ACCIDENT

Aircraft Type and Registration:	Reims Cessna F406 Caravan II, G-TWIG
No & Type of Engines:	2 Pratt & Whitney Canada PT6A-112 turboprop engines
Year of Manufacture:	1987
Date & Time (UTC):	22 October 2004 at 1033 hrs
Location:	37 miles north-west of Inverness
Type of Flight:	Public Transport (non-revenue)
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Airline Transport Pilots Licence
Commander's Age:	35 years
Commander's Flying Experience:	2,735 hours (of which 510 were on type) Last 90 days - 170 hours Last 28 days - 48 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft and its commander were concluding the fifth sector of the day when, shortly after starting a descent for Inverness, the aircraft's rate of descent became unsteady and it started to turn left. The available evidence indicated that the aircraft struck the ground in a steep, left, spiral dive. The extreme fragmentation of the wreckage suggested a high impact speed, probably in the region of 350 kt. Major airframe and powerplant failures were discounted but otherwise, there was insufficient evidence to draw firm conclusions about the reasons for the sudden deviation from controlled flight and secondly, the absence of any evidence consistent with an attempt to recover from the dive. Two safety recommendations made recently to the EASA concerning flight recorders were re-iterated.

Factual information

History of the flight

On the day of the accident the pilot reported at the company's Inverness office at 0515 hrs for a single-crew, five-sector duty during which he was to deliver freight to the Northern and Western Isles in the company's Reims Cessna F406 (F406). This was the routine schedule for the aircraft on a Friday. The schedule included a three-sector triangle flying newspapers and magazines to Kirkwall and Sumburgh, before returning empty to Inverness. These sectors would be followed by a return flight to Stornoway, again positioning back to Inverness empty, to arrive at 1035 hrs.

The first four sectors proceeded without incident and the aircraft arrived at Stornoway at 0950 hrs, 20 minutes after the scheduled time of arrival (STA). The aircraft was parked on the apron for 18 minutes. During that time the pilot and company ground staff unloaded the cargo of newspapers. At the same time, the aircraft was refuelled with 280 ltr of fuel. During the turn-around the cabin door, pilot's emergency exit, the two left nose-compartment hatches, and both baggage compartment hatches in the wing lockers were opened. The airport's surveillance camera recording showed that they were all closed again before the aircraft departed. The right nose-compartment hatch remained closed and undisturbed. On completion of the unloading, the pilot reminded one of the ground staff that the forward support strap for the integral aircraft steps, incorporated into the lower half of the cabin door, must be connected before anyone put their weight on the steps; otherwise the door/steps hinges might be damaged.

The pilot sometimes went into the company office in the Terminal for a cup of coffee before flying back to Inverness, but on this occasion he said that he was returning without delay; the aircraft was due to be used for training that afternoon. Before leaving, he told the ground staff that he would see them the following Tuesday, when he was due to fly one of the operator's British Aerospace Jetstream 31 (J31) aircraft to the Western Isles, and he invited them to join him at his leaving party in Inverness the following Saturday. (The pilot was about to start his final week with his employer before taking up a position with a large, short-haul jet operator in England.) He also thanked the staff for their leaving present and was described as being in his normal, happy and jovial mood.

At 1011 hrs the aircraft was cleared to taxi for a departure from Runway 36 and backtracked to the threshold of the runway before beginning the takeoff. The pilot was instructed to maintain runway heading after takeoff until the aircraft was passing an altitude of 3,000 ft. He was cleared for takeoff at 1015 hrs. The aircraft was seen to become airborne at or just before the intersection with Runway 25. It then levelled at a height of about 50 ft above the runway. When it crossed the threshold of Runway 18, a number of witnesses saw the aircraft pull up sharply but smoothly to a pitch attitude between 45º and 70° above the horizon. The aircraft maintained this attitude until it reached what was estimated to be an altitude of 3,000 ft. It then commenced a right turn, which one witness considered as being 'steeply banked', and departed to the south-east en-route to Inverness. A wide beach to the north of the runway stretches for 1,500 m; beyond that there is low-lying terrain with the sea (Loch A Tuath) stretching out to the north-east. There was no evidence that the aircraft had pulled up to avoid any obstacle.

At 1019 hrs the pilot was instructed by Stornoway ATC to call Scottish Control. Thirty seconds later he called Scottish Control and advised them that he was passing Flight Level (FL) 70 in the climb to FL85. Scottish Control instructed him to "squawk ident" so that they could positively identify the aircraft on radar. Once identified, the aircraft was cleared to climb to FL95, its planned cruising level along advisory route W6D. (The cruising level for the outbound sector to Stornoway was FL85.) Thereafter, Scottish Control provided the pilot with a Radar Advisory Service (RAS). At 1028:41 hrs Scottish Control instructed the pilot to call the RAF Lossiemouth Radar Controller. The pilot did not respond so 11 seconds later, Scottish Control repeated the instruction. The pilot immediately acknowledged this second transmission. It is possible that the aircraft was in a known radio blind spot when the first transmission was made.

At 1029:07 hrs the pilot called the Lossiemouth Radar Controller advising him that he was at FL95. The

Lossiemouth Controller confirmed that the aircraft was identified and informed the pilot that he, the controller, was providing a RAS. The pilot acknowledged the radar service he was receiving and, at 1029:34 hrs, he requested descent. By this time the aircraft was in the area where it was usual for the pilot to make such a request. However, the controller commented that, initially, he instructed the pilot to "standby" because the aircraft had been handed over to him "a bit early". At 1029:50 hrs he cleared the aircraft to descend to FL75 and instructed the pilot to report when level. The pilot acknowledged in a clear, unhurried voice. This was the last transmission heard from the pilot. The ATC controller observed G-TWIG's descent rate on radar, which appeared to be typical for that flight. At 1032:59 hrs he advised the pilot that there was temporary loss of radar contact and, as a consequence, the ATC service was reduced to a Flight Information Service (FIS). There was no reply from the pilot. Twenty seconds later the radar controller called the pilot again and immediately another aircraft, a helicopter, transmitted on the frequency.

Over the next minute the Lossiemouth Radar Controller and the helicopter's crew conducted a dialogue during which the periods of silence totalled 25 seconds. Following that conversation, the Radar Controller called G-TWIG eight times in the space of seven and a half minutes. On each occasion there was no reply from the aircraft and, during that period, there were no other transmissions on the frequency.

From the ATC radio recordings, the pilot sounded lucid and calm from the time he requested clearance to taxi at Stornoway until his last transmission at the top of descent. He did not transmit an emergency call and he gave no indication of any problems.

Search and Rescue activity

At 1036 hrs Lossiemouth ATC informed the Scottish Air Traffic Control Centre (Military) Distress and Diversion (D&D) Cell at Prestwick of the situation. D&D attempted to contact the pilot of G-TWIG on the aeronautical emergency frequency, 121.5 MHz. There was no response. At 1046 hrs Lossiemouth also contacted the Aeronautical Rescue Co-ordination Centre (ARCC) at Kinloss and passed all the known details of the aircraft's disappearance. Further unsuccessful attempts were made to contact G-TWIG by radio from ground stations and another aircraft that was flying from Stornoway to Inverness some 25 minutes behind G-TWIG. Two Tornado aircraft were diverted from their training flights to search the vicinity of the last radar contact. While it was possible to make a visual search of some of the valleys, the crews reported that cloud was covering a plateau of high ground in the area. At 1107 hrs a Sea King Search and Rescue (SAR) helicopter was launched from RAF Lossiemouth. The coastguard helicopter based at Stornoway was also mobilised and the airborne search was augmented by mountain rescue teams from Dundonell and Kinloss.

The aircraft wreckage was found by a mountain rescue team the following day at 1330 hrs. It was located at an elevation of 2,480 ft amsl on Meall Feith na Slataich, a broad mountain ridge in a remote area of the Highlands, 30 nm to the north-west of Inverness. The severity of the impact had scattered the aircraft over a wide area and into many pieces. When viewed from the air, even in good visibility, the small size and large spread of the fragments made the aircraft difficult to distinguish amongst the intermittent quartz type rocky outcrops.

Four people who were fishing on Loch Vaich, 5 nm to the south-east of the crash site, and a number of estate staff, who were working in the area, all heard a loud bang or explosion on the day of the accident at about 1030 hrs. The noise had come from the direction of the crash site but no-one had seen any sign of an aircraft. Later, some of them saw the two Tornado jet aircraft and an SAR helicopter which had been searching the area.

