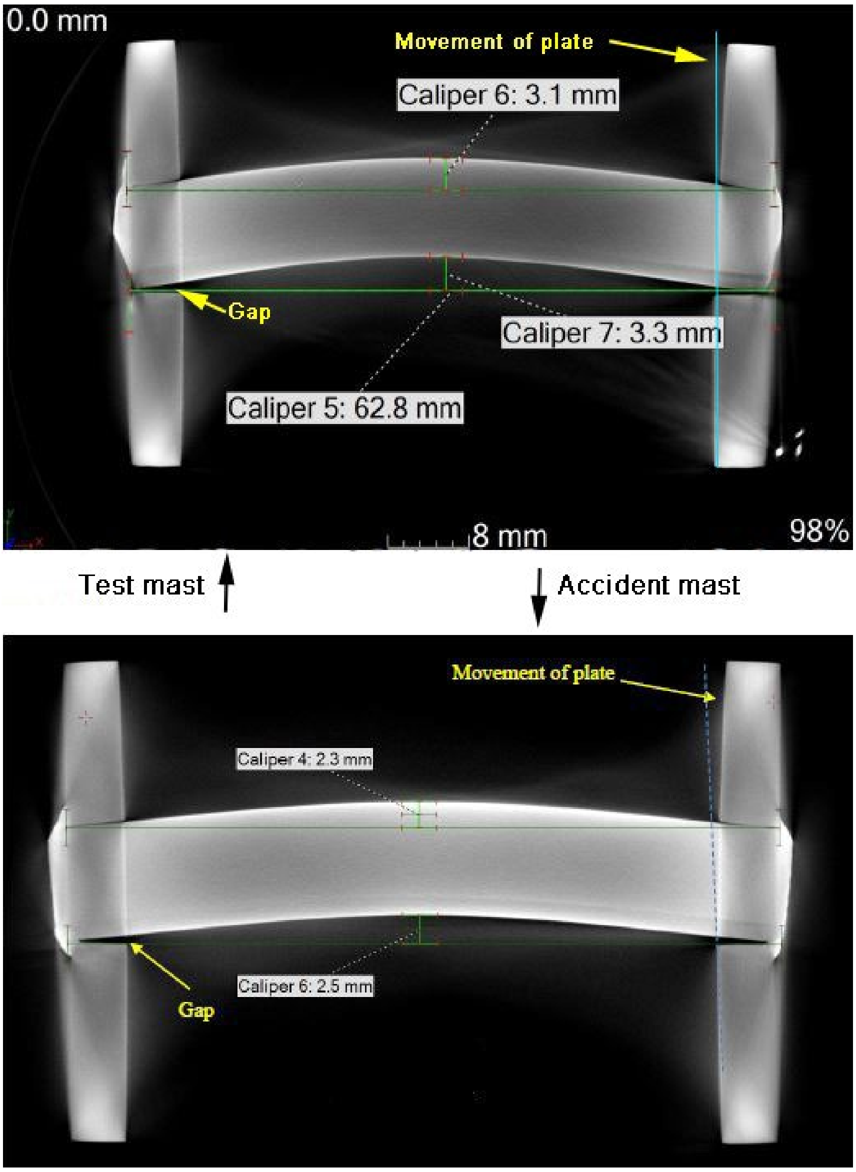


Figure 31

Plastic deformation of the roll stop bar post-test (top)
compared with the accident mast (bottom)

The gimbal block had also failed in a similar manner to the accident block, though as the force applied was only in the horizontal plane, only the vertical cracks were present. However, they were located in the same positions and had progressed to similar extents. Figure 32 shows this by highlighting the same cracks with the same-coloured arrows. It also shows the identical indentation marks and distortion left on the side of the channel by the roll stop bar.

