**ACCIDENT**

| | |
|---|---|
| **Aircraft Type and Registration:** | RAF 2000 GTX-SE, G-REBA |
| **No & Type of Engines:** | One Subaru EJ22 piston engine |
| **Year of Manufacture:** | 2001 |
| **Date & Time (UTC):** | 1 June 2006 at 0927 hrs |
| **Location:** | West of Simon's Stone, Colliford Lake, Bodmin Moor, Cornwall |
| **Type of Flight:** | Private |
| **Persons on Board:** | Crew - 1 Passengers - None |
| **Injuries:** | Crew - 1 (Fatal) Passengers - N/A |
| **Nature of Damage:** | Gyroplane destroyed |
| **Commander's Licence:** | Private Pilot's Licence |
| **Commander's Age:** | 69 years |
| **Commander's Flying Experience:** | 242 hours (of which 191 were on type)<br>Last 90 days - 5.4 hours<br>Last 28 days - 1.5 hours |
| **Information Source:** | AAIB Field Investigation |

**Synopsis**

The gyroplane was being flown to Bodmin Airfield in Cornwall by the pilot who was also the owner and builder. Approximately 2.8 nm north-east of Bodmin Airfield at a height of about 450 ft agl, the main rotor blades stopped. The gyroplane fell to the ground fatally injuring the pilot. The main rotor blades had contacted the vertical stabiliser, propeller and rudder.

Test flying was conducted by the UK CAA identified undesirable handling characteristics of the RAF 2000. As a result the CAA has published Mandatory Permit Directive MPD 2006-013, restricting operation of the type.

The investigation has identified an undiagnosed medical problem, pre-impact mechanical interference of the control runs and undesirable handing characteristics of the gyroplane, but has not identified the precise cause of the accident. However any combination of these factors could have caused the accident. Four Safety Recommendations have been made.

**History of the flight**

On the day of the accident a witness had also assisted the pilot with some maintenance of the gyroplane on the day before, he watched the pilot taxi his gyroplane on to the field and park it with the engine running. He could also see a golf bag and clubs in the right seat but could not tell if they were secured. He spoke to the pilot, who explained that he was going to Bodmin Airfield to meet some friends and then was going to play golf.

The pilot made a telephone call following which he boarded his gyroplane and taxied to Runway 04. He used the pre-rotator to increase the main rotor rpm and then departed normally from the runway making a left turn and climbing away to the south-west.

The weather was recorded at Exeter Airport at 0850 hrs as wind, 6 kt from 310º, visibility greater than 10 km with no cloud beneath 5,000 ft and no significant weather, temperature 15ºC, dew point 9ºC, sea level pressure 1030 mb. At the accident site, the police helicopter pilot recorded the 1,000 ft wind from a GPS navigation system as being 12 to 15 kt from 340º and the 2,000 ft wind as 20 kt from 360º. The weather was clear, the surface temperature was 20ºC and there was no significant turbulence.

Shortly after departure from Watchford Farm, the pilot contacted the Exeter Approach controller and informed her that he was at 1,500 ft. The pilot did not report any abnormalities and left the Exeter frequency at 0838 hrs.

The gyroplane tracked initially 260º passing to the north of Oakhampton before turning left on to a track of 240º for Bodmin Airfield. As far as could be established, and apart from two descents near local landmarks, the gyroplane maintained its altitude and heading until approaching Colliford Lake when it descended. It passed along the northern shore of the lake where witnesses estimated the height at between 100 ft and 200 ft, flying slowly. The pilot was clearly visible and returned the waves of some children. The witnesses saw the gyroplane make a gentle climb to the west towards Simon's Stone before losing sight of it. A number of witnesses working in the fields in the area of Deweymeads and Simon's Stone saw and heard the gyroplane pass overhead and estimated the height at approximately 300 ft to 500 ft. Descriptions of the engine noise varied; "normal at high power" was one description, and "intermittent, akin to an rpm limiter operating on a motorbike", was another.

About this time, the pilot contacted the AFISO at Bodmin Airfield. The RT was not recorded but the AFISO stated that the pilot reported that he was approaching from the east. The AFISO passed him the joining instructions for Runway 31 with a QFE of 1007 hPa which the pilot repeated back correctly. There was no indication of any difficulty or abnormality.

A witness walking her dog on Blacktor Downs some 1,100 metres from the accident site watched the gyroplane approaching from the east. It appeared to be maintaining height and heading and then "as if caught in a crosswind, the rotor blades came together above the gyroplane". The engine cut out at about the same time and the gyroplane dropped to the ground.

**Medical and pathological information**

Following a post-mortem examination, the pilot was found to be suffering from very severe coronary artery disease. The pathologist reported that:

> *'Coronary heart disease of this magnitude could potentially cause a number of symptoms ranging from chest pain and abnormalities in the heart rhythm through to collapse or even sudden death. The pilot had no past medical history of heart disease and had not complained of any symptoms which could be related to his heart; this however does not preclude the possibility of his having had a cardiac-related episode of*

*medical incapacitation in flight. Pathological investigation was unable to provide any evidence as to whether this had indeed occurred. However, if other strands of the investigation suggest that incapacitation was likely, then the degree of coronary artery disease identified at the autopsy certainly provides a possible mechanism for such incapacitation.'*

The toxicological analysis was negative; there was no evidence of drugs or alcohol in the pilot's body.

**Gyroplane description**

The RAF 2000 is a Canadian designed kit-built two-seat gyroplane of conventional layout with a pusher engine configuration. It is fitted with a two-bladed glass-fibre main rotor which turns in an anti-clockwise direction when viewed from above. The blades incorporate an aluminium spar. The rotor mast can be moved fore and aft in order to adjust the gyroplane Centre of Gravity (CG) to accommodate pilot weights of between 135 and 265 pounds.

The gyroplane was equipped with a Subaru EJ22 carburetted engine producing 130 horsepower, driving a three-bladed 'Warp Drive' carbon fibre propeller, which rotates, when looking forward, in an anti-clockwise direction. The engine operates on 91 to 93 Octane Mogas and the gyroplane is equipped with a fuel tank of 25 US Gallons capacity, giving an endurance of around four hours. The gyroplane has a maximum airspeed of 140 mph and a maximum cruise speed of 90 mph.

**Wreckage and impact information**

The gyroplane crashed on the edge of an area of marsh land to the West of Colliford Lake on Bodmin Moor (see Figure 1) and came to rest on its left side on a heading of 287º M. Ground marks indicated that the it struck the ground from a near vertical descent with some sideways movement to its left.

The left side of the gyroplane was extensively damaged, the fuel tank had ruptured and there was a strong smell of fuel in the area. There was localised damage to the leading edges of both main rotor blades. One blade was trapped under the engine and both blades were bent downwards along the majority of their length. All three of the propeller blades had broken off close to the hub.

Pieces of the canopy and items from the cockpit had been thrown forward by approximately 25 m on a heading of 211º M. A second wreckage trail consisting of the broken propeller blades and parts of the fin and rudder were found approximately 54 m to 150 m from the crash site. Most of the items were found between 90 m and 120 m on bearings of between 272º M and 316ºM to the gyroplane.

The pilot was sitting in the left seat and was secured by a four-point harness. The buckle of the harness had been forced open by mud penetrating the cockpit area; the position of the body indicates that this probably occurred after the gyroplane had lost most of its momentum. The right control column had been removed from the gyroplane and a set of golf clubs had been secured in the right hand seat by the lap strap. During the impact the golf bag had slipped through the belt and lodged in the area of the rudder pedals. A pair of golf shoes and a shoe horn were also discovered in the area of the right-hand rudder pedals.

**Flight Recorders**

There was no legislative requirement for a flight recorder to be installed.