Pilot information

The pilot started his flying training in the USA in 1998 and qualified as an 'airplane' and instrument flying instructor on single and multi-engined light aeroplanes. In 2000 he returned to the UK to continue his training for a commercial pilot's licence for aeroplanes. In March 2001 he was issued with a UK Commercial Pilot's Licence (Aeroplanes) and commenced employment as a co-pilot, flying the Dornier 228 on a short-term contract for an overseas operator, based in Aberdeen. That contract ended in July and he was offered employment with another regional operator in Scotland. He declined the offer in the hope that he might secure a position on larger aircraft further south. The events of September 2001 and a subsequent downturn in the aviation market thwarted his aspirations and he accepted a full-time position with that same operator in June 2002.

By all accounts he had much enjoyed the nearly two and a half years he had spent flying passengers and freight, predominantly around Scotland and to the Northern and Western Isles. He had started on single-pilot duties on the company's F406. Eleven months later he transferred to the company's Jetstream 31 (J31) as a co-pilot and in July 2003 he combined that duty with his previous role on the F406. In October 2003 he was issued with his JAR Airline Transport Pilot's Licence (Aeroplanes), valid until 2008, and he completed command training on the J31. He flew the J31 exclusively until January 2004, while he accrued some experience as its commander. Then, once more, he combined his duties on the J31 with single-pilot operations on the F406. He had commented that he would probably not experience such enjoyable flying again.

In August 2004 he successfully underwent the selection procedure for a short-haul jet operator who he was due to join in November.

A week before the accident the pilot had swapped the 'standby' duty, for which he was rostered on the date of the accident, with the F406 duty allocated to another pilot. It was understood by the other pilot that the request was made because it would then be the accident pilot's last flight into Stornoway in the F406 before he left the company. However, his roster showed that he still had a J31 duty and three more F406 duties the following week. The last was on the Friday and would have involved the same routing as that on the date of the accident. Certainly, three of the ground staff in Stornoway were expecting the pilot to fly there on the following Friday's F406 flight.

There were a number of references in the pilot's training file to good performances and there was no record of him experiencing any difficulties during his conversion or recurrent training on either the F406 or the J31. He had revalidated his F406 type rating and his Single Pilot Aeroplane (SPA) instrument rating on 30 June 2004. His JAA Class One medical certificate, with no limitations, was valid until 5 November 2004. All his other annual and triennial checks were in date and, in all respects, he appeared to be medically fit and well.

The pilot had been on standby duty from 0800 hrs until 1600 hrs the day before the accident but he was not required to fly. The following morning he reported at 0515 hrs, giving him a 13 hours and 15 minutes rest period prior to the accident duty and the benefit of no flight duty period since landing a J31 at 2015 on

20 October 2004. The pilot's previous flight in an F406 had been on 18 October 2004.

The pilot was described, by those who knew him at work, as a steady, jovial individual, who was well-liked and respected. He was considered to be a conscientious, able aviator and one who was particularly known for adhering to standard operating procedures and for being safety conscious. His family and his fiancée said that he was physically very fit and that he had a happy personal life. He had also carried out at least one other 'exuberant' departure in an F406 when flying single-pilot without a payload.

Description of the aircraft and relevant systems

The Reims Aviation F406 Caravan II is an un-pressurised utility aircraft. Its interior can be configured to carry passengers and/or freight, or surveillance equipment. The main entry door is on the left side of the rear fuselage and is available in several configurations. The door on G-TWIG consisted of front and rear sections. The forward half was hinged at its leading edge and thus opened forwards. The rear section was split longitudinally in the middle, the upper part opening upwards on a gas strut and the lower section, containing integral steps, opening downwards. This door also served as the normal means of entry and exit for the pilot(s). In addition, an escape hatch, incorporating the left side cockpit window immediately aft of the window, was provided for the pilot, with two additional escape hatches on the left and right sides of the cabin. Additional freight/luggage space was available in the nose and aft sections of the engine nacelles, with access to the latter being via lockable doors on the upper surfaces. The nose baggage area was equipped with two doors on the left side and one on the right side.

The landing gear is of conventional, tricycle design, retracted and extended by hydraulic actuators powered by engine-driven pumps.

The aircraft is powered by two PT6A-112 turboshaft engines driving McCauley three-bladed, variable pitch propellers. All PT6 engines consist of two independently rotating sections; the gas producer and the free power turbine. The former directs a high energy gas stream at the latter, which drives the propeller through a reduction gearbox. Cockpit controls include a power lever and propeller rpm lever for each engine. The rpm lever is connected to a propeller control unit (PCU), which incorporates a governor assembly. The latter controls engine oil pressure ported through a transfer tube to the inside of the dome that forms part of the propeller hub. This results in forward movement of the dome, which, because it is connected to the propeller blades via levers, causes the blade angles to reduce. However, dome movement is opposed by the combined force of an internal spring (the feathering spring) and the effects of centrifugal counterweights mounted on each of the blades. The propeller blade angle is thus set by the position of the piston and will vary according to the power and rpm selected by the pilot. A 'beta system' prevents the blade angles reducing below a pre-set value in flight, - the primary blade angle (PBA). The 'beta range' of propeller blade angles is the area of operation below the PBA (14° in this case) used on the ground for taxiing and reverse thrust. Control is by means of the power lever below the 'idle' detent and is connected to the beta valve, mounted on the front of the PCU, via a reverse thrust cam box assembly. It is the beta valve that regulates oil flow to the propeller dome in this mode of operation. In the air, when the blade angle reduces to the PBA, a flange on the dome contacts the 'beta nuts', which are attached via rods to a brass slip ring on the propeller shaft. A carbon block, located in a groove in the slip ring is connected, via a feedback arm, to the beta valve. Any additional forward movement of the dome causes the beta valve to reduce the oil pressure, thus preventing the blade angle reducing below the PBA.

The governor within the PCU should prevent the propeller from overspeeding; however, each engine is also equipped with an overspeed governor that prevents excessive rpm that could result from a failure within the PCU.

The primary flying controls are manually operated and mainly comprise cables, bellcranks, pulleys and quadrants. The elevator, aileron and rudder trim systems are all cable driven, with screw-jack assemblies attached to the trim tabs on each elevator, the left aileron and the rudder. They are operated via trim wheels on the cockpit pedestal.

The aircraft's elevator trim tab can be adjusted manually using a trim wheel on the centre console or by the electrical trim system. The electric trim system consists of an electrically operated drive motor and clutch assembly, which receives power through a two-way switch (pitch up and pitch down) and an autopilot/electric elevator trim disconnect switch. Both are located on the left arm of the pilot's control wheel. Operation of the electric trim switch disconnects the autopilot. On G-TWIG (which was equipped with a Sperry 1000A autopilot) operation of the disconnect switch disabled the electric trim when the switch was depressed and released. The electric trim then remained disabled until the trim switch was actuated once more.

The flaps are selected electrically and operated hydraulically by means of an actuator mounted on the rear spar of the wing centre section.

The avionic fit on the F406 varies according to operator requirements. G-TWIG was equipped with an ARC (formerly Sperry) 1000A autopilot system. This was a relatively unsophisticated device, compared with modern equivalents, but it could maintain a heading and altitude; additional features included navigation, approach and go-around modes. There was no 'altitude acquire' function although climbs and descents could be achieved by means of a thumbwheel on the control panel. This could be rotated so that the aircraft adopted the desired nose-up or nose-down attitude. An alternative way of achieving the same result was to depress a 'pitch sync' switch on the control yoke which temporarily disconnected the autopilot. The aircraft was then manually placed in a new attitude which was held by the autopilot on releasing the switch. The autopilot controlled the aircraft via servo motors operating on the aileron and elevator circuits. It also trimmed the aircraft in pitch by means of the elevator trim actuator. Finally, a yaw damper was incorporated into the autopilot system, with an actuator operating on the rudder. The autopilot could be switched off by means of a switch on the control panel, a disconnect switch on the control yoke or by operation of the electric trim switch, also on the control yoke.

Accident site details

The aircraft had crashed into rough, undulating terrain at an elevation of around 2,500 ft. The ground was a mixture of peat bog and grassland, with rocky outcrops. The impact area had granite beneath the surface, which combined with what was evidently a high impact speed, had caused extreme fragmentation of the aircraft. A shallow crater had been formed, with some wreckage scattered to the rear of it, but the majority having been thrown forwards over a distance of approximately 250 metres. The distribution of the wreckage suggested a steep impact angle, estimated at around 70°, with the wreckage throw indicating an impact track of approximately 200°M, which was at right angles to the approximately south-easterly course the aircraft had been following towards Inverness. Many wreckage items were lightly burned, indicating that a fireball had occurred at impact. This would have resulted from misting fuel following the disintegration of the wing tank structure, with likely ignition sources being electrical or hot engine exhaust gases. There was no evidence of a pre-impact fire.