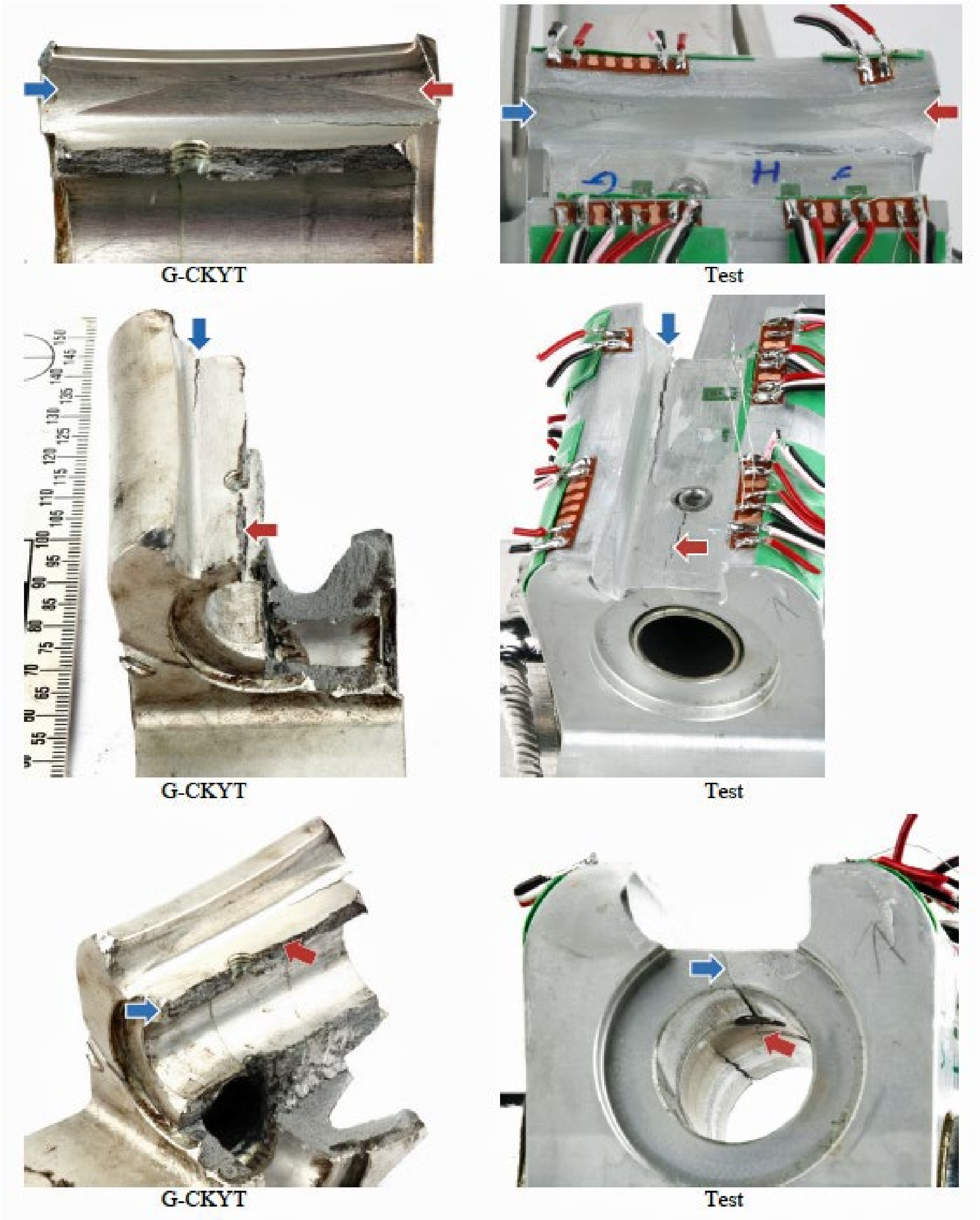


Figure 32

Cracks in the gimbal block post-test compared to the same cracks seen on the accident gimbal block

The brackets holding the gimbal block to the test rig had also deformed in a similar manner to the ones from the accident, with the same elongation of the bolt holes. The brake block assembly also showed the same rotational distortion.

Load analysis

Assessment of the load at which the damage occurred to each component was calculated based on the data from the strain gauges. The roll stop bar started to plastically deform under a moment or torque of 300 Nm. A theoretical calculation for the bar material shape and strength indicated that a simply supported beam (not fixed at either end) would start to yield at a load of 7.7 kN or 140 Nm of torque in this application. This demonstrated that the welds restrained the bar to some extent. However, the theoretical calculation for a fully supported beam (completely held at both ends) shows it would have sustained 90 kN or 1,620 Nm before it yielded in plastic deformation.

The indentations formed on the side of the gimbal block channel where the roll stop bar was in contact with it, resulted from a torque of 1,500 Nm or an 83 kN load being applied. Due to the distortion of the bar, this was effectively transmitted as a point load of approximately 41.5 kN on each end of the roll stop bar. If this load was applied to the gimbal block material with a Brinell Hardness test indenter, it would result in spherical dents of diameter 7 mm. The sizes of the indentations on the gimbal block were 5 mm at the forward end and 6 mm at the aft end. This shows a similar order of magnitude. The difference in size can be explained by the fact that the bar was continuing to bend under load, resulting in the maximum point of stress continuously moving and the load increasingly acting tangentially to the block, unlike the indenter which applies a constant, perpendicular load. The widest parts of the indentations on the accident gimbal block were obscured by secondary damage, so it was not possible to do a direct comparison.

The gimbal block failed at an applied load of 83 kN during the test. A theoretical calculation based on the material thicknesses at the crack locations and the quoted Ultimate Tensile Strength (UTS) of the material, suggest that this load should have been 91 kN or 1,642 Nm. Possible reasons for the discrepancy are:

- Features of the gimbal block, such as the grub screw hole acting as a stress raiser.
- A reduction in the UTS due to the material grain orientation used in the gimbal block.[19]
- The radii of the gimbal block corners acting as stress raisers.

Test conclusion

The results from the test showed that the load transfer through the gimbal block was quite complex, but that the test closely replicated the damage to the gimbal block retrieved from the wreckage of G-CKYT. Although only torque loads transferred through contact between the mast roll stop bar and the gimbal block were applied during the test, the damage seen on the gimbal block, support plates and mast, demonstrated that this contact had also occurred during the accident sequence.

Footnote

[19] The gimbal block is extruded aluminium, which gives a longitudinal grain orientation. The maximum UTS is achieved in this direction. In the transverse direction (90° to the grain) the UTS typically reduces by 15-20%.

Analysis

Physical and eyewitness evidence confirmed the rotor head of G-CKYT separated in flight, causing the fuselage to fall to the ground in a non-survivable accident. The impact resulted in a post-crash fire, following ignition of the highly flammable fuel released by the disruption of the fuselage structure. The investigation centred on determining the cause of the separation.

There was no evidence of the pilot suffering any in-flight incapacitation. He had already completed two flights that morning, the preceding flight lasting over an hour. Despite this, the student had rested between flights and had not displayed any signs of fatigue to his instructor.

The instructor assessed the weather conditions as suitable for the student's solo flights, with only light winds along the runway at Inverness Airport. The instructor regarded winds aloft to be 'not challenging' while the Met Office described the conditions as 'benign' in their aftercast. The possible temporary increase in wind speed reported in the TAF was not due to occur until after the student's return. The forecast wind speed aloft was not considered a problem by the instructor who had considerable experience operating in the area. The student had made no adverse comments on his return from his previous flight, not long before, and there was no evidence of the conditions causing him a problem. The pilot of the aircraft that had flown through the same area as the gyroplane over Black Isle only shortly before the accident, and at a similar altitude, had also reported smooth flying conditions.

Due to the disruption caused by the impact, it was not possible to determine whether the ballast had shifted during the flight. Equally, it was not possible to determine whether during the accident sequence the pilot had reverted to fixed wing flying techniques. Whilst both are possible, it is considered that these and the other operational factors are unlikely to have directly contributed to the accident.

The investigation determined the aircraft had been correctly released to service with no contributory maintenance issues identified.