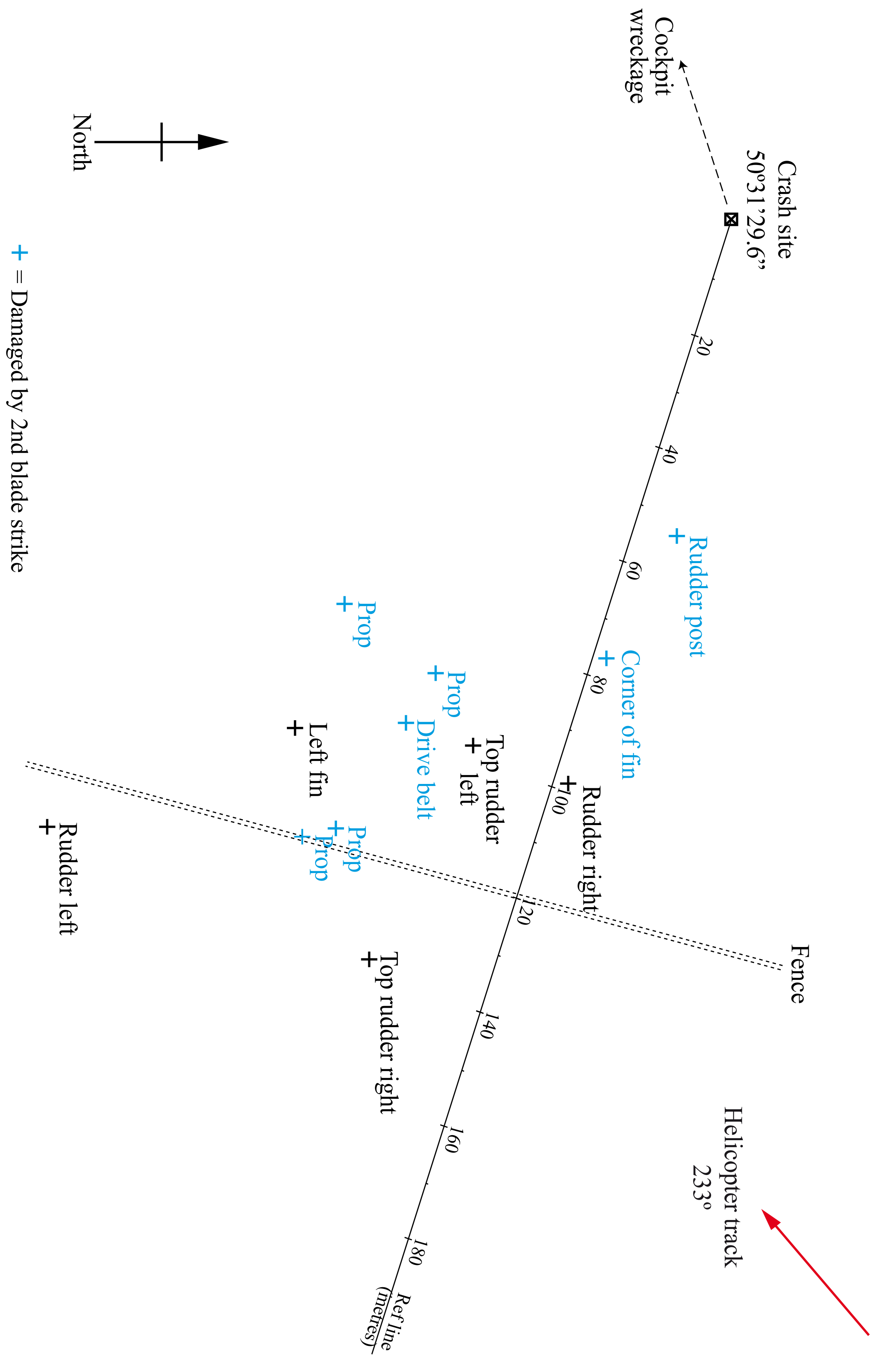


**Figure 1**
Wreckage distribution

*(a) Global Positioning System*

A Garmin International global positioning system (GPS), model GPSIII Pilot, was recovered from the accident site. Although the unit had sustained impact damage, (the display panel had been rendered inoperative by an impact to the bottom left corner) it was successfully downloaded at the AAIB. The download provided three track logs, the last of which was from the accident flight.

The accident track log consisted of 312 data points; a data point consisted of GPS time, GPS position and ground speed information[1].

The recording frequency of data points was dynamically controlled by the unit: if the aircraft speed and track remained near to constant the number of data points recorded per minute would reduce. Similarly if the rate of change of speed or track increased (outside preset limits which GARMIN advised are proprietary) the number of data points recorded per minute would increase.

*(b) Portable Data Assistant (PDA) GPS*

A PDA[2] with an in-built GPS receiver and a Secure Digital (SD) memory card were also recovered from the accident site. The PDA had suffered significant impact damage and could not be powered. The SD card contained a number of files, of which five were found to contain historical video footage of G-REBA and data files relating to a flight planning software utility[3] which was later confirmed as incorporating a track log recording function.

**Footnote**

1 Speeds were the average between two data points.
2 PDA with an integrated GPS. Manufactured by MiTAC, model number A201.
3 Pocket FMS.

With the assistance of the software manufacturer it was confirmed that the PDA had been operational during the accident flight and sections of a track log were eventually recovered[4]. The track log consisted of data points being recorded once per second, with each data point containing GPS time, GPS position, ground speed and GPS height[5].

*(c) Radar data*

Primary radar data was available from the Burrington Radar site. The system recorded time stamp and positional information every eight seconds. In the event that no primary return was available, a data point with time stamp only would be recorded. No altitude data was recorded as Mode C equipment was not installed on the aircraft. The last data point recorded was approximately 790 m from the accident site.

*(d) GPS data*

The data indicated that the aircraft had flown a distance of 62.6 nm and the GPS calculated average speed was 55.3[6] kt. Data points were on average recorded every 13 seconds with the aircraft travelling about 360 m between each data point. Table 1 details the final 12 data points recorded by the GPS. During the final three data points rapid changes in groundspeed can be observed.

**Footnote**

4 The complete track log could not be recovered as some sections of the data had been overwritten by data from other software applications running on the PDA at the time of the accident flight. The Pocket FMS software manufacturer believed this may have been as a result of a problem in the operating system, but this could not be confirmed.
5 The track log also contained part of a vehicle journey to the airfield, prior to the flight. Through testing of the same model of PDA and verification of track log GPS height against Ordanance Survey spot heights along the car journey it was confirmed that GPS height data was referenced to mean sea level and at the points checked the difference was no greater than +/- 50ft.
6 Based on all data points so does not represent the average cruise speed.

| Date / time | Altitude | Distance between points | Time between data points (seconds) | Ground Speed (kts) | Track |
|---|---|---|---|---|---|
| 01/06/2006 9:10:37 | NONE RECORDED | 0.2 nm | 00:00:11 | 65.9 kt | 241º mag |
| 01/06/2006 9:10:48 | NONE RECORDED | 0.2 nm | 00:00:11 | 65.0 kt | 240º mag |
| 01/06/2006 9:11:01 | NONE RECORDED | 0.2 nm | 00:00:13 | 64.2 kt | 243º mag |
| 01/06/2006 9:11:14 | NONE RECORDED | 0.2 nm | 00:00:13 | 65.8 kt | 244º mag |
| 01/06/2006 9:11:29 | NONE RECORDED | 0.3 nm | 00:00:15 | 66.8 kt | 246º mag |
| 01/06/2006 9:11:43 | NONE RECORDED | 0.3 nm | 00:00:14 | 67.9 kt | 247º mag |
| 01/06/2006 9:11:55 | NONE RECORDED | 0.2 nm | 00:00:12 | 65.8 kt | 245º mag |
| 01/06/2006 9:12:06 | NONE RECORDED | 0.2 nm | 00:00:11 | 70.6 kt | 240º mag |
| 01/06/2006 9:12:22 | NONE RECORDED | 0.3 nm | 00:00:16 | 72.2 kt | 238º mag |
| 01/06/2006 9:12:26 | NONE RECORDED | 427 ft | 00:00:04 | 63.2 kt | 234º mag |
| 01/06/2006 9:12:27 | NONE RECORDED | 119 ft | 00:00:01 | 70.7 kt | 233º mag |
| 01/06/2006 9:12:30 | NONE RECORDED | 157 ft | 00:00:03 | 31.0 kt | 224º mag |