Within the broken rock of the impact crater, it was possible to discern the impression made by the wing leading edges. The remains of the wing-tip navigation light bulb-holders were found at each extremity of the impression. This indicated that the wing was structurally intact at the time of the impact although the degree of fragmentation of the wreckage meant that it was difficult to determine whether any panels from elsewhere on the aircraft had become detached prior to impact. The distance between the two wing-tip impact positions was 54 ft, compared with the wingspan of around 49.5 ft. This indicated that the aircraft yaw axis was at an angle of approximately 22°, left wing low, relative to the ground at impact.

The accident site was in a remote location and could only be accessed on foot or, weather permitting, by helicopter. Following the on-site examination, the Royal Air Force Aircraft Recovery and Transportation Flight gathered the wreckage together in groups of large bags, which were formed into under-slung loads for a series of helicopter flights to a collection point close to a road. The wreckage was then taken to the AAIB's facility at Farnborough for a detailed examination.

Detailed examination of the wreckage

i) General

The severely fragmented wreckage was sorted to extract identifiable system components such as airframe, power plant, flying controls, electrical equipment, and transparencies. Windscreen fragments were examined for evidence of bird remains but none was found. The remains of a number of cockpit instruments and controls were also recovered and identified, although the degree of damage was such that their examination contributed little to the investigation.

The examination established that the flaps and landing gear were retracted and that all the extremities of the aircraft were accounted for with the exception of the nose cone. However, since this was the first part of the aircraft to strike the ground, it is probable that it was damaged beyond recognition. Pieces of the forward fuselage structure immediately aft of the nose and the weather radar antenna were identified.

The main door had suffered severe damage. The only part that had survived reasonably intact was the rear lower section that included the steps; this showed evidence of longitudinal crushing, which suggested that the door was in position at impact, and that it had been compressed between the trailing edge of the forward section and the aft door aperture. This in turn suggested that the forward door section had been in position.

Distortion of the locking mechanisms of the nacelle baggage doors confirmed them as being secured at the time of the impact. Also, fragments of the forward nose baggage doors were identified by means of lettering painted on the external surfaces. The degree of fragmentation suggested that they were most probably closed at impact. The rearmost nose baggage compartment door on the left side was not positively identified. Pieces of the pilot's escape hatch and the over-wing cabin exits (all outward opening) were identified, although it was not possible to confirm that they were secured at impact.

ii) Flying controls

a) Primary flying control system

The steep nature of the impact had resulted in severe fore-aft compression of both the horizontal stabilisers and the elevators. It was noted that both elevator balance weights were present. The elevator controls at the rear of the aircraft consisted mostly of rods and bellcranks; there was no evidence of pre-impact failures in any of them. The rudder surface had remained attached to the severely damaged fin and both ailerons were recovered. The fragmented nature of the wreckage meant that it was not possible to differentiate between many of the pieces of the flying control operating cables in terms of whether they originated from the aileron, elevator or rudder circuits. However, all the failures bore the characteristics of overload, with no evidence of pre-impact failure.

b) Secondary flying controls

Representative portions of the flap surfaces were recovered and identified, indicating that they were present on the aircraft at impact. The hydraulic actuator was found with its ram in the retracted position, indicating that the flaps were retracted at impact.

The aileron trim actuator was not recovered and identified, although it was established that its attachment to the aileron tab had failed in overload. Only a small piece of the aileron trim tab was found; however the elevator and rudder tabs were complete and had remained attached to their respective surfaces. The rudder trim actuator was found in its approximate mid-travel position.

There were two elevator trim actuators on this aircraft, operating tabs on both elevators. Both units were present in the wreckage and the linkages to the tabs were intact. Each actuator comprised a 'twin-pack', which consisted of two screw-jacks driven by sprocket assemblies which in turn were operated by chains that formed part of the elevator trim circuit. Operation of the pitch trim system (whether by means of the manual or electric system, or by the autopilot), thus caused all the jack-screw assemblies to move in unison. A diagram of one actuator, together with photographs, is shown at Figure 1. Rotation of the sprockets caused the sliders (which were attached to rods that moved the tabs) to move back and forth: they extended for nose-down trim and retracted for nose-up trim. All the sliders were extended by a similar amount. Comparison with an intact aircraft revealed that the slider positions equated to almost a fully nose-down trim condition.

During the high-speed impact, in which the airframe must have disintegrated extremely quickly, tension in the trim operating cable/chain system would have been lost due to foreshortening of the fuselage. However, as the tail section broke up, there may have been scope for considerable snatch-loads to be applied to localised lengths of cable close to the elevators. Whilst such loads may have moved the trim actuators, the simultaneous distortion that was occurring in the structure and tab linkages would have resisted such movement leading to overload failures in the cable. As a consequence, it is likely that little significant slider movement occurred during the impact. Therefore, the 'as-found' positions of the elevator trim actuators were most probably representative of the pre-impact settings.

iii) Engines

The engines had broken up to the extent that the gas-producer sections were exposed. Most of the blades

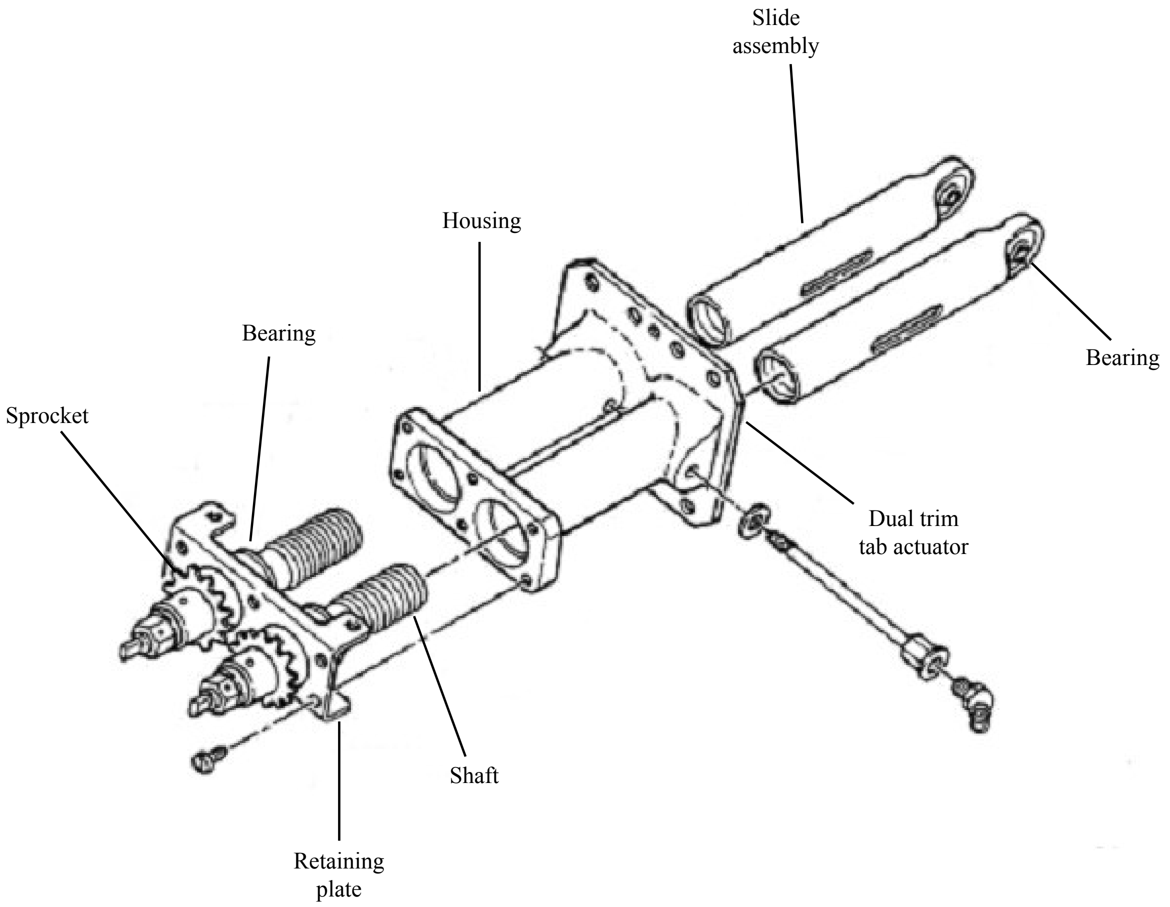

Diagram of elevator trim jack

Right elevator trim jack

Left elevator trim jack

Figure 1

Details of pitch trim jack

in the axial compressors had been torn off in a manner that indicated high rpm at impact. It was not possible to quantify the power setting from the condition of the compressors. However, the degree of damage was the same in the compressor assemblies of both engines, indicating a symmetrical power condition.