Gimbal block failure sequence

A rig test conducted by the investigation applied a load to the left side of the gimbal block roll stop channel, by rotating the mast about the roll pivot bolt until the roll stop bar pressed against it. As the force with which the bar pressed against the gimbal block was increased, the welds locating the roll stop bar in the mast side plates failed. This allowed the ends of the bar to move, which meant the roll stop bar now started to bend. As a consequence of this change in shape, the loading on the gimbal block changed from being evenly distributed along the length of the roll stop bar, to being focussed on the two contact points at each end. This significantly concentrated the load, resulting in indentation marks forming in the aluminium of the gimbal block. As the load continued to increase, cracks started to form in the block and at a load of 83 kN (1,500 Nm torque applied at the mast) the block was no longer able to resist the applied force.

Laboratory analysis of the failed rotor head components identified very characteristic damage to the gimbal block, including indentations and distortion on the left side (looking forward) of the roll stop channel and vertical and horizontal fractures through the body of the block. Detailed inspection of these fracture surfaces confirmed they were caused by continuous overload from an applied force greater than the UTS of the material. The roll stop bar on the mast was also distorted and the welds attaching it to the mast side plates had failed on both sides. In addition, the support brackets between the block and bridge, and those which held the brake block, showed twisting deformation resulting from a torque load.

The damage to the gimbal block and mast from the test closely matched that seen on the accident gimbal block and mast. The differences were considered to be due to the fact that the test was stopped before complete fracture of the block (for safety reasons) and that only the torque (or rotational) load component from contact between the mast roll stop bar and the gimbal block was applied during the test.

The indentations, deformation and fracture damage seen on the gimbal block, the twisting deformation of the support plates, and the deformation of the mast support plates, welds and roll stop bar, all demonstrated that the same contact between the roll stop bar and the gimbal block had occurred during the accident sequence. The damage also demonstrated that the resulting loads had been the likely cause of the vertical crack features seen on both the accident and rig test blocks.

While there would almost certainly have been a difference in the rate at which the load was applied between the accident flight and the rig test, this would not have affected the response of the material and as such could be discounted.

In flight, the gyroplane fuselage hangs from the roll pivot bolt fitted to the gimbal block. This also applies a vertical component to the force on the gimbal block equal to the weight of the fuselage (Figure 33). The damage to the accident gimbal block showed both vertical and horizontal fracture surfaces, with the vertical cracks occurring first, as seen in the rig test. Analysis of the fracture surfaces confirmed the overload had occurred during a single continuous event. As the cross-sectional area of the block carrying the weight of the fuselage was reduced by the vertical cracks during the accident flight, the horizontal cracks also formed due to overload. These cracks joined together resulting in a section of the gimbal block breaking off (Figure 33), allowing the rotor to detach from the fuselage. The separation of the rotor head was therefore caused by a structural failure of the gimbal block from exposure to dynamic flight loads during a single event.

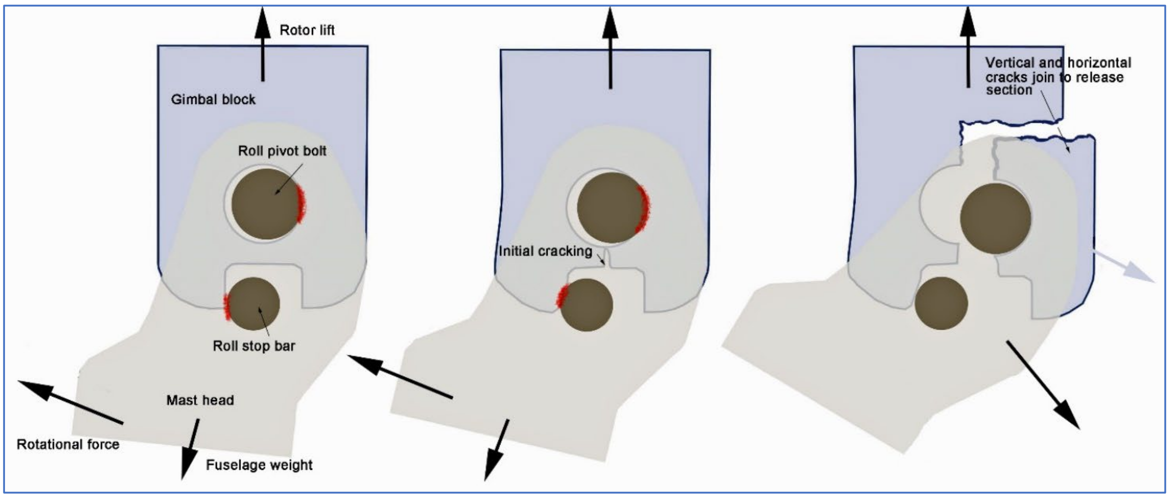


Figure 33

Simple illustration of the final failure sequence of the gimbal block

Flight sequence north of Avoch

The student performed a turn north of Avoch prior to tracking towards Munlochy Bay. Radar data from the previous flight also shows that the student performed a number of orbits both to the left and right throughout the flight.

The turn north of Avoch was at an estimated bank angle of 30° which was considered by the instructor to be a *'normal'* turn. However, during the turn, the airspeed fluctuated between approximately 50 and 92 mph and the altitude reduced by 193 ft. Vertical speed also fluctuated, reaching up to 1,000 ft/min and, as the turn was completed, the aircraft was descending at approximately 500 ft/min with an increasing airspeed.

This indicated that the student was having difficulty keeping the aircraft level and at a constant airspeed, which may not be considered unusual for a student pilot. However, his training record did not indicate that he had a history of issues with the accuracy of his flying, and it is possible that the student may not have been attempting to maintain specific parameters as closely as might be the case with an instructor on board.

Flight sequence leading to failure

The wreckage trail identified an approximate point by which time the rotor head must have already detached from the mast. This was around the time when the recorded data recovered from the GNSS became unreliable.