**Table 1**

*(e) Data from Portable Data Assistant (PDA) GPS*

The data contained in the PDA shows that the aircraft took off at about 0813 hrs on a heading of 060º. Shortly after takeoff, the aircraft made a left turn onto a heading of about 220º and climbed progressively to about 1,300 ft amsl. Figure 1 provides height, speed and terrain elevation below the track. The last data point was recorded at 0912:17 hrs, at which time the aircraft was about 370 m (0.2 nm) from the crash site. The ground speed was 73 kt and GPS height amsl was about 1,250 ft (about 450 ft agl). The average speed during the cruise phase was calculated at 63 kt.

The elapsed time between the last recorded GPS data point and PDA GPS data point was about 13 seconds. Figure 2 provides the two tracks overlaid on an OS map.

*(f) Track and topography*

If the aircraft track had been maintained, the aircraft would have passed almost overhead of Bodmin Aerodrome. Had the aircraft been maintaining the last recorded GPS height amsl, which was about 1,250 ft, the height agl would have been no less than about 500 ft before reaching Bodmin Aerodrome.

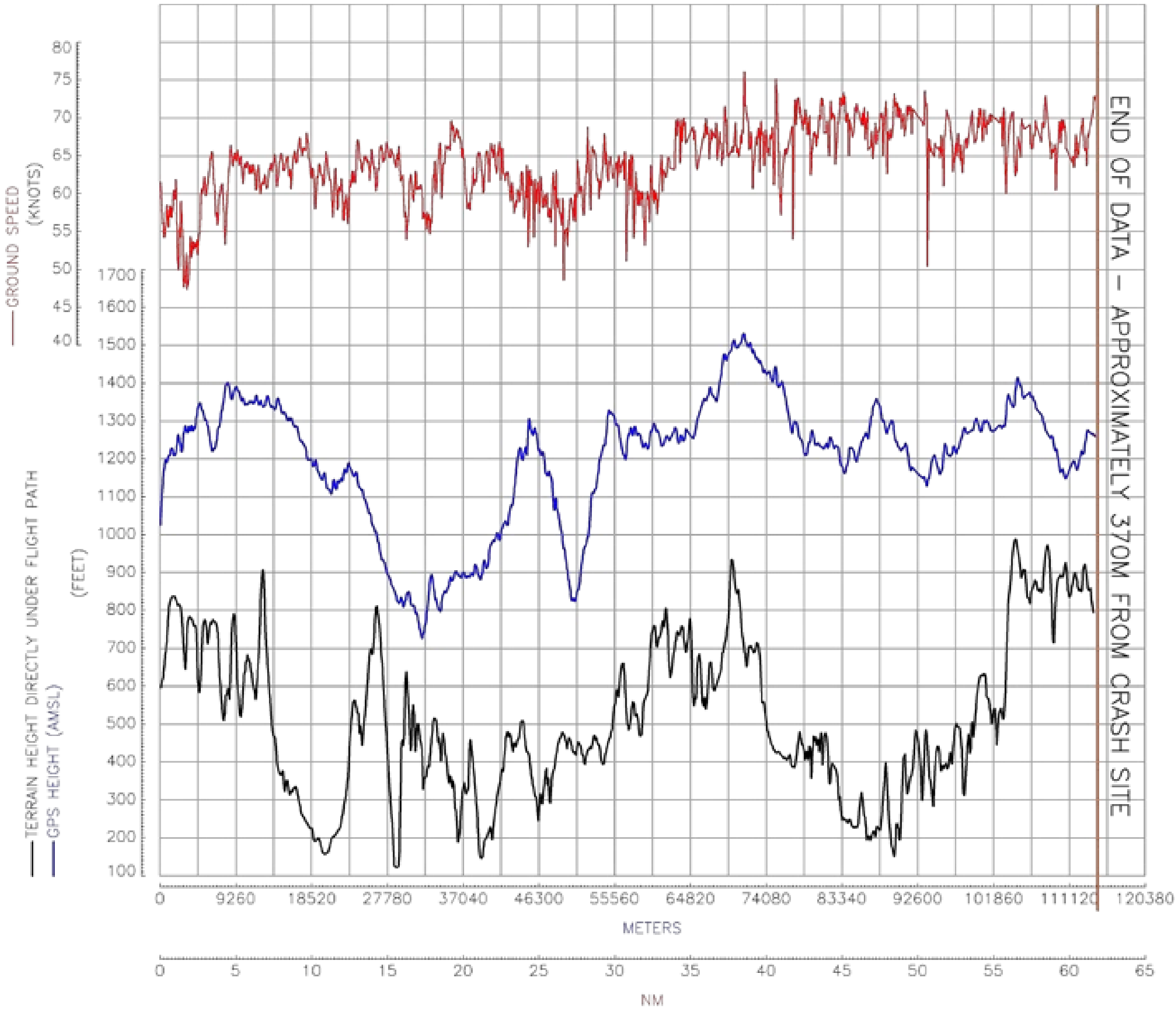


**Figure 1**

PDA GPS Data

**Detailed examination of the wreckage**

*1) General*

The cockpit area, fuel tank and fuel system were extensively damaged. The keel had failed 44 cm aft of the mast and the direction of the damage indicates that this occurred when the gyroplane crashed. The mast, which was bent and distorted to the right, had partially fractured 40 cm above the keel. With the exception of the pilot's right-hand lap strap securing bracket, which failed in overload, the remainder of the harness assembly remained intact. During the crash much of the structure was scratched and distorted. Deep abrasion marks were discovered on the engine frame, adjacent to the battery bay, but these might have occurred prior to the crash.

*2) Engine*

Fractures in the engine casing and distortion of the mounting brackets were all consistent with the engine