The remains of the engine casings, which had been severely compressed in the impact, were cut open to expose the turbine sections. Once again, the symmetrical nature of the damage was apparent, both on the gas producer and free power turbine discs.

Many of the engine components and accessories were examined in the presence of a representative from the engine manufacturer. The filter elements in the fuel pumps were clear, the pump gears were intact and the fuel control unit (FCU) drive couplings were undamaged. The FCU's themselves were severely damaged, although internal components such as diaphragms had remained intact, and the diaphragm chamber in the unit from the right engine was still primed with fuel.

Both cam-box[1] assemblies were recovered but it was not possible to determine which assembly related to each engine. It was noted that on one unit, the beta arm together with its associated roller, was in the reverse-pitch portion of the cam slot. Additionally, the locking wire was missing from the pinch bolt, which clamped the arm onto its splined shaft. The torque necessary to turn the pinch bolt, in a tightening direction, was measured using a torque wrench and was found to be around 15 to 18 lbf in. As a comparison, the locking wire was removed from the bolt on the other unit and the tightening torque was found to be around 40 lbf in. The Maintenance Manual figure was 32 to 36 lbf in. Also the splines beneath the pinch bolt with the missing locking wire were damaged to the extent that they had a worn appearance. It was not possible to determine whether this was caused before or during ground impact. The 'as-found' torque value on the pinch bolt, at around half the specified figure, could not be described as excessively low, but it did raise the possibility of a potential loss of synchronisation, due to slippage of the lever on the shaft, between the power lever in the cockpit and the propeller pitch control.

iv) Propellers and their control systems

All six propeller blade roots were found scattered around the accident site because the hubs had shattered on impact. All the blades were recovered with the exception of one outer section, and all had suffered considerable leading edge damage. The fracture face on the blade fragment, adjacent to the missing section, was indicative of an overload failure on impact. Although it was not possible to determine from which propeller assembly some of the blades originated. The similarity of the damage to them all suggested a symmetrical power condition, or at least a similar rpm, at impact.

The propeller control units were identified but they were in such a severely damaged condition that they could not be tested. However, internal examination of the governors indicated no evidence of pre-impact mechanical failures and there were no flyweight contact marks on the internal surfaces of the governor housings that might have indicated an overspeed condition. However, no significant pieces of the overspeed governors were found that could have confirmed this finding.

In many accidents it is possible to determine a propeller pitch angle at impact by establishing, with the aid of witness marks, the position of the pitch change mechanism relative to an internal piston. Alternatively, a similar

Footnote

1 Translates power lever movement to the fuel control unit and the propeller control unit

process can be used to establish the angular position of each blade root relative to the "spider" portion of the hub in which the blades are located. In this accident, the degree of fragmentation was such that these methods were not available. However, portions of the feathering springs were recovered, together with fragments of the steel tubes in which they had been located. It was found that areas of the internal bores of the tubes showed evidence of indentations made by the individual spring coils during the impact. The average spacing between the coil imprints can vary according to the fore-aft position of the dome, which in turn is a function of the propeller blade angle. The imprints were measured (see Figure 2), which revealed that the spacings were the same for both tubes, indicating that the left and right propeller angles were very similar. Using the measured spacing of 8.33 mm, the propeller manufacturer was asked to determine the corresponding blade angle.

Figure 2

Remains of feathering springs, showing coil imprints on tube bores

The manufacturer was also asked to calculate blade angles at the estimated impact speed of 350 kt at both maximum engine power and flight idle engine power, at the temperature and altitude of the accident site. The assumed propeller speed was 1,650 rpm in all cases. The calculations yielded the following information: at flight idle power the blade angle should have been 48.7° and at maximum power the angle should have been 53.4°.

The 'as-found' blade angle, for both propellers was 55.2°. It was stated that the blade angle would increase by approximately 2.7° for every 50 kt increase in airspeed, with temperature and altitude changes resulting in comparatively smaller blade angle changes.

The manufacturer additionally stated that the propeller blade angle range went from 88.5° at the feathered position to -13.5° at full reverse, giving a total angular range of 102°. An intact feathering spring has 25 coils and the amount of dome (and hence spring) movement per degree of blade angle change was given as 0.7112 mm. Because there are 24 gaps between the 25 coils, this corresponds to a change in the coil pitch of 0.0296 mm per degree, which illustrates how the blade angle is highly sensitive to changes in the coil spacing. Put another way, if the 8.33 mm measurement was subject to an error of ± 5% (either through measuring error or movement at impact), then the derived impact blade angle would be subject to an error range of ± 14° or so. Thus, while it would be tempting to conclude from the apparent impact propeller blade angle of 55.2° that the aircraft struck the ground with the engines at high power and at a speed in excess of 350 kt, the possible error range could also encompass a low power condition, albeit at blade angles above the beta range. In addition, the scope for spring movement caused by the impact cannot be quantified except that it is likely to be less for a steep, fast impact compared to a shallow, slow impact. On the other hand, if movement did occur, there would be no reason why it should be the same for both propeller hubs. The fact that the spring coil pitch was the same for both propellers gives some confidence to the deduction that they reasonably represented the pre-impact settings.

The beta feedback linkages were recovered from both engines, although the carbon blocks were missing. The blocks had each been mounted in a 'horseshoe' shaped bracket, which in turn was attached to a pin that was located in a hole in the feedback arm and secured by means of a circlip. The twisted remains of the pin were still attached to the end of the right engine feedback arm. However, there was no sign of the pin from the left engine feedback arm and the location hole was noted to be in pristine condition. This absence of damage gave rise to the possibility of a pre-impact disconnect, due, perhaps, to the pin detaching from its horseshoe bracket. According to both the engine manufacturer and the propeller manufacturer, in this eventuality, a spring in the beta valve housing would act to push the (now unrestrained) feedback arm forward, allowing the valve to port oil away from the propeller dome, thus feathering the propeller. From the analysis of the feathering spring marks, described earlier, it is clear that this did not occur.

Examination of an intact engine revealed that even if the circlip somehow became removed from its groove in the end of the pin, the provision of a guide pin mounted on the engine casing would prevent the feedback arm from lifting off the pin. Thus, in order for the feedback arm to become free, the pin itself would have to fail. This seemed unlikely, in view of the fact that the joint would be subjected to low in-service loads and also because of the consequence of the propeller being feathered. It was therefore concluded that the undamaged locating hole in the left propeller beta feedback arm was the result of a quirk of the impact, in which the pin was pushed cleanly out of the hole, due either to removal of the circlip or failure of the pin itself.

v) Autopilot

The possibility of an autopilot malfunction was considered, which, for example, might have caused a sudden nose-down command that the pilot was unable to oppose.

The autopilot manufacturer's original Failure Mode Effect Analysis (FMEA) was obtained during the investigation, and it contained a number of potential failure conditions that would result in a sustained control input in any of the axes. With regard to the pitch axis, many of these failures would cause the autopilot to disengage when the pitch angle exceeded 21° up or down. However, in some failures the autopilot would not disengage, resulting in a 'hardover' condition. In these cases the FMEA stated that the system had been demonstrated to meet the Federal Aviation Administration (FAA) certification requirements in that the pilot was able to overcome the servo motor force and hence retain control of the aircraft. The certification documentation supplied by the manufacturer stated that, for the pitch, roll and yaw axes, the force levels had to be within 50 lbs, 30 lbs and 150 lbs respectively. Test flight measurements showed that the actual forces were 45 lbs, 25 lbs and 60 lbs.

Although parts of the autopilot servos were recovered and identified, these yielded no useful information. The autopilot computer and other associated electronic components had been destroyed in the impact, and so could not be tested. However, the mode control panel was recovered in a relatively intact condition. Each of the push-button switches contained a caption segment, illuminated by light bulbs. These were examined under a microscope[1] in an attempt to establish if any of them were illuminated at impact: all were found to have "cold" or unlit indications. Immediately before the accident, the aircraft had been following a south-easterly course towards Inverness and it would have been standard practice to engage the autopilot in HDG (heading) mode. However, the aircraft was at an extreme attitude at impact and, even if the pilot had not disengaged the autopilot, it is probable that it would have disengaged automatically during the descent as the pitch and roll angles exceeded the limits.

vi) Miscellaneous items

In addition to the light bulbs from the autopilot mode control panel, the remains of the two adjacent warning annunciator panels were recovered. Many of the warning segments were missing but most of the missing bulbs were found in the wreckage; however, it was not possible to establish which systems they belonged to. All the bulbs were examined under a microscope and all but two showed clear evidence of being OFF at impact. Some filament stretching was apparent on the remaining two bulbs.