Immediately prior to this, the student pilot had performed a turn which started at an estimated bank angle of 35-40° to the left, but then increased up to approximately 45°. From the instructor's comments, 45° was considered to be a *'steep turn'.* While the bank angle was an estimate, it confirms this turn ended steeper than the earlier turn to the right over Avoch and likely required the application of significant backstick to prevent the nose dropping. This would have increased drag, requiring more engine power to maintain height, probably close to full power. These inputs required coordination to achieve a level turn.

The instructor had not explicitly briefed the student to use only up to 30° angle of bank and had formed the expectation that he would limit himself to this. The instructor believed that this limitation was implicit in his briefings to '*fly around the Black Isle*' to gain more experience of handling the gyroplane.

During the final left turn, the recorded data shows that the student pilot had allowed a rate of descent to develop in the initial part of the turn, which was then reversed to a moderate climb. As the turn continued, the vertical speed in the climb reduced, possibly due to the student pilot relaxing the back pressure on the control stick in anticipation of rolling out of the turn.

Just before the structural failure, the aircraft rolled from a left turn directly into a right turn which would have resulted in the fuselage starting to swing from the right to the left (viewed from behind). By this stage, a recorded instantaneous rate of descent of nearly 1,500 ft/min had developed which was above the rate by which the student would have previously recovered during training and by which the instructor would have expected recovery action to have been taken.

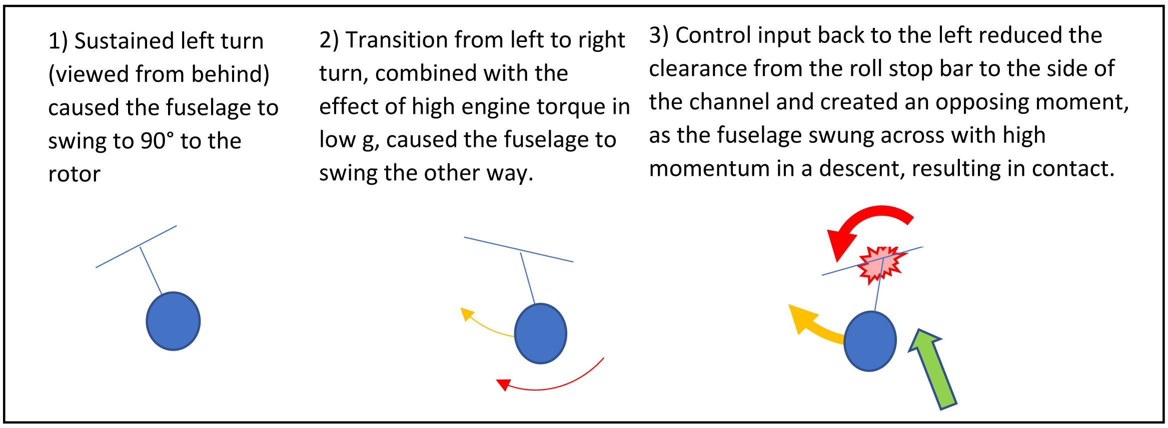
The student's training record indicated that he actively participated in the training feedback process and demonstrated an awareness of the importance of flying within the POH guidance. A level turn, if flown accurately, should not in itself have been hazardous and there was no evidence to suggest the student would deliberately choose to enter a manoeuvre that would result in a high descent rate or low g. It is therefore considered likely that the sequence of manoeuvres inducing a high rate of descent was an inadvertent result of the pilot's difficulty in maintaining a level turn.

The recorded rate of descent continued to increase, reaching approximately 3,200 ft/min two seconds later; a higher descent rate than would be achievable in normal operation. Given the final position of the fuselage, the recorded track data and the limitations in rate of descent achievable for an intact Cavalon, the investigation determined that the very high rate of descent seen in the data, if accurate, most likely occurred after the rotor became detached.

Failure sequence

It was not possible to determine the exact point of failure of the rotor head but, based on the recorded data, from 1249:43 hrs onwards the vertical acceleration was decreasing below 1 g as the aircraft rolled from the left into the right turn. The combination of reducing bank angle and reducing vertical acceleration identified by this analysis suggests that the rotor head was unloaded enough for a few seconds as the pilot transitioned between left and right roll manoeuvres to initiate the sequence of reactions which likely resulted in critical contact between the gimbal block and the roll stop bar. Though not identical, given the variation in assumptions used, the accident sequence was consistent with the DLR's theoretical modelling. This demonstrated that even with vertical accelerations above '*near weightless'*, the torque from an engine at high power causes an induced rotation of the fuselage clockwise about the roll pivot bolt to the extent that there is insufficient roll authority to correct it.

When the gyroplane transitioned between the left and right roll, the fuselage would have swung across with significant momentum. The torque induced rotation of the fuselage would probably have felt to the pilot like an uncommanded roll to the right, likely triggering an instinctive left roll input to counter it. This input would have changed the angle of the rotor relative to the horizontal. The lift and gyroscopic force and the weight of the rotor assembly opposing it effectively acts at the rotor pivot bolt which is a fixed distance away from the roll pivot bolt. The gyroscopic forces, the horizontal component of the lift and the weight vector would therefore create a moment around the roll pivot bolt and thus the contact point between the gimbal block and the roll stop bar. This would act to oppose the moment created by the fuselage rotating in the opposite direction, driven by the engine torque and inertia. This would likely have resulted in an impact between the bar and the gimbal block channel sufficient to generate the force required to cause the block to fracture, as confirmed during testing (Figure 34).


1) Sustained left turn (viewed from behind) caused the fuselage to swing to 90° to the rotor

2) Transition from left to right turn, combined with the effect of high engine torque in low g, caused the fuselage to swing the other way.

3) Control input back to the left reduced the clearance from the roll stop bar to the side of the channel and created an opposing moment, as the fuselage swung across with high momentum in a descent, resulting in contact.