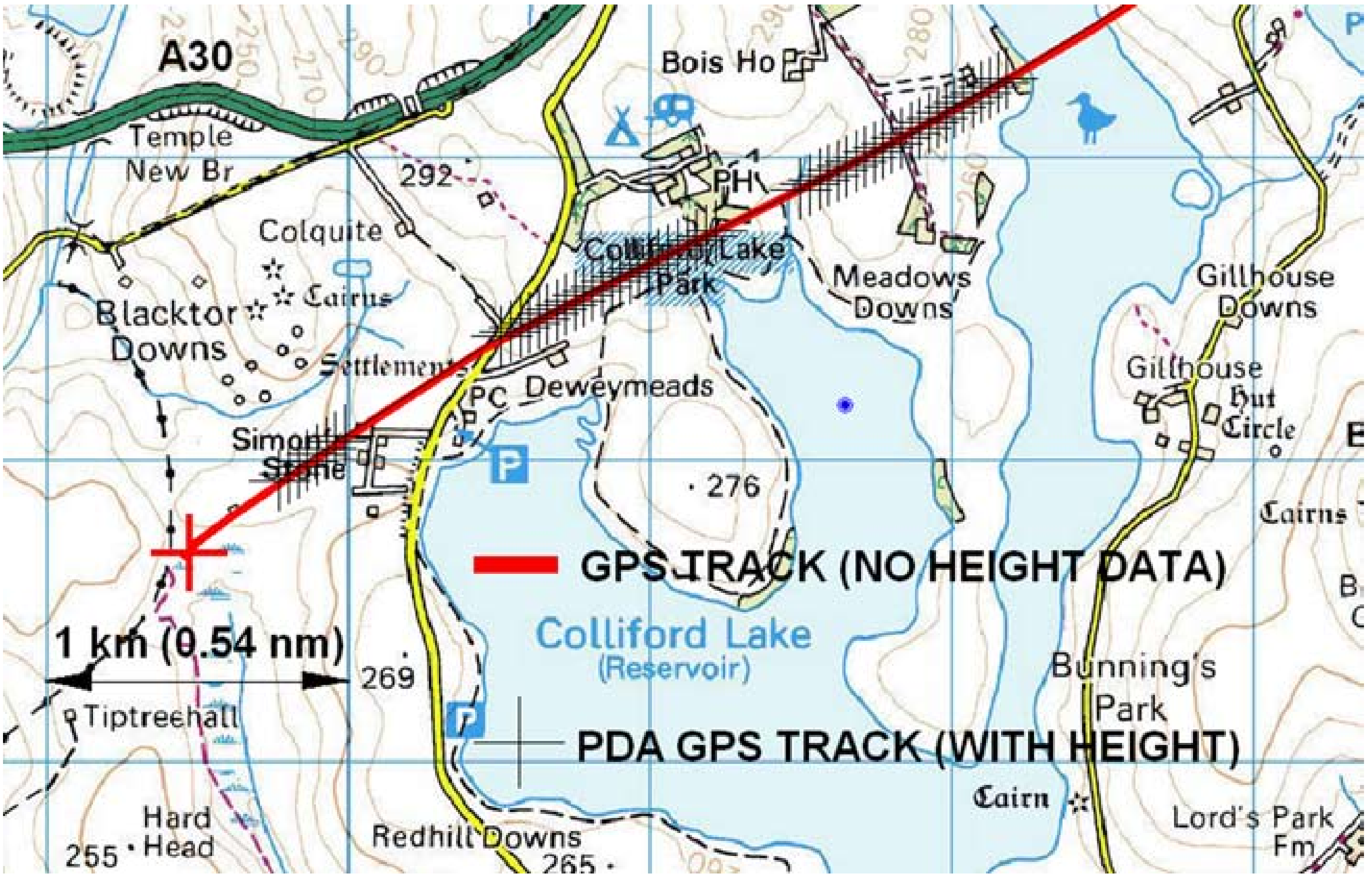


**Figure 2**

GPS and PDA GPS tracks

striking the ground. Whilst it was not possible to run the engine, it was possible to rotate the crankshaft and observe the movement of the internal components. Both cylinder heads were removed and the pistons were found to be connected and in good condition. The spark plugs were a light grey colour which indicated that the engine had been operating normally. The engine valves and pistons all operated normally and there was no evidence of seizing or overheating. The exhaust and induction systems appeared to be intact and the throttle control was still connected to the carburettor. The timing belt, which was still routed around the engine pulleys, had failed in overload. The overall assessment was that the engine had been in good condition and had been operating normally prior to the accident.

*3) Propeller blades and drive*

The drive belt from the engine to the propeller reduction gear had failed in overload but was assessed as being in otherwise good condition. All three blades had broken away from the hub and sections 50 cm, 52 cm and 30 cm long were found in the wreckage trail.

Reddish brown streaks were discovered along the leading edges of all three blades. These streaks glowed when exposed to ultraviolet light indicating that they were probably organic in nature and were most probably made by insects or vegetation.

*4) Flying controls*

The pilot's left rudder pedal had broken off and the right rudder pedal layshaft had popped out of the right mounting bracket, which had distorted during the impact. The rudder hinge rod, which was still connected to the cables, was distorted and had a dent similar to the profile of the leading edge of a main rotor blade at a position just above the upper hinge point. Continuity of the rudder cables was established between the rudder pedals and the rudder attachment point.

With the exception of the torque levers, continuity of the cyclic control was confirmed between the control column and the gimble activation arm. Both torque levers, which are mounted at the base of the mast, had failed at the point where the bolts secure the levers to the cross shaft (see Figure 4). The left lower control rod was badly bent during the impact and broke during the recovery of the gyroplane. At 34 cm from the bottom of the rod there were deep abrasion marks along the rod for approximately 40 mm. The lock nut on the lower fitting on the left upper control rod had been

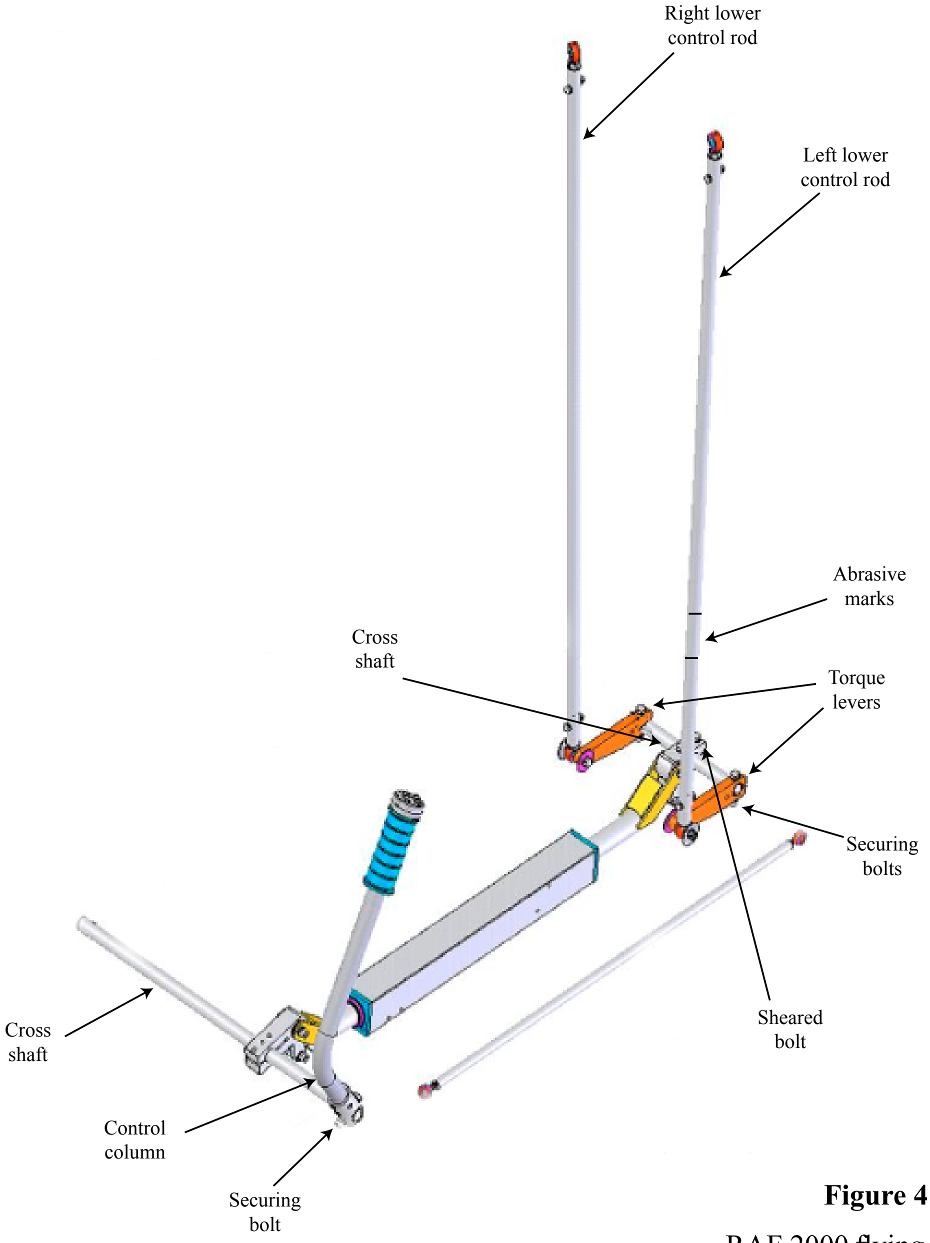


**Figure 4**

RAF 2000 flying controls

fully wound off and the fitting was loose. Abrasion marks were also discovered at 80 mm and 35 cm from the bottom of the right lower control rod. The lock nut on the fitting on the right upper control rod was found to be loose. The bolt used to secure the pilot's control column to the cross shaft had four washers between the column and the nut. The bolt which secured the torque lever to the cross shaft had failed in shear. Both trim springs were still connected to the control rods. The trim indicators were in the fully down position and the trim cables were unwound from the barrels inside the trim mechanism, so that there was no tension in the trim springs and no trim force applied to the control system.