During a flight in a similar aircraft it was noted that in cruise conditions, no lights were illuminated on the warning panels apart from the 'particle separators' caption. It was the normal practice of G-TWIG's operators to leave the particle separators, in the engine intakes, in the 'open' position so the lights would have been illuminated. The engine air bleed valve regulators were found to be in the 'open' positions.

The cockpit area had been extremely fragmented in the impact and most of the switches, controls and instruments

Footnote

[1] When bulbs are illuminated, the heated filaments become extremely ductile and an impact can result in extensive filament stretching within the glass envelope. This feature can thus provide evidence that the bulb was lit at impact.

had been destroyed. For example, the face of one attitude indicator was found, but there were no witness marks that could have provided an impact indication. The brass rotors from two air-driven gyros were found: one bore evidence of circumferential scoring, indicating that it had been rotating at impact, when it would have come into contact with its casing. The other rotor had no circumferential marks, although this did not necessarily suggest that it was stationary at impact. One gyro case was found; its internal surface had been heavily scored. It was not possible to identify whether these components originated from the attitude indicators or directional gyros.

The directional indicator from the captain's side was found in a relatively intact condition. The heading bug was positioned at 129°; the selected course towards Inverness.

Calibration of the pitch trim system

Because the pitch trim actuators were found in the full aircraft nose-down position, it was decided to conduct an evaluation flight on a similar aircraft to assess the trim settings for the same centre of gravity position as the accident aircraft. Full nose-down pitch trim was applied with the aircraft descending through 8,000 ft at 205 KIAS. To prevent the aircraft's nose dropping, a significant rearward force (about 30 to 45 lbf) had to be applied to the control yoke. This evaluation was somewhat subjective but it demonstrated that control of the aircraft was manageable in this condition. Moreover, if the nose was allowed to drop, the aircraft could be recovered to a level attitude with only one hand on the control yoke.

The aircraft was then flown in several speed/attitude combinations and, for each trimmed condition, the position of the trim indicator pointer was marked on an adjacent piece of adhesive tape. On the ground, the trim actuator extension was measured for each of the marked positions and at the full nose-up and nose-down positions (although the aircraft was not flown at the full nose-up trim condition). The total linear travel of the actuator, which extended for nose-down trim, was 0.75 in from the nose-up to nose-down marks. With the aircraft in a cruise descent at 205 KIAS it was found that the actuator ram was 0.125 in away from the full nose-down position; in fact this value was found to change little for the level flight condition.

Also, during the evaluation flight, the rate of electrical trim operation was noticeably slower in comparison to typical manual operation of the trim wheel.

Additional aircraft information

The aircraft's technical log was recovered from the accident site. The pilot had calculated a takeoff weight of 6,787 lb. With the aircraft in the freight configuration, no cargo and only himself on board, the centre of gravity would have been within the permitted range. It is estimated that at the time the aircraft disappeared from the radar screen, it had burned approximately 200 lb of fuel and, consequently, weighed about 6,580 lb. At this weight, in a clean wing configuration and with the wings level, the aircraft's stall speed would have been 83 KIAS. G-TWIG's maximum take-off weight was 9,850 lb. At that weight and at sea level, the maximum manoeuvring speed is 162 KIAS. Abrupt control movements should not be made above that speed.

The manufacturer's Aeroplane Information Manual contains an emergency procedure for an *Electric Elevator Trim Runaway.* It states:

1. *Control Wheel – OVERPOWER as required.*
2. *AP/TRIM Disconnect Switch – DISCONNECT immediately.*
3. *Manual Elevator Trim – AS REQUIRED.*

NOTE

After the electric trim has been disconnected and the emergency is over, pull the electric trim (ELEV TRIM) circuit breaker. Do not attempt to use the electric elevator trim system until ground maintenance has been completed.

There was also a note within Supplement A3 of G-TWIG's Pilot's Manual which stated that in the event of any King 275/325 autopilot malfunction, the battery master switch may be turned off. No such note was included in the section dealing with emergency procedures for the King autopilots or in the Flight Manual Supplement for the Sperry 1000 A autopilot fitted to G-TWIG.

While experience has shown that it is possible to control the aircraft at the maximum operating speed with full nose down elevator trim, a definitive figure for the force required at the control column was not forthcoming.

Cabin heating is provided by diverting hot compressor bleed air from the engines and mixing it with cabin air to obtain the desired temperature. This mixed air is also routed to the windshield defrosting and defogging outlets.

The flight load limitations for the aircraft at maximum gross weight with the flaps retracted are minus 1.44g to + 3.6g. With the flaps at the takeoff position, these limits are reduced to 0g and +2.0g.

An exercise conducted in 2000 at the International Test Pilots School, based at Woodford in the UK, examined the lateral and directional stability and control characteristics of the F406. The report did not reveal any adverse handling qualities and the lowest score given by the pilot using the Cooper-Harper Handling Qualities Rating Scale, on a declining scale from one to ten, was three. This equates to an aircraft characteristic for which minimal pilot compensation is demanded to achieve the desired performance in a selected task or required operation. This score was given by the testing pilot when assessing the aircraft's behaviour while maintaining 30º angle of bank turns to the right and, secondly, when rolling out of rudder-free aileron-only turns. This reflected comments by other pilots, who have flown the F406, that the aircraft type, which had been in production for 19 years, did not possess any vices. It had been mentioned that the aircraft type is more responsive in pitch than it is in roll but this was an observation, not a criticism of the aircraft.

Aircraft handling procedures

For takeoff and climb the propeller speeds are set to 1,900 rpm, the maximum. For the climb and cruise flight phases, the propeller speeds were normally reduced to 1600 rpm. The normal climb speed for the F406 is 140 kt. In the cruise, the Operations Manual instructs crews not to exceed the maximum cruise torque shown in the Aeroplane Flight Manual. For the conditions estimated at FL95 on the accident flight, maximum cruise torque at a propeller speed of 1,600 rpm should have given an aircraft speed of 205.5 KIAS, equivalent to 234 kt true airspeed (KTAS). This compares with the aircraft's normal cruise speed of between 200 and 205 KIAS and somewhat less than the aircraft's maximum operating speed of 229 KIAS. During this phase of flight it was customary for the pilot to engage the altitude and heading hold modes of the autopilot.

The operator's Operations Manual instructs pilots that '*before visible moisture is encountered with an OAT between +4ºC and -30ºC*' they are to '*ensure that all aircraft anti-icing systems are ON and operating*.' These anti-icing systems include pitot heat, stall vane heat, the engine intake inertial separators, the propeller de-icing systems and the electrical windshield anti-ice systems.

The Operations Manual also provides the following guidance on the operation of the aircraft de-icing system in flight:

> *'Position de-icer switch to AUTO when ice has accumulated to a thickness of approximately half an inch on the leading edges.*
>
> *No adverse aerodynamic effect will be produced by the operation of the de-ice boots other than a slight increase in prestall buffet and speed .....*
>
> *NOTE: Since wing and horizontal stabilizer de-icer boots alone do not provide adequate protection for the entire aircraft, known icing conditions should be avoided when possible. If icing is encountered, close attention should be given to the pitot static system, propellers, induction systems and other components subject to icing. The de-ice system will operate satisfactorily on either or both engines. During single-engine operation, suction to the gyros will drop momentarily during the boot inflation cycle.'*

The aircraft Information Manual states that an '*accumulation of a ½ inch of ice may cause a cruise speed reduction of up to 30 knots as well as a significant buffet and stall speed increase.'*

Before commencing descent, it is likely that the pilot would have obtained the latest meteorological information for Inverness from the airport's Automatic Terminal Information Service (ATIS). To initiate descent, the normal practice is for the pilot to lower the nose of the aircraft by rotating the pitch command wheel on the autopilot control panel, which also disengages the altitude hold mode of the autopilot. Power is also reduced. Using this method, the pitch attitude change is proportional to the amount of rotation of the pitch command wheel. If the aircraft's pitch attitude had exceeded approximately 20° up or down, a disconnect function should have automatically disconnected the autopilot.