Figure 34

Response of the fuselage to the roll reversal inputs

Blade flapping

It is possible under very low to zero g conditions that the rotor rpm can reduce to the extent that blade flapping occurs leading to contact between the blades and the teeter stop as the blade flaps downwards on the retreating side. If this is allowed to continue it can reach the stage where loss of control of the rotor head occurs. However, this level of blade flapping is more typically experienced on the ground when the rotor rpm starts off low before decaying further.

There were superficial marks on the accident rotor blades showing that contact with the teeter stops had occurred, however they were different on each blade which is inconsistent with blade flapping and there was no plastic deformation of the blade surface, or the teeter stops. They were, however, consistent with other damage on the blades which occurred as they hit the ground following release from the gyroplane. Given that rotor rpm increases during a steeply banked turn, and the period of low g in question was very brief, it is also unlikely that it had reduced sufficiently as the rotor unloaded to make blade flapping a factor in this accident. This is reflected in the DLR modelling which shows that even over a period of 8 seconds below 1 g and reducing to a minimum of 0.3 g, the rotor rpm does not drop outside of the normal operating range. As with normal operation the forces generated by the rotor react through the rotor pivot bolt without requiring contact of the teeter stops.

Roll stop bar welds

The manufacturer stated that the roll stop bar and gimbal block were not intended to come into contact in flight and as such the welds on the roll stop bar were not designed to carry any significant load. However, the welds inspected were generally of poor quality with regard to size, shape and consistency. The design drawing for the mast assembly specified a fillet weld, but did not specify the throat size of the weld required. As such, there was no consistency in the strength of the weld and no easily measurable quality inspection criteria which could be applied to the welds during production without conducting x-ray inspections[20]. None of the welds inspected on the accident or test mast met the basic requirements for the definition of a fillet weld and could not meet the minimum fillet weld throat size recommended by the European welding standards, because the roll stop bar length was specified to be too short by the design. The roll stop bar on the mast supplied for testing did not meet the drawing requirements for the bar length and the production process required part of the weld to be intentionally machined away to accommodate the washers on the roll pivot bolt, further reducing its strength.

While not causal to the accident, a key element of the failure sequence of the gimbal block was the failure of the welds holding the roll stop bar in position. Rather than being structural welds, they effectively just located the bar in position and failed under a relatively low load. Theoretical analysis showed that had full strength welds been used, they would have remained intact under a much greater load, the roll stop bar would then not have started to deform at a low load, maintaining an even distribution in the load transferred to the gimbal block and allowing the combined structure to support a load greater than that which failed the block in the practical test. While it was not possible to determine the exact load that was experienced by the gimbal block and mast during the accident, it can be stated that had full strength welds been present, the capacity to withstand contact loads between the gimbal block and the roll stop bar would have been greater, providing an increased safety margin in the event of unintended contact.

Contact between roll stop bar and gimbal block in flight

The conical impressions on the side of the gimbal block channel resulting from contact with the roll stop bar seen on the accident block, had also been seen previously in several takeoff accidents on this gyroplane type. Although the reasons for contact in these scenarios were different from the accident flight, it appears the consequences of the contact were not investigated any further. The manufacturer stated that contact was not intended to occur in flight and as such there was no requirement to consider it or design the structure to be strong enough to resist it. This approach is supported by the wording of the relevant certification requirement T675, which only requires the control stop to withstand loads intentionally applied by the control system design.

Footnote

[20] X-ray inspections were not used as part of the production process.

Roll control inputs under normal circumstances are small and within the 8° of clearance available. Equally under normal rotor load factor (≥1) the fuselage would rotate perpendicular to the rotor in a turn, maintaining the clearance rather than being subject to engine torque induced rotation in the opposite direction. This investigation showed that there is a transition point where contact can result. The lack of any previous record of other complete failures of the gimbal block would suggest the degree of contact between the roll stop bar and gimbal block which resulted in the accident was unusual.

Contact between the gimbal block and roll stop bar whilst airborne was not considered during the design of this type of rotor head. A minimum threshold force is required to leave a permanent impression in the gimbal block material if contact does occur. There is no inspection requirement in place to capture in-flight contact events, and inspection of the gimbal block is only routinely conducted after a ground contact. Damage to the gimbal block, if found during generic maintenance, would likely result in the gimbal block being rejected. However, there are no specific inspection criteria in the maintenance programme, or as the result of an in-flight event, targeted at finding gimbal block damage, identifying and recording the fact it had occurred in flight. Thus, there is no record of the reason for replacement of damaged gimbal blocks that would provide supporting evidence on the frequency of in-flight occurrences. As such, there was no evidence available to the investigation, other than the accident flight, to confirm under what exact circumstances contact to any extent could occur in flight on gyroplanes fitted with the Rotorkopf III design. The small control angle range of 8° and the undamped, free rotation of the fuselage around the roll pivot bolt means that, other than through the actions of the pilot, there is nothing to prevent contact occurring. Yet there is no means of indicating to the pilot how much margin to contact remains, nor any warning for the pilot of when contact is occurring. The manufacturer stated that they did not design the mast and gimbal block interface to be able to withstand a specific contact force because they did not anticipate contact would occur in flight. However, there is no supporting data to assess what safety margin from contact (if any) is provided during flight within the approved envelope, what manoeuvres flown with what parameters could result in inadvertent contact, or what loads on the gimbal block could result from contact if it does occur. As such, it was not possible to assess whether the manufacturer's approach was reasonable.

Additionally, there is no specific requirement within BCAR Section T which addresses whether unintended control stop contact should be anticipated in flight nor what level of load the structure should withstand, if the possibility of unintended contact cannot be definitively excluded. Based on the evidence available to the investigation, it appears that the manufacturer's approach to the issue of contact has been accepted by the airworthiness authorities without comprehensive supporting evidence.

The investigation has determined that this accident likely resulted from a flight manoeuvre which was initially within the approved envelope of the gyroplane but then, likely inadvertently, resulted in a vertical acceleration of less than 1 g. This led to induced torque rotation from the engine which, combined with a reversal of the roll direction, resulted in catastrophic contact between the gimbal block and the roll stop bar.