*5) Rotor*

The rotor mast had been set at CG position No 3 and the upper portion of the mast was tilted backwards by approximately 4º in relation to the lower portion of the mast. The lower adjustable mast bolt was covered in a heavy layer of surface corrosion along its shank and it was difficult to remove the bolt. The mast and rotor assembly appeared to have been correctly assembled in accordance with the gyroplane build manual.

The rotor head was distorted and the main rotor securing bolt and pre-engage disc were bent. However, all the damage to the rotor system indicated that it occurred when the gyroplane crashed.

The blade pitch, as measured between the blade root and hub bar, was 5º for the black blade and 4.5º for the white blade. The hub bar was also found to be set equidistant between the teeter towers. A black indelible pen had been used to write '*6.34*' on the teeter tower, '*5.58*' on the hub bar adjacent to the white blade and '*5.54*' on the hub bar adjacent to the black blade.

*6) Rotor blades*

The metal spars on both blades were intact and there was localised damage to the leading edge of the blades. The position of damage to the rotor blades, designated white and black, was referenced to the distance along the blade from the rotor pivot point.

The white blade had bent upwards at a position 94 cm spanwise, and then bent downwards at 1.4 m. On the lower surface there were black carbon smears at 96 cm to 1.1 m and gold paint smears at 2.1 m to 2.7 m. There was also a single black rubber mark at 2.5 m. A small area of leading edge adjacent to the carbon smears had sustained some impact damage. A 30 cm length of the leading edge at 2.6 m was also damaged.

The inboard 1.7 m of the black blade had been extensively damaged as a result of the engine crushing it in the impact. At 2.16 m the blade started to bend downwards and on the lower surface there were black carbon smear marks at 82 cm to 93 cm and gold paint marks at 2 m to 2.3 m. There was evidence of some impact damage to the leading edge adjacent to the carbon smears and a small area of impact damage at 2.3 m.

*7) Rudder and fin*

The rudder, which had broken into four main pieces, and the upper third of the fin, were found in the wreckage trail. When the rudder and fin were reconstructed there was evidence that the tail section had been struck three times by the main rotor blades. The evidence consisted of a clean cut at the trailing edge of the top part of the fin; a shadow along the left side of the fin and an indentation along the rear wheel trailing arm.

*8) Golf bag*

The golf bag and shoes found in G-REBA were loaded into the right seat position on another gyroplane, which also had the control column removed, to establish if either the golf clubs or shoes could have fouled the flying controls. With the golf bag secured by the lap strap, and forced as close to the controls as possible, it was still possible to obtain the full range of movement of the controls. From the layout of the cabin it is likely that the shoes would have been placed on the floor behind the golf bag. In this position it is highly unlikely that in normal flight they would have been able to move to a position where they could have restricted the movement of the rudder pedals. The AAIB was later advised by an experienced RAF 2000 instructor that the fuel tank, which forms the base of the seats, was slightly different on G-REBA from the gyroplane on which the trial was undertaken. However, in his opinion the design of the tank on G-REBA would have meant that there would have been a greater clearance and, therefore, a lower probability that the golf bag would have restricted the movement of the controls.

**Previous accident**

On 24 April 2004, shortly after taking off, the same pilot and gyroplane clipped the top of a six foot hedge and, as a precautionary measure the pilot landed in the field immediately beyond the hedge. However the gyroplane landed heavily, the main rotor blades struck the ground and the gyroplane rolled over on to its side. An entry in both the engine and aircraft log book dated 18/9/04, and 134:45 airframe hours, stated *'Airtest of a/c. See aircraft worksheet 18/9/04. Permit maint release'.* Two worksheets with this date, both referenced 1 of 1, were provided to the AAIB with the gyroplane documentation.

One worksheet recorded the work required as *'EJ22 engine shock loaded during roll over. Crankshaft required to be replaced as per RAF manual.* The rectification block recorded that this work had been carried out and both the 'Eng' and 'Insp' signature blocks were signed by a PFA Inspector.

The second worksheet recorded the remaining work carried out to recover the gyroplane from the accident. On this worksheet the owner signed the 'Eng' and a PFA inspector the 'Insp' signature blocks for the following work:

*'Nose wheel replaced*

*Windscreen, right door and back panel replaced*

*Main mast & cheek plates replaced and assembled as per build manual*

*Control rods & gimble head replaced with new parts from RAF*

*All axel struts replaced with new from RAF*

*Main rotor & hub bar obtained from Newton Air Ltd*

*3 new warp drive blades installed'*

It is possible that in the accident, the load in the control rods and torque levers might have exceeded the design loads. Therefore the manufacturer stated that after being informed of the roll-over he provided the owner with a copy of Product Notice 37, which specifies the inspections and components to be replaced following an accident. The notice states that the *control system must be dismantled, the components inspected and all hardware must be replaced.* Whilst the owner subsequently ordered a number of parts, the investigation was unable to establish if he fitted new torque levers to the gyroplane. Whilst the Product Notice 37 is not specific, the manufacturer has advised that the torque levers are amongst the parts which should be replaced.

**Mandatory Permit Directive (MPD) 2006-003**

MPD 2006-03 was issued by the CAA on 24 March 2004 and required a number of components in the control system to be replaced in order to meet the requirements of British Civil Airworthiness Requirement (BCAR) Section T. Whilst there is no entry in the aircraft logbook to indicate that the modification had been embodied the manufacturer stated that they had supplied the owner with the modification kit in the month before the accident. A PFA inspector, who assisted the AAIB with the examination of the gyroplane, confirmed that the modified components were fitted on the gyroplane. Two days before the accident a witness was asked to assist the pilot by holding the control column whilst he replaced a part in the control system. The part was later identified as the torque lever cross tube, which was provided in the modification kit. A second witness stated that he spoke to the pilot the day before the accident when he briefly mentioned that he had recently completed a major modification, but the gyroplane was now flying slightly sideways and so he was going to make further adjustments to it. The second witness subsequently saw the owner taxi around the field and take off. The gyroplane had been put back in the hanger and the owner had left the airfield before the witness had the chance to talk to him again. On the day of the accident, the first witness spoke with the pilot before he departed for Bodmin and no mention was made of the modification or handling qualities of the gyroplane.

There was no documentation to indicate that the modification had been embodied, nor was the owner's usual PFA Inspector aware that the work had been carried out. Therefore there was also no evidence that a duplicate inspection had been carried out following embodiment of the modification. Moreover, it became apparent during the investigation that some other RAF 2000 owners did not realise that a duplicate inspection was required following embodiment of MPD 2006-03. Therefore, on the 14 July 2006, in AAIB Special Bulletin S6/2006, the following Safety Recommendation was made to the Popular Flying Association.

**Safety Recommendation 2006-087**

It is recommended that the Popular Flying Association takes the immediate steps to ensure that a Duplicate Inspection is carried out following the embodiment of MPD 2006-03 on the RAF 2000.