The pitch command wheel signals operate through the autopilot servo actuator, which drives the pitch control circuit. This is separate from the elevator trim control. An alternative method of changing the pitch attitude is to depress the pitch synchronization button, located on the right arm of the pilot's control wheel, and manually select a new pitch attitude, before releasing the button and allowing the autopilot to maintain that attitude. The pilot can also fly the aircraft manually by disengaging the autopilot.

On this company's operations it was typical for the aircraft to descend at 220 KIAS. The Operations Manual advised crews that:

> *'crew and passenger comfort is aided by the avoidance of steep descents and rates of descent above 800 fpm should be avoided.'*

The Information Manual explains that, if a baggage door is left unlatched, it may open as the nose of the aircraft is raised during takeoff. However, the door will not hit a propeller nor will there be any unusual handling characteristics. In such a situation the airspeed should be kept below 120 KIAS.

The operator's pilots received recurrent training in techniques for recovery from unusual positions.

Meteorological information

During the investigation a meteorological aftercast was obtained for the area around the accident site on the morning of the crash. At 1000 hrs the synoptic situation showed an area of low pressure centred between the Shetland Islands and Norway, which fed a light, unstable, north-westerly airflow over the route from Stornoway to Inverness. The weather was mainly cloudy with occasional showers. Surface visibility was 10 to 20 km reducing to 4,000 m in showers. A band of more persistent rain lay to the south of the route, aligned west to east from Skye to Aberdeen.

The cloud consisted of few/scattered stratus at 1,200 to 1,500 ft amsl, scattered/broken cumulus or strato-cumulus at 2,500 to 3,000 ft amsl and broken strato-cumulus with a base at 5,000 ft amsl. These layers may have increased in amount and extent over the mountains. Photographs taken by some holidaymakers on the day of the accident, 5 nm to the south-east of the accident site, appear to show a cloudbase at about 2,500 ft amsl when compared with the elevation of the mountains in the pictures.

These conditions were reflected in the meteorological observations taken at Stornoway and Inverness airports around the time of the accident. Of the two, Inverness had the worse weather.

It is possible that there was some dynamic turbulence over the tops of the mountains, as a result of the winds and the extent of the high ground, and it is highly likely that there was some convective turbulence in the cloud.

The freezing level was at about 5,000 ft amsl and airframe icing was considered to be likely in cloud above that level. The wind velocity at 5,000 ft amsl and at 10,000 feet amsl was 320º/20 kt. At 5,000 ft the air temperature was -0.3°C. and at 10,000 ft it was -9.4°C. The air pressure at mean sea level was 990 mb.

The pilot of another aircraft, flying from Stornoway to Inverness about 25 minutes astern of G-TWIG at FL75, stated that he had experienced smooth conditions and no icing during his flight. When he was established in the cruise at FL75, he recalled that he had been flying between layers of cloud. He estimated that there was a fairly dense layer of cloud between 500 ft and 1,000 ft below him and about 6 octas of cloud approximately 1,500 ft above him. He did not encounter any precipitation until he was overhead Inverness.

Medical and pathological information

The post mortem report concluded that there were no pathological findings to help determine the cause of the accident and that the pilot died as a result of the multiple injuries sustained in the accident. It was impossible to say whether the pilot was conscious or unconscious in the period preceding the accident. There was no evidence of any underlying disease and toxicology analysis showed no abnormal indications.

Recorded data

The aircraft did not carry any mandatory recording devices and there was no requirement to do so. A GPS unit was found in the wreckage but it was of a type that does not record track information.

The sources of event data available were recorded radar tracks from Stornoway and Tiree radar heads, a report from a controller who was viewing the unrecorded radar returns from the Kinloss and Lossiemouth radar heads, and radio communication recordings.

Post-accident position data was taken from a GPS unit carried to the site during the investigation to pinpoint the impact location. In-flight GPS and radar recordings were taken from another aircraft flown in the area at a later date to evaluate the radar performance limitations in the area.

Radar system characteristics

In order to understand the analysis of the radar data used in this investigation a few of the basic system characteristics and limitations are given below.

There are two types of radar system currently used for civil aviation in the UK, primary and secondary radar. Radar heads have one or both of the primary and secondary systems and both use rotating antennas. Primary radar sends out pulses and detects when one bounces back from an aircraft. Primary radar tracks provide slant range and bearing from the radar head only. Secondary radar sends pulses to a transceiver on board the aircraft which then responds with an aircraft identity code and additionally, if selected, the aircraft's pressure altitude. Thus secondary radar tracks provide aircraft identity and altitude as well as slant range and bearing; however, the aircraft equipment must be operational. Another limitation of secondary radar aircraft equipment is that on aircraft of this size, there is only one transponder antenna. This is installed on the bottom of the aircraft, providing reasonable coverage during manoeuvring, but at more extreme attitudes it can cause loss of secondary radar signal depending on the orientation of the aircraft to the radar head. Other relevant radar characteristics are the line of sight of the radar head to the aircraft and the resolution and accuracy of the radar track position.

Radar needs direct line of sight to an aircraft in order to detect it. High ground between the aircraft and the radar head interrupts the passage of radar pulses and creates a radar shadow. This effect is exacerbated with distance between the aircraft and radar head because of the curvature of the earth.

Each radar position does not represent a point in the airspace but a volume of airspace which for convenience may be visualised as a box with dimensions defined by the resolution and accuracy of the range, bearing and altitude systems. The range and altitude sides remain fairly constant with regards to resolution and the effects of errors. However, although the angular bearing resolution is constant, the horizontal distance (width) this represents increases with distance from the radar head.

In this case, the resolution of the recorded radar data was limited to 1/16 nm in range and 0.088° in bearing. These increments are quite large compared to the distance travelled in the 8 seconds between each radar sweep. Thus the distance travelled between each radar sweep is not a single value but a band of possible values. This resolution tolerance also affects speed and heading calculations. So, given this resolution tolerance, determining aircraft manoeuvres between individual returns cannot be done in detail. Trending flight parameters over many sweeps during steady flight can be done with more accuracy because the band of possible values becomes smaller compared to the distance travelled. Radar altitude resolution is always limited to the 100 ft intervals of the aircraft's transponder resolution which provides similar limitations as per range and bearing.

A further relevant limitation of secondary radar is that it rejects, and therefore does not track, secondary radar returns reporting an altitude change of 1,000 ft or more since the last sweep.

Radar data derived flightpath

The recorded radar tracks from Stornoway and Tiree are given in Figure 3 together with the type of radar, the location of the radar head, the advisory route being flown and the accident site.

The Tiree radar tracks, whilst providing both primary and secondary radar returns, were fragmented due to shadowing by terrain half way between the radar head and the flight path. Another problem with the Tiree data was that the forward motion of the aircraft was aligned with the bearing resolution of the radar which, at these distances, is very poor compared to the range resolution. However, this did make the Tiree source good for assessing the aircraft's across-track motion.