The negative load factor element of the structural requirements was not demonstrated by test, but was based on a theoretical assessment of a simple assumed load path. Whilst the POH prohibits conducting low g manoeuvres, it doesn't specify the exact margin below 1 g where the risk of damage exists. The POH quotes structural limits of -1 g and -0.5 g but emphasises the need to respect the in-flight operating limits at all times. The in-flight limits are, however, not specific and refer only to 'low g' and 'near weightlessness'. This may lead a pilot to assume the stated structural limits provide a safe margin with regard to the risk of component failure. Operating within these limits also relies on the pilot's ability to assess g without reference to a suitable indication or warning system, neither of which are installed on the aircraft. The investigation found no supporting research data to determine how accurately a pilot can sense g values less than 1 g to support this approach.

Mitigation of risk of contact

There are typically three generic risk mitigation routes which are used within aviation, either individually or in combination. These are:

1. Operational limitations.
2. Structural design and testing.
3. A safety case based on probability of occurrence demonstrating a failsafe design.

Applying these to the specific issue of contact between the gimbal block and the roll stop bar would require the following:

1) Publishing evidence based, detailed and specific operational limitations, including an appropriate safety margin, which if observed will ensure damaging contact does not occur, and providing the necessary indication or warning system to ensure pilots can accurately operate within those limitations. This approach will also require a supporting training syllabus and guidance material to increase awareness of how to conduct approved manoeuvres within the published limits and the correct recovery techniques to avoid unintended exceedances.

2) Defining limit and ultimate loads for the gimbal block and mast, using an appropriate safety factor and based on the highest dynamic loads which can be encountered from any level of contact between the roll stop bar and gimbal block resulting from manoeuvres within the approved flight envelope. This should take account of inadvertent contact which can be reasonably foreseen from conducting approved flight manoeuvres with a defined margin of handling error or inaccuracy. All components should be designed and tested to demonstrate that they meet these defined load requirements without permanent deformation in the case of limit load or without failure for ultimate load.

3) Compilation of a system safety assessment which demonstrates that based on supporting evidence the probability of occurrence of catastrophic contact between the gimbal block and the roll stop bar is extremely improbable and does not result from a single cause, and that hazardous contact is extremely remote.

However, option three is based on the common certification regulation 1309 found across both EASA and FAA certification requirements for fixed and rotary wing aircraft. It is typically used for assessing the reliability of system operation but can take account of the structural implications of a failure of that system. Given that there is nothing in the control system or operating limitations to prevent contact with the control stops and no supporting evidence that contact cannot occur under normal operation, such contact cannot be considered a failure of the system. Requirement 1309 is also not included or referenced in BCAR Section T. This effectively precludes option 3 as an appropriate mitigation in this case.

When this accident was discussed with the CAA, they stated that their preference was to avoid pilots operating in any flight phase where contact with the roll stops could occur. This is a valid approach to mitigate the risk of structural failure, but as highlighted in paragraph 1) above, it requires limits to be well defined, identifiable by the pilot in flight with relevant training provided.

The investigation recognises that this issue may not be unique to the Rotorkopf III rotor head and may affect a number of other gyroplane designs with a simple roll pivot rotor head design. However, as the accident occurred to a gyroplane fitted with the Rotorkopf III rotor head, a recommendation relating to this specific rotor head is appropriate. To ensure that actions to mitigate the risk of contact are both independently assessed as adequate and mandated where appropriate, the following recommendation is made to the UK CAA as the regulator responsible for continued airworthiness of all models of gyroplanes fitted with the Rotorkopf III certified under BCAR Section T.

Safety Recommendation 2024-017

It is recommended that the Civil Aviation Authority introduces mitigations to reduce, as far as reasonably practicable, the risk of a catastrophic failure resulting from contact between the gimbal block and the roll stop bar on all gyroplanes fitted with the Rotorkopf III rotor head and those of similar design.

In order to address similar risks which may exist in other gyroplane designs submitted for certification in the future the following Safety Recommendations is made:

Safety Recommendation 2024-018

It is recommended that the Civil Aviation Authority reassess the requirements and acceptable means of compliance in BCAR Section T for issuing approvals to gyroplanes, in light of the failure mode identified from the dynamic loading of the gyroplane rotor head in flight, to ensure manufacturers demonstrate to an acceptable level, through appropriate test and/or analysis, mitigation of the risk of catastrophic structural failure from dynamic loads in flight.

Pilot training and awareness

The investigation highlighted the criticality of pilot awareness of the load factor being applied to the rotor during all flight manoeuvres. Training is an essential element of building this awareness, however, the investigation also identified that there was no relevant guidance for gyroplane instructors and examiners in Standards Document 44. Therefore, to ensure standardisation of training delivery and examination of the subject of low g manoeuvres in gyroplanes, the following Safety Recommendation is made to the CAA.

Safety Recommendation 2024-019

It is recommended that the Civil Aviation Authority publishes guidance on the subject of rotor load factor during flight manoeuvres for the theoretical training and testing of pilots undertaking the gyroplane PPL syllabus and the gyroplane instructor and examiner qualifications.

Certification

G-CKYT was certified as a permit aircraft, which has the lowest level of airworthiness design validation and as such is subject to commensurate limitations on its operation. Given historical issues around the safety of gyroplane designs, for use in the UK, the Cavalon was required to comply with certification requirements specified in BCAR Section T. The introduction to BCAR Section T is clear that it is only intended for use in certifying permit aircraft, and this is reflected in the relatively simple specification and compliance requirements it contains. This was typified by structural requirement T337, which only required the consideration of limited vertical static loads and the use of a simple static test to demonstrate compliance. This contrasts with the testing and analysis which models the more complex real-world dynamic response and associated complex structural loads necessary to obtain a full type design approval under EASA CS-23 or CS-27.