In response to this Safety Recommendation the PFA wrote to all RAF 2000 owners on 10 July 2006 reminding them that embodiment of MPD 2006-03 required a duplicate inspection. The letter also advised owners as to how duplicate inspections should be recorded and carried out.

**Tests and research**

*Gyroplane stability research by Glasgow University*

The stability of gyroplanes has been under investigation by Glasgow University, supported by the UK CAA, for at least 10 years. In a published paper (Houston, 1996) Professor S S Houston concluded:

> *'The vertical position of the centre-of-mass in relation to the propeller thrust line is of significant consideration in gyroplane longitudinal stability; ...the rotorspeed degree of freedom is strongly coupled with the 'classical' rigid-body modes of motion, in particular the phugoid; ...changes in phugoid stability, and therefore rotorspeed behaviour, may occur for configurations with main rotor thrust line passing close to the centre-of-mass....'*

*Power pushover*

Whilst the numerical analysis of gyroplane pitch stability is relatively recent, the gyroplane community has long been aware of what it has termed the 'Power pushover'. This is commonly described as being due to the propeller thrust acting above the vertical CG of the gyroplane and tending to pitch the gyroplane nose down. In normal flight the lift or rotor thrust developed by the main rotor blades opposes the propeller thrust and balances the nose-down pitching moment. If the gyroplane is disturbed in pitch, either by turbulence or control input, this may result in a 'pushover' or 'bunt' manoeuvre. As the normal 'g' reduces, the rotor thrust also reduces proportionately allowing propeller thrust to become the dominant force. If the onset of the bunt manoeuvre is rapid, loss of rotor thrust is also rapid and, with a high propeller thrust setting, the propeller thrust causes the fuselage to pitch nose-down and the tail to rise. If this situation occurs, the main rotor blades may flap back or if the pilot makes a large aft cyclic input to correct the situation, the blades are able to strike the tail surface and the propeller. It is notable that the Glasgow University research has found a strong coupling between pitching motion and rotorspeed, since reduced rotor speed adversely affects rotor disc stability.

*Flight tests*

Following a previous accident involving an RAF 2000 autogyro, G-CBAG on 17 May 2002, the AAIB made several Safety Recommendations aimed at evaluating the handling characteristics of the UK gyroplane fleet. Safety Recommendation 2003-03 recommended that the CAA should assess the RAF 2000 for compliance with BCAR Section T and if necessary recommend appropriate modification to achieve compliance. The CAA accepted this Safety Recommendation and, having evaluated the other types on the UK register, was about to conduct flight tests on the RAF 2000. Therefore the proposed evaluation was combined with an effort to identify possible cause(s) of the accident involving G-REBA.

A series of test flights were carried out in the UK using an RAF 2000, registration G-ONON, which was of similar specification to G-REBA. Following the flight tests in the UK, a test flight was made in Medicine Hat, Canada with the manufacturer's recommended instructor pilot accompanying the CAA test pilot. The gyroplane was an RAF 2000, C-FLDE. This differed from G-REBA in that it was equipped with a more powerful 2.5 litre Suburu engine fitted with fuel injection driving a four-bladed propeller. It was also fitted with a 'Stabilator' designed to improve the longitudinal handling qualities of the gyroplane and an electric pitch and roll trim system. Unlike G-ONON, this gyroplane was equipped with instrumentation to record specific parameters. Throughout all the tests flown, the gyroplane operation remained entirely within the manufacturer's (Rotary Air Force) published envelope. The purpose of the UK test flights was to undertake a handling qualities assessment of the RAF 2000 autogyro and assess the test gyroplane against the latest issue of BCAR Section T. The test flight conducted in Canada investigated the handling qualities of the gyroplane fitted with the 'Stabilator'. The onboard instrumentation was also used to document the relevant results.

During the flights carried out in the UK, the CAA test pilot gained experience of flying the gyroplane and during the tests identified a number of deficiencies when trying to establish compliance with BCAR Section T. Both gyroplanes tested exhibited marked longitudinal dynamic instability when flown above 70 mph and directional instability with cabin doors fitted. The conclusion of the UK flight tests was:

> *'The gyroplane had unacceptable longitudinal dynamic stability above 70 mph and unacceptable directional stability with the doors fitted.'*

Following the test flight of the RAF 2000 in Canada, the CAA test pilot concluded that:

> *'The Stabilator dramatically improved the gyroplane's trim system however the gyroplane tested exhibited similar static and dynamic stability characteristics to a similar gyroplane tested without a Stabilator.'*

In essence, the test flying identified significant instability of the gyroplane as speed was increased above 70 mph. With the thrust line above the CG an inherent nose-down pitching moment existed which increased with an increase in power. Although dynamically unstable above 70 mph, the gyroplane exhibited relatively strong longitudinal static stability. When the gyroplane was trimmed for the higher speed cruise, typically above 70 mph, a noticeable aft force was required on the cyclic control in order to slow the gyroplane down. Releasing the cyclic control when flying more slowly than the trimmed cruising airspeed, resulted in a nose down pitch. Pitch trimming is achieved by a trim wheel on the centre console. Approximately 60 rotations of the wheel are required to trim the gyroplane from speeds between 50 mph to 80 mph. This lengthy process does not make re-trimming simple and also requires the pilot to fly the gyroplane with his left hand whilst using his right to perform the trim adjustments. This requires the pilot to be equally competent at flying the gyroplane with either hand, which does not come naturally to some pilots.

During flight testing, G-ONON appeared to have a well damped convergent phugoid long term response (LTR) at slow speeds and the gyroplane was comfortable being flown at speeds up to 65 mph. At 60 mph the LTR was damped and convergent. Maintaining pitch attitude ± 2º was easy and could for periods of three to six seconds be accomplished with no inputs to the cyclic control. At 65 mph a 'release-to-trim' input of the cyclic control excited a lightly damped phugoid with a period of around eight seconds. Maintaining pitch attitude ± 2º at 65 mph was more difficult requiring constant small (2 mm) inputs to the cyclic control. At 70 mph natural turbulence excited a divergent phugoid which had a period of approximately five seconds and a time to double amplitude of approximately 10 seconds. Testing was curtailed after eight seconds to prevent excessive pitch attitudes being reached. Maintaining pitch attitude ± 4º at 70 mph was very difficult requiring continual small (2 mm) inputs to the cyclic. Flying at speeds between 70 mph and 100 mph required increasing attention and required good visual cues, that is to say, a clearly defined horizon.

It was also noted during flight testing that with the doors fitted, the gyroplane had no inherent directional stability and would not naturally yaw into the prevailing sideslip. Additionally, if feet were taken off the rudder pedals, the rudder would not centre but would pay off into the prevailing sideslip, reducing directional stability further. In flight, constant small rudder inputs were required to maintain heading accurately (± 2º).

Throttle chops were conducted in level flight at 70 mph. In each case the gyroplane rolled to the left and yawed noticeably to the right. A slight pitch-up was followed by a tendency for the nose to drop as airspeed reduced. Maintaining heading initially required moderate pilot attention due to the poor directional stability.

With regard to the gyroplane's behaviour in the pitching plane, the test pilot concluded that although stable at lower speeds, it was clear that the dynamic instability of the gyroplane occurred at higher airspeeds with a corresponding increase in workload, noticeable above an indicated 70 mph.

Following these evaluations, the UK CAA issued Mandatory Permit Directive MPD 2006-013 which imposed flight limitations on the type. In particular, the 'never exceed' speed $V_{NE}$ was reduced to 70 mph, the doors were required to be removed for flight, and flight when the surface wind exceeds 15 kt was prohibited.