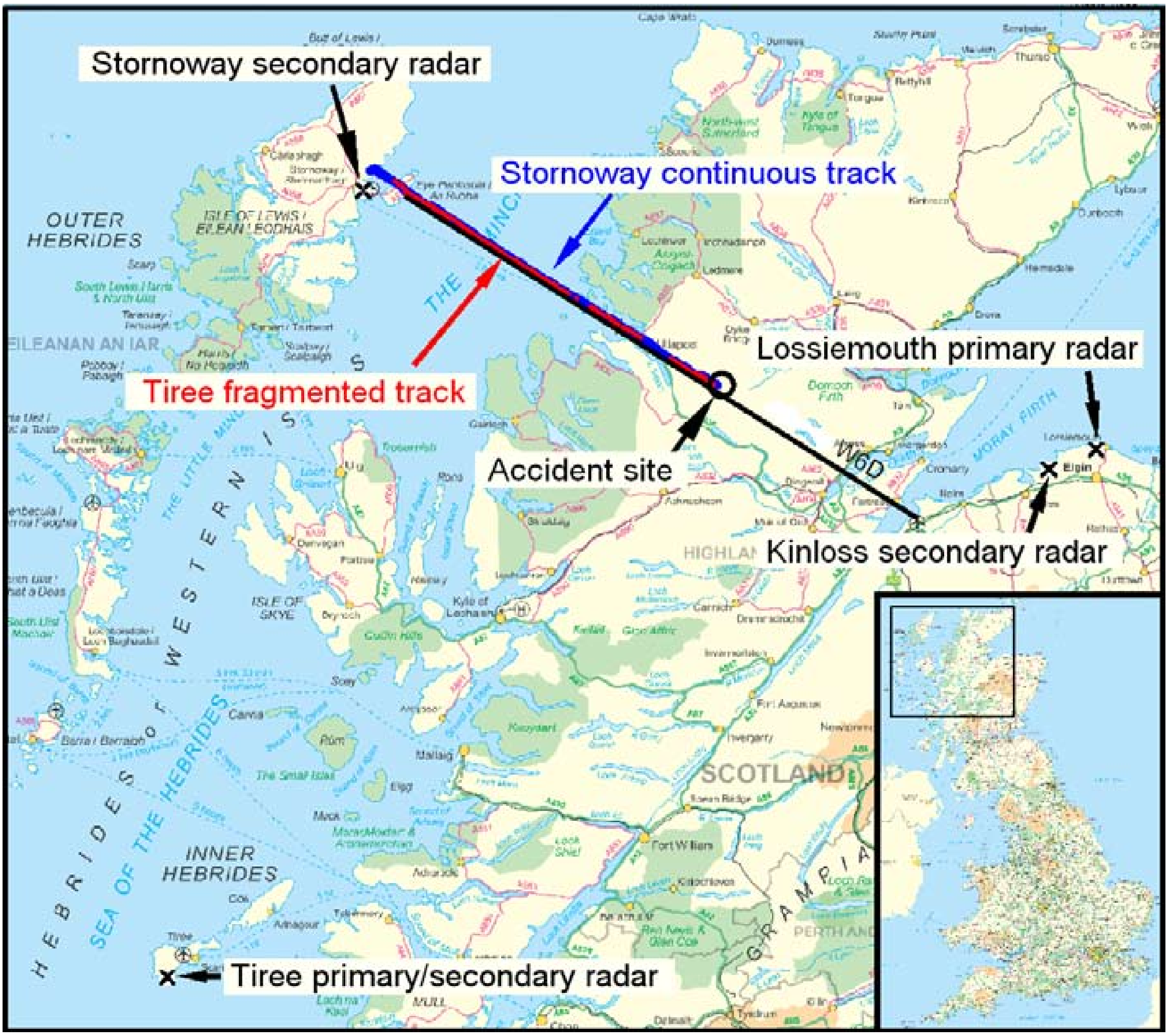

Figure 3

Geographical locations of the accident site, radar tracks, advisory route flown and relevant radar heads

The Stornoway radar provided continuous secondary radar data which covered all the Tiree data tracks and more. The aircraft flew away from the Stornoway radar head and so its forward motion was aligned with the 'tighter' range resolution of the radar. Therefore the Stornoway data was used for the general flight overview and speed calculations. Figure 4 shows these in detail.

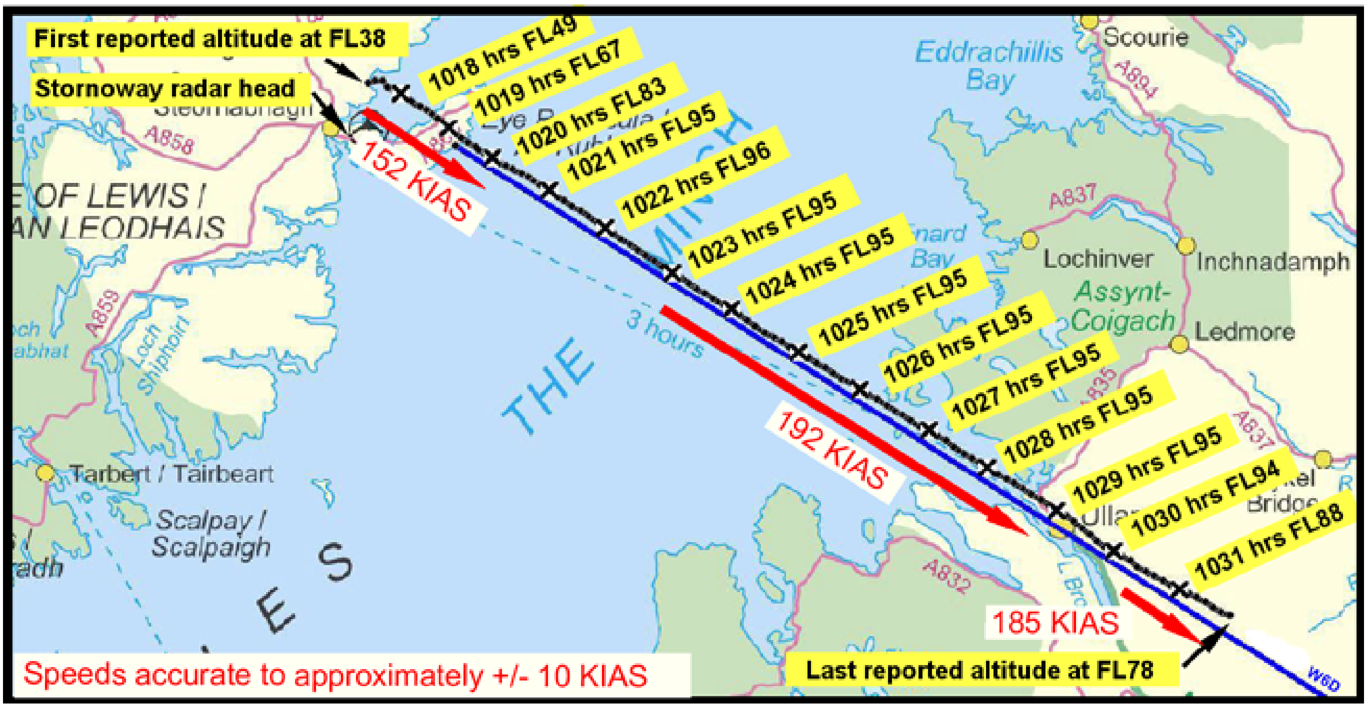

Figure 4a

The Stornoway secondary radar track with reported altitude

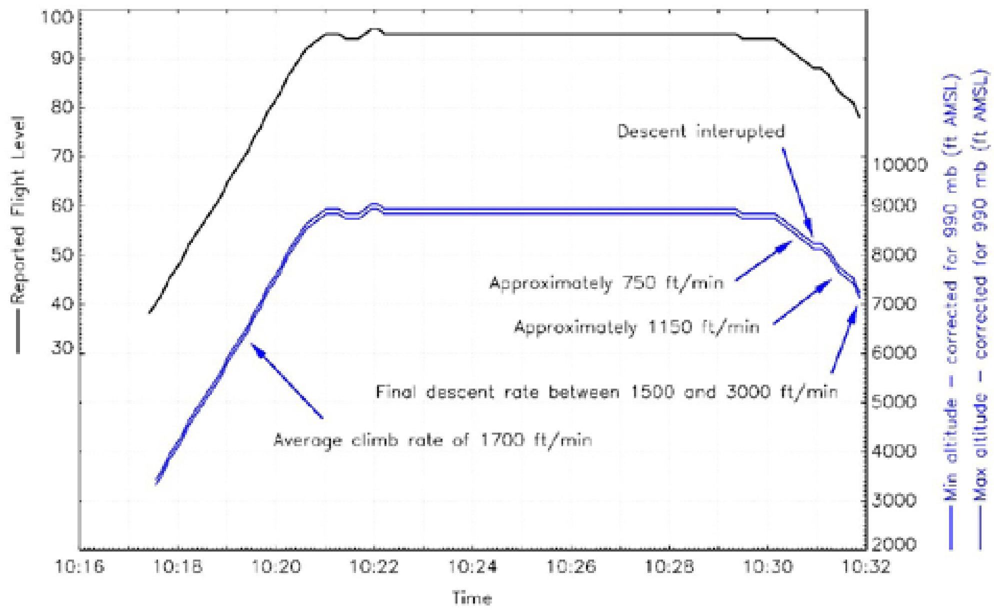

Figure 4b

The Stornoway secondary radar track derived parameters

The Tiree data correlated with the Stornoway data. The reported altitude was also verified by comparing the intermittency of the Tiree data with the line of sight limits of the Tiree radar head, given the terrain between the aircraft and the radar head.

The track initiated at 1017 hrs at FL38. The aircraft climbed to FL95 with an average climb rate of 1700 ft/min. During cruise the aircraft maintained a ground speed of 240 kt equating to a true airspeed of 220 kt and an indicated airspeed of 192 kt. The aircraft tracked slightly to the left of the centreline of advisory route W6D. The aircraft was cleared to descend to FL75. The descent was initiated and averaged 750 ft/min until FL88 (approximately 8,200 ft amsl) at which point the descent rate started to fluctuate, approximately 50 seconds before the aircraft track was lost. Due to the coarse nature of the altitude data, it was difficult to determine the flight path between individual radar returns. However, the average descent rate between the last two recorded points was between 1,500 ft/min and 3,000 ft/min. The last radar point was at 1031 hrs with the aircraft at FL78 which was approximately 7,200 ft amsl.