However, in the case of the Cavalon Pro, BCAR Section T was also used as the basis for issuing a Certificate of Airworthiness, which allows the aircraft to be used for commercial work. This change in purpose normally increases the analysis and testing requirements imposed on a design and would typically be associated with more stringent and demanding certification compliance requirements. For the Cavalon Pro this did result in some additional compliance requirements added through CRI E-01, but structurally the Cavalon Pro is the same design as the basic Cavalon, and no additional compliance testing was required to certify it.

The manufacturer stated that they extensively compared the requirements in BCAR Section T with those of EASA CS-VLR, which is used to issue Certificates of Airworthiness on very light helicopters. The CAA and the manufacturer presented a case that a comparison with the requirements of EASA CS-VLR is a more appropriate benchmark, given the size and weight of the gyroplane. However, EASA CS-VLR is also a simplified airworthiness code used for certifying light helicopters which are primarily used for leisure and pilot training activities only. As the Cavalon Pro is intended for commercial use, a comparison with EASA CS-27 or CS-23 is considered more appropriate.

This accident demonstrated that catastrophic structural failure could occur from flight loads which are encountered inadvertently by the pilot, because such scenarios were not adequately defined and analysed during the certification process, due to the simplified requirements of BCAR Section T. The investigation considered that this represents a safety concern for aircraft intended for commercial operations. As such, the following Safety Recommendation is made:

Safety Recommendation 2024-020

It is recommended that the Civil Aviation Authority reassess the certification and acceptable means of compliance requirements for issuing Certificates of Airworthiness to gyroplanes intended to be used for commercial operations, to ensure manufacturers demonstrate, through appropriate test and analysis, mitigation of the risk of catastrophic structural failure from dynamic loads to a level comparable with equivalent Certificate of Airworthiness aircraft certified to design regulations such as Certification Specifications 23 and 27.

Component conformity

The investigation identified differences between the approved design drawing and components released for service on both the accident mast and the mast supplied by the manufacturer for testing. These differences related to the roll stop bar length and installation welds.

It is a fundamental airworthiness requirement that production parts conform to the drawing which defines the approved certification standard. Non-conforming parts must either be rejected by a manufacturing quality control inspection or have an appropriate production permit or concession documented before they are released to service. There was no evidence identified that either was the case for these components inspected as part of the investigation. The manufacturer responded that they did not consider the issue to be an airworthiness concern.

As this finding was not determined to be causal to the accident, and was based on examination of only two masts, it was considered outside the scope of the investigation to assess whether non-conforming parts had been released to service and what airworthiness risk that may pose. Assessing the implications of this finding and any necessary mitigation falls within the oversight role of the relevant airworthiness authorities. For gyroplanes certified and manufactured to UK requirements, design and manufacturing oversight is the responsibility of the CAA.

Conclusion

The accident occurred when the gyroplane rotor head separated from the mast in flight. Forensic analysis of the failed gimbal block and mast confirmed that the separation was caused by a structural overload failure of the gimbal block from a single continuous exposure to dynamic flight loads.

Testing and analysis of a new production mast and gimbal block closely replicated damage seen on the accident mast and gimbal block, demonstrating that the same contact between the roll stop bar on the mast and the side of the channel on the gimbal block had occurred during the accident.

Factual evidence from the accident site and recorded data, together with engineering and operational analysis, allowed the investigation to identify that this contact sequence, and the loads resulting from it, most likely occurred because of the difficulty experienced by the student pilot in consistently flying a level turn to the left, followed by a reversal to the right. This inadvertently resulted in a vertical acceleration below 1 g, briefly unloading the rotor and allowing an unopposed rotation of the fuselage around the roll pivot bolt due to the torque of the engine.

Modelling and analysis have shown that contact with the roll stops can occur with this specific sequence of manoeuvres in a flight regime above the 'low g' or 'near weightlessness' limits defined in the POH.

The gyroplane was found to have been correctly released to service with no maintenance issues identified relevant to the accident. A number of operational factors were considered and it was likely that the pilot inadvertently allowed the aircraft to enter a low g flight regime close to, or potentially exceeding, that prohibited by the Cavalon POH.

Whilst fully compliant with BCAR Section T regulations, the accident highlighted limitations in the design, testing, manufacture and operating limitations for the Cavalon and Cavalon Pro gyroplane types. These limitations are also likely to be relevant to other gyroplane types certified to this standard. The investigation also highlighted issues with the gyroplane training material regarding the awareness of rotor load factor by pilots. Four Safety Recommendations have been made to address these issues.

Safety Recommendations

Safety Recommendation 2024-017

It is recommended that the Civil Aviation Authority introduces mitigations to reduce, as far as reasonably practicable, the risk of a catastrophic failure resulting from contact between the gimbal block and the roll stop bar on all gyroplanes fitted with the Rotorkopf III rotor head and those of similar design.

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It is recommended that the Civil Aviation Authority reassess the requirements and acceptable means of compliance in BCAR Section T for issuing approvals to gyroplanes, in light of the failure mode identified from the dynamic loading of the gyroplane rotor head in flight, to ensure manufacturers demonstrate to an acceptable level, through appropriate test and/or analysis, mitigation of the risk of catastrophic structural failure from dynamic loads in flight.

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Safety Recommendation 2024-020

It is recommended that the Civil Aviation Authority reassess the certification and acceptable means of compliance requirements for issuing Certificates of Airworthiness to gyroplanes intended to be used for commercial operations, to ensure manufacturers demonstrate, through appropriate test and analysis, mitigation of the risk of catastrophic structural failure from dynamic loads to a level comparable with equivalent Certificate of Airworthiness aircraft certified to design regulations such as Certification Specifications 23 and 27.