*Metallurgy*

A metallurgist inspected a number of components using visual and low level optical techniques and made the following observations:

General

The failure of the rotor mast, gimbal arm and various bolts occurred due to overload, with no evidence of any pre-existing condition that would have contributed to the failure.

Left lower control rod

The left lower control rod failed as a result of bending overload separation. The deep abrasion marks 34 cm from the bottom of the control rod were identified as longitudinal frettage corrosion damage which had resulted from high contact pressures and large sliding movements. The metallurgist considered that the restriction resulting from this contact could have been sufficient to overload the torque levers.

Engine frame

The frettage damage on the engine frame adjacent to the battery bay was also caused by a sliding action and was similar to the frettage damage on the left lower control rod.

Torque levers

The torque levers exhibited signs of plastic deformation and had failed as a result of having being overloaded. There was no evidence of progressive separation of the metal by either fatigue or stress corrosion. However, the properties of the metal used in the torque levers makes it difficult to differentiate between a failure caused by very low cycle fatigue (up to 200 cycles) or by the levers having been subjected to an excessively high load. Therefore low cycle fatigue of the torque levers could not be ruled out.

An electrical conductivity check of the metal used in the torque levers gave average values of 45% IACS[7] and a Vickers Hardness test gave values of 111 HV for the left torque lever and 112 HV for the right torque lever. These tests indicate that the tensile strength of the material was approximately 430 $N/mm^2$ and that the material had probably been solution treated and artificially aged.

The PFA, using the material strength estimated by the metallurgist and the dimensions of the torque levers fitted to G-REBA, established that both levers met the requirements of BCAR Section T, which states:

> *'The parts of each control system from the pilot's control stops must be designed to withstand pilot forces of not less than (for stick controls) 445N fore and aft, and 300N laterally.*
>
> *The parts of each control system from the control stops to the attachment to the rotor hub (or control areas) must be designed to at least*

**Footnote**

7 International Annealed Copper Standard.

*withstand the maximum pilot forces obtainable in normal operation; and if operational loads may be exceeded through jamming, ground gusts, control inertia, or friction, support without yielding 0.60 times the limit pilot force (for stick controls) 445N fore and aft, and 300N laterally.'*

Comparison with other gyroplanes

A comparison was made of the control and rotor system on G-REBA with four other RAF 2000 gyroplanes. The comparison established that the rotor blade pitch (5º) was similar to the other gyroplanes. The manufacturer confirmed that the rotor blade pitch was within the acceptable range. The length of the left control rods on G-REBA was slightly greater than for the other gyroplanes, whereas the right control rods were of a similar length. This difference was due to the build tolerances and the positioning of the torque levers and control columns on their respective layshafts.

The comparison also established that the abrasion marks at the base of the right lower control rod were probably caused by the trim springs rubbing against the control rod. It was noted that a number of other owners of RAF 2000 gyroplanes had identified this problem and introduced their own modifications using plastic sheaths and blade tape to protect the control rods from the trim springs. Whilst it is unlikely that the rubbing of the trim springs against the control rod played any part in this accident, on the 14 July 2006, in AAIB Special Bulletin S6/2006, the following Safety Recommendation was made to the Popular Flying Association.

**Safety Recommendation 2006-090**

It is recommended that the Popular Flying Association considers introducing a modification to the lower control rods of the RAF 2000 to protect them from being damaged by the trim springs.

The left lower control rod from G-REBA, which had the deep abrasion marks 34 cm from the bottom of the control rod, was compared with the equivalent control rod on another gyroplane where it was noted that the marks were in line with the battery tray. It is, therefore, probable that the marks on the engine frame adjacent to the battery tray and the control rod were caused by these two items rubbing against each other.

Whilst operating the controls on one of the gyroplanes used in the comparison, it was noted that the excess safety chain, fitted to one of the trim springs, jammed between the lower control rod and undercarriage strut thereby restricting the roll control of the gyroplane. The chain on G-REBA had been set up such that there was no free hanging excess chain and, therefore, it is unlikely that it would have caused the control to jam. However, on the 14 July 2006, in AAIB Special Bulletin S6/2006, the following Safety Recommendation was made to the Popular Flying Association.

**Safety Recommendation 2006-088**

It is recommended that the Popular Flying Association takes the necessary immediate steps to ensure that the safety chain connected to the trim springs on the RAF 2000 does not jam the moving parts in the control system.

In response to these two Safety Recommendations, the PFA has amended the Type Acceptance Data Sheet (TADS) for the RAF 2000 at issue 4 dated 14 December 2006 and at issue 5 dated 2 July 2007 to include special inspection points dealing with the trim spring and pushrod abrasion issues.

**Discussion**

There was no evidence that the pilot had experienced difficulties handling the gyroplane, or expressed concerns about flying it. The weather was good and he was properly licensed to conduct the flight. At the time of the flight he had no history of medical problems.

The flight, from Watchford Farm up until immediately before the accident, appears to have been normal. The pilot, on contacting Bodmin Radio made no mention of any abnormal situation or difficulties. As he passed along the north shore of Colliford Lake, the pilot returned the waves made by two children before climbing away to the west. The estimated heights provided by the majority of the witnesses of between 300 ft to 500 ft appear to have been accurate. They also saw the gyroplane in steady flight, not executing any violent manoeuvres. The witness on the bridge at Blacktor Downs was quite specific that the gyroplane appeared in steady flight. It then appeared to be caught in a crosswind, the rotor blades came together above the gyroplane and the engine cut out at about the same time.

Evidence from witnesses and the pilot's GPS indicates that the gyroplane was flying at cruise speed on a heading of 233º when the rotor blades struck the tail assembly, causing the rotor to stop. The gyroplane then continued through the air for approximately 120 m on a heading of approximately 300º before striking the ground.

Missing tips on two of the propeller blades, marks on the rudder and paint marks on the rotor blade indicate that the white blade was the first to strike the tail assembly when the rotor was tilted back by approximately 37º. Damage to the fin and rudder, rudder hinge post, propeller blades, and paint marks and damage to the leading edge of the rotor blades indicate that a second high energy strike involving the black blade occurred when the rotor was tilted back by 45º. It is probable that it was this strike that broke all the propeller blades and drive belt. Marks on the fin and tail wheel assembly, and paint marks and leading edge damage to the white blade indicate that a third strike occurred when the rotor was tilted back by approximately 52º.

The propeller drive belt failed in overload when the propeller blades were struck by the main rotor blade and then fell, under gravity, to the ground. Whilst the distribution of the broken parts of the rudder and fin had been affected by their size, shape and local air currents, this would not have been the case for the relatively heavy rudder hinge post which was knocked to the right of the gyroplane. The drive belt and rudder post are believed to have failed as a result of the second main rotor blade strike. From the wreckage distribution it is assessed from the relative position of the gyroplane track, drive belt and rudder post that the gyroplane was probably flying forwards on a heading of about 233º when the accident occurred.

Whilst there was no entry in the aircraft logbook or any associated worksheets, there was evidence that the owner had recently embodied MPD 2006-03, which required the replacement of a number of components in the control system. It would also appear that the day before the accident the owner was still making adjustments to the control system following the modification.

The investigation discovered that two of the lock nuts on the control rod end fittings were loose. It is possible that one might have come loose in the crash when the control rods were subject to high bending forces. However, the other lock nut had been backed fully off the thread and must have been in this position before the impact. There was also evidence of the trim springs rubbing against the lower control rod and a high pressure moving contact between the left lower control rod and the engine frame.

The loads that the control system must be cable of withstanding are specified in BCAR Section T, which is based on the force that a pilot would be able to exert to clear a control restriction. The PFA confirmed that the control system met the strength requirement of BCAR Section T and it is considered unlikely that the pilot would have flown the gyroplane, following a major modification to the control system, if it required an unusually high force to move the stick. It is also considered unlikely that rubbing contact of the lower control rods against the trim springs and engine frame would have been sufficient to cause a control restriction which could not be overcome.