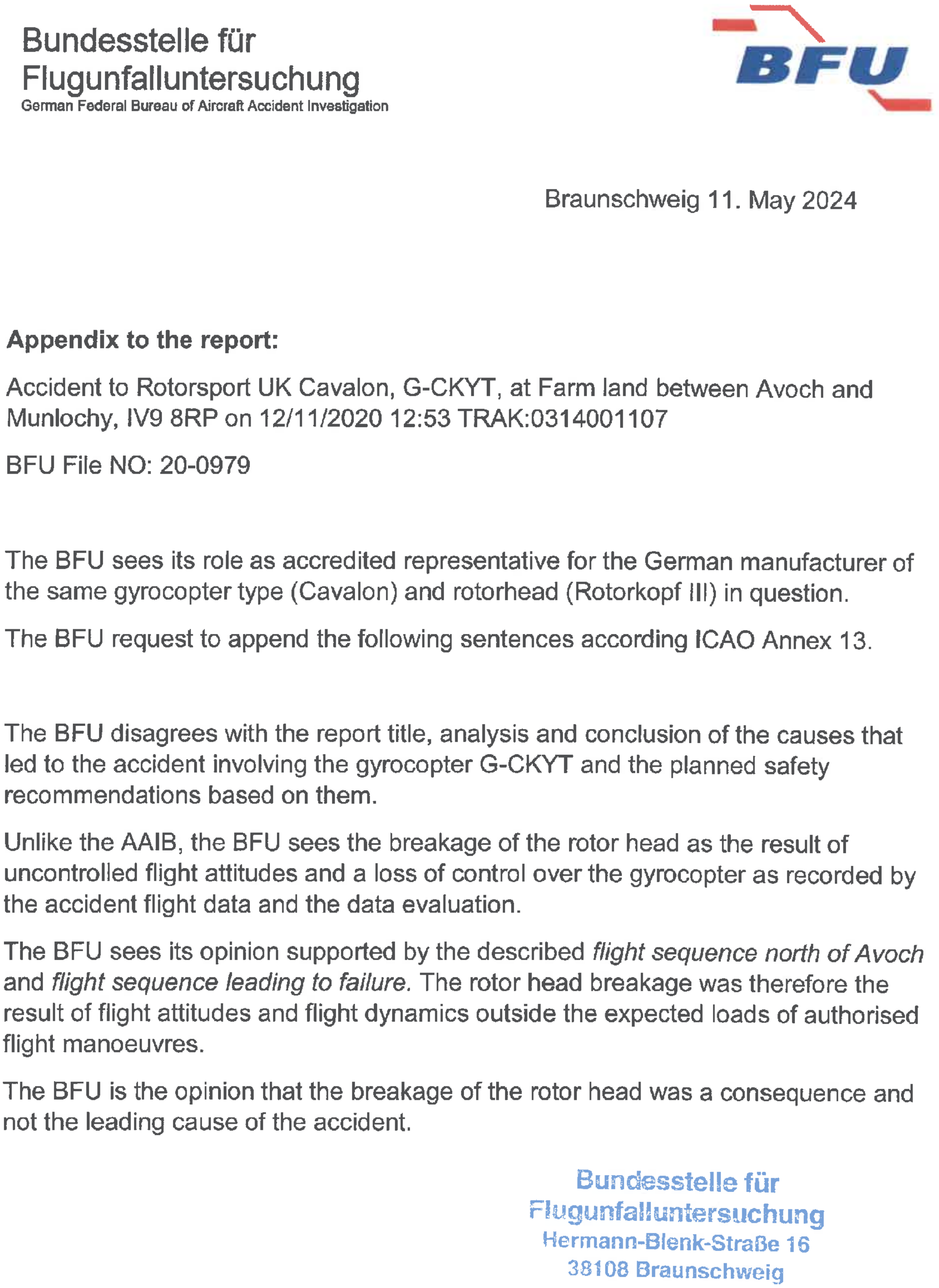
Bundesstelle für Flugunfalluntersuchung (BFU) comments

Standard 6.3 of Annex 13 to the Convention on International Civil Aviation provides that the State conducting the investigation shall send a copy of the draft Final Report to all States that participated in the investigation, inviting their significant and substantiated comments on the report as soon as possible. If the State conducting the investigation receives comments within the period stated in the transmittal letter, it shall either amend the draft Final Report to include the substance of the comments received or, if desired by the State that provided comments, append the comments to the Final Report.

The BFU, representing the state of design and manufacture, provided comment on the draft Final Report. The BFU Accredited Representative, stated that in their opinion the failure of the rotor was a direct consequence of a complete and unrecoverable loss of control of the gyroplane. As such, the flight loads which resulted in the failure were outside of the design requirements and neither the current design of the Cavalon nor the certification regulations require amendment as a result of this accident. They stated that in their opinion the loss of control of the gyroplane was a result of the actions of the pilot.

Several adjustments were made to the report as a result of comments received during the consultation process. However, the investigation did not find evidence indicating a complete and unrecoverable loss of control before the catastrophic failure of the rotorhead, and so this point of disagreement is appended to the Final Report.

Appendix - BFU statement



Bundesstelle für
Flugunfalluntersuchung
German Federal Bureau of Aircraft Accident Investigation

Braunschweig 11. May 2024

Appendix to the report:

Accident to Rotorsport UK Cavalon, G-CKYT, at Farm land between Avoch and Munlochy, IV9 8RP on 12/11/2020 12:53 TRAK:0314001107

BFU File NO: 20-0979

The BFU sees its role as accredited representative for the German manufacturer of the same gyrocopter type (Cavalon) and rotorhead (Rotorkopf III) in question.

The BFU request to append the following sentences according ICAO Annex 13.

The BFU disagrees with the report title, analysis and conclusion of the causes that led to the accident involving the gyrocopter G-CKYT and the planned safety recommendations based on them.

Unlike the AAIB, the BFU sees the breakage of the rotor head as the result of uncontrolled flight attitudes and a loss of control over the gyrocopter as recorded by the accident flight data and the data evaluation.

The BFU sees its opinion supported by the described *flight sequence north of Avoch* and *flight sequence leading to failure.* The rotor head breakage was therefore the result of flight attitudes and flight dynamics outside the expected loads of authorised flight manoeuvres.

The BFU is the opinion that the breakage of the rotor head was a consequence and not the leading cause of the accident.

Bundesstelle für
Flugunfalluntersuchung
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38108 Braunschweig

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