Consideration was given to the torque levers having been damaged in the previous accident and then failing during the final flight. Whilst it was not possible to establish if the torque levers had been replaced, the gyroplane had flown for a further 50 hours and there was no evidence of fatigue or any pre-existing damage to the levers. It is, therefore, considered unlikely that damage sustained to the gyroplane during the previous roll-over contributed to this accident.

The metallurgist was of the opinion that frettage damage to the left lower control rod and the engine frame would have required a high contact pressure that would have increased the load in the control system. This increased load might have been sufficient to cause the low cycle fatigue failure of the left torque lever. With the modification having been carried out just prior to the accident flight, it is possible that the number of cycles of the lower control rod at the higher loading would have been less than 200; this would make detection of a fatigue failure difficult. Had the left torque lever failed then the pilot would have been unable to control the rotor and the right torque lever would have either failed in overload in the air, or when the gyroplane struck the ground. In summary, with the evidence available, it was not possible to determine if the left torque lever failed when the gyroplane struck the ground, or whether it failed as a consequence of the left lower control rod rubbing against the engine frame.

The layout of the control system is such that there are a number of different ways for it to be set up. Moreover, the lower control rods move up and down in a semi-elliptical path and, consequently, contact between the control rod and the engine frame may only occur part way through the range of movement. Therefore it is essential that the control system is examined for restrictions as it is being moved through its full range of movement. From the available evidence it would appear that the owner undertook the modification, and subsequent adjustments, by himself and would therefore have only been able to check visually for restrictions with the control column set at fixed positions. The investigation also discovered that one of the lock nuts on the control rod had been fully backed off, which raises the possibility that it was not properly locked by the owner following the embodiment of the modification or subsequent adjustment of the control system. It is for these reasons that duplicate inspections are carried out following disturbance of aircraft control systems.

The requirement for duplicate inspections is brought to the attention of owners by PFA Technical Leaflet 2.01‘*Responsibilities of the Aircraft Owner*’, which states:

> *‘Where control systems are broken down and re-assembled (other than those designed for connection prior to each flight by the pilot), duplicate inspections are required. If two PFA inspectors are not available, a pilot/owner may carry out the second inspection.’*

Instructions on the requirement for duplicate inspections following the disturbance of flying controls during maintenance are also provided to PFA inspectors in Notes to PFA Aircraft Inspectors (SPARS). It was noted on another RAF 2000, examined during this investigation, that whilst an inspector had signed for inspecting the work following embodiment of MPD 2006-03, there was no record of the duplicate inspection having been carried out. The owner of the gyroplane confirmed that a duplicate inspection had not been carried out because he did not appreciate that such an inspection was required. There was no requirement in the manufacturers Product Notice (40) and the only indication in the MPD that a further inspection might be required was the following statement:

> *'During embodiment and after completion, the work must be inspected at appropriate stages by a person approved either by the CAA or the PFA. Compliance with this MPD and appropriate inspections should be in accordance with normal PFA procedures and recorded in the aircraft log book.'*

Two people were killed on 21 August 2004 in an accident involving a flexwing aircraft following the incorrect modification of primary structure. Whilst a duplicate inspection was required, it was not carried out. As a result of that accident the following Safety Recommendation was made to the Civil Aviation Authority (CAA):

> **Safety Recommendation 2005-085**: It is recommended that the Civil Aviation Authority ensure that Service Bulletins involving work conducted on primary aircraft structure include a statement that duplicate independent inspections are required, and that both inspections are to be recorded in the aircraft logbook.

In their response to this recommendation the CAA wrote:

> *'The CAA accepts this recommendation insofar as it relates to the need for a duplicate inspection. However, the CAA does not consider it appropriate to amend Service Bulletins with requirements for duplicate/independent inspections. This requirement is contained in the BMAA guide to airworthiness which identifies the need to carry out independent inspections whenever work is carried out on primary structure and the CAA consider this to be the most appropriate place for this information. The CAA has written to the BMAA and microlight aircraft manufacturers requiring them to identify alterations and modifications that affect primary structure in service Bulletins and other change documents.'*

The CAA response relies on the fact that the owner/inspector recognises that the disturbance to the control system, or primary structure, warrants a duplicate/independent inspection. However, some owners might not possess the necessary knowledge to realise that an additional inspection is required. There are also a number of sports aviation aircraft where the wing is fitted, or unfolded, and the control system reconnected prior to flight without there being a need to carry out a duplicate/independent inspection. It is therefore possible that following a modification there could be some confusion as to when a duplicate/independent inspection is required, and therefore the following Safety Recommendation is made:

> **Safety Recommendation 2007–052**
>
> It is recommended that the Civil Aviation Authority includes a statement in all Mandatory Permit Directives affecting aircraft operating under Permits-to-Fly to clearly advise owners if the work content requires a duplicate or independent inspection.

In the absence of any technical evidence of engine or rotor system failure, the possibility of rotor blade to airframe contact due to gyroplane manoeuvring must be considered. The flight tests conducted by the CAA test pilot determined that at air speeds above 70 mph IAS, the gyroplane becomes longitudinally dynamically unstable. Additionally the gyroplane was directionally statically unstable with the doors fitted. Of significance was the pronounced 'open loop' divergent nose-down pitch attitude at 70 mph recorded on the flight test data.

The last four GPS data points recorded on the accident flight are indicative of the gyroplane pitching nose-up then nose-down. The points recorded are groundspeeds of 83 mph, 72 mph, 80 mph and 35 mph. From these ground speeds a tail wind component of 4 mph should be subtracted in order to obtain airspeed, although it should be noted that GPS based speeds are subject to errors arising from inaccuracies in GPS position data. Nonetheless, on that basis the gyroplane was slowed from 79 mph to 68 mph in 4 seconds. This could have been the result of aft cyclic to climb or a reduction in power to slow down or a combination of both. The gyroplane then accelerated from 68 mph to 76 mph in one second. This represents either a large nose-down attitude change and/or an increase in tail wind component. The final data point recorded three seconds later was 31 mph.

It is probable that the rotor blades stopped, as seen by the witness, while the gyroplane was accelerating from 68 to 76 mph, and at that point, only its momentum was carrying it forward. The wreckage indicated a near-vertical impact and therefore the 35 mph data point was not the moment the gyroplane struck the ground. The witness did not hear the engine power reduce but it did appear to stop. This may have been the engine stopping due to the rotor contact with the tail or the pilot suddenly closing the throttle.

**Conclusions**

From the information set out three possible causes were identified:

1. The pilot suffered either a total or partial incapacitation which may have rendered him unable to control the gyroplane. It pitched rapidly nose-down and the rotor thrust reduced precipitating a 'power pushover'. The rotor blades struck the tail surface and stopped.
2. The pilot had attempted to slow or climb the gyroplane for some reason, moving the cyclic aft of the trimmed, cruise position. The cyclic control was then released and the gyroplane pitched forward resulting in a 'power pushover'. In attempting to correct the nose-down pitch, a positive aft movement of the cyclic was made which caused the rotor blades to strike the tail and stop.
3. A technical failure of the gyroplane structure or flight control system occurred.

The exact cause of the accident could not be determined but the vulnerability of the gyroplane to 'power pushover' during nose-down pitching manoeuvres was considered a factor. The tendency for the gyroplane to be unstable in pitch at speeds above 65 mph was probably a contributory factor. The pilot had gained a level of experience that should have enabled him to maintain control in normal circumstances. If, however, he were distracted or incapacitated, possibly due to the dormant medical condition, this would have reduced his ability to control the gyroplane.

**Reference:** Houston, S. (1996) *Longitudinal Stability of Gyroplanes*, The Aeronautical Journal of the Royal Aeronautical Society, January 1966 edition.