Figures 5 and 6 overlay both the Stornoway and Tiree data to provide a more detailed profile of the aircraft's flight path during the last portion of the flight.

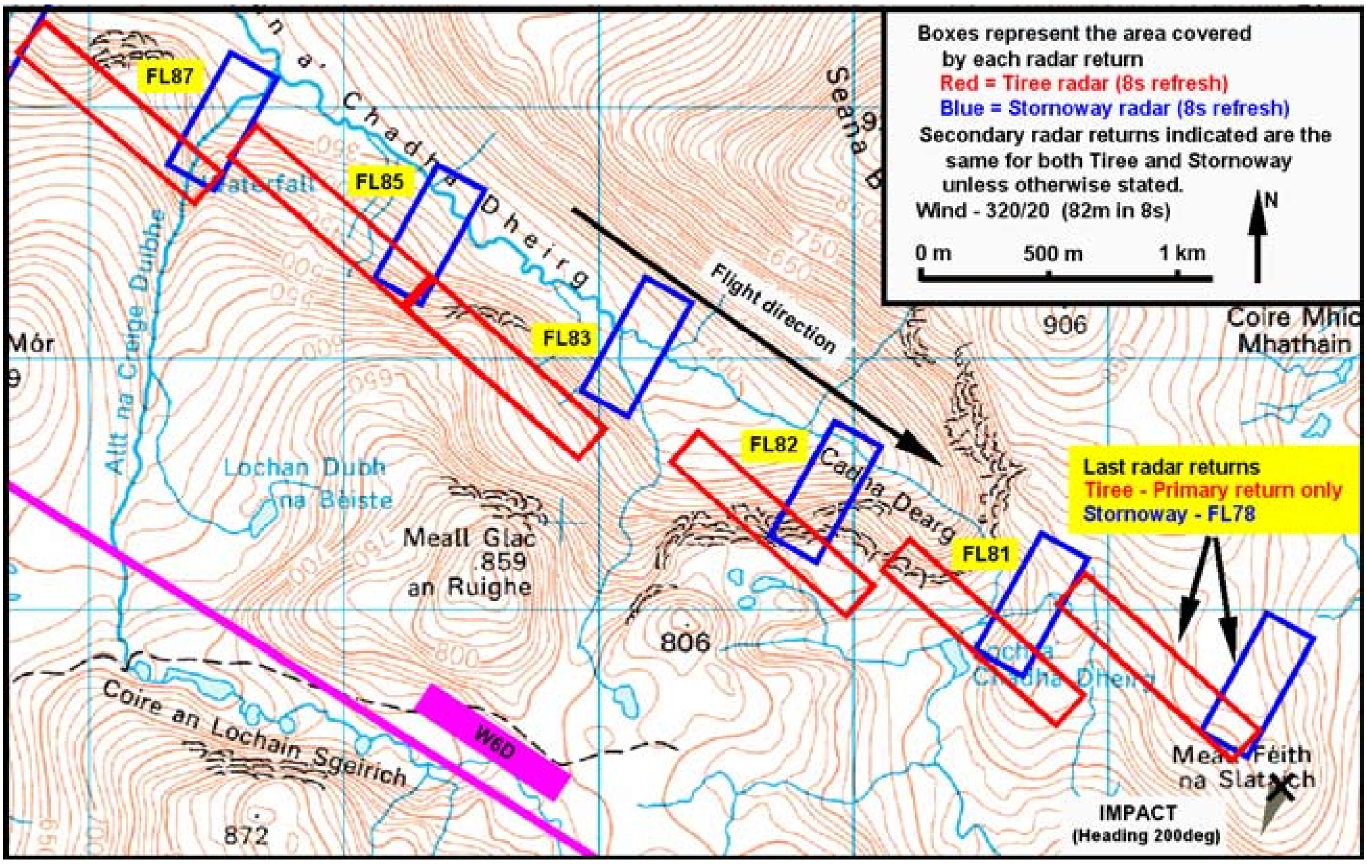

Figure 5

Overview of the final radar track points from Tiree and Stornoway against the impact site, impact orientation and local terrain.

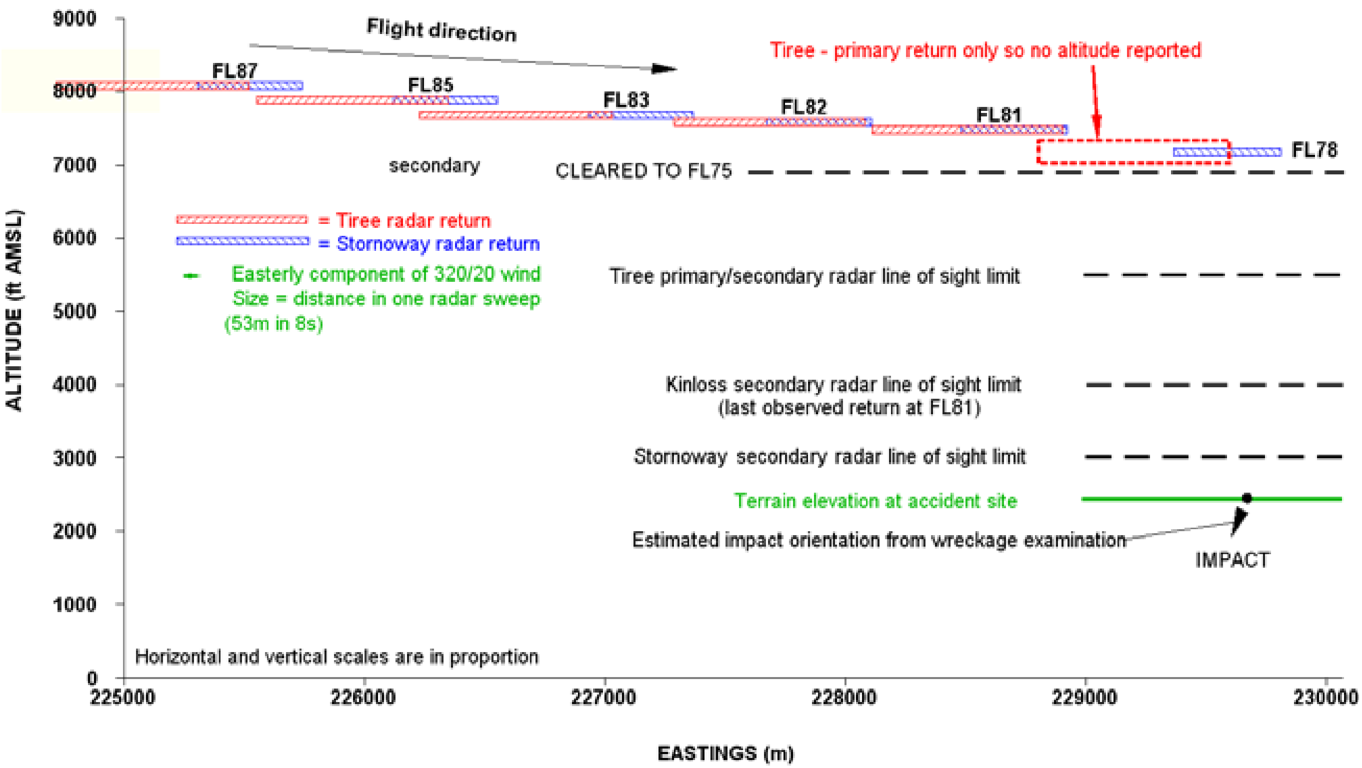

Figure 6

View of the final radar track points from Tiree and Stornoway, as viewed from a point to the South of the accident site

Pertinent points to note from the radar tracks are:

1. Despite being vertically separated by nearly 5,000 ft, the aircraft impact was within a few hundred metres of the final radar return.
2. The aircraft turned left relative to its previous flight path in the last few radar sweeps.
3. Reaching the impact point required a significant change in heading after the relative motion of the last radar points.
4. None of the radar heads recorded, or were observed to display, the aircraft after it descended through FL78 despite having line of sight capabilities significantly below this level.
5. The Tiree secondary radar did not detect the aircraft at FL78 despite Stornoway secondary radar and Tiree primary radar detecting it. Also, the observer of the Kinloss secondary radar did not recall seeing any returns below FL81.

Additional information

No one saw the impact and there were no impact signatures recorded on seismographs. The pilot was 76 inches tall (6 ft 4ins) but his seated height was not determined. The maximum distance between the pilot's seat cushion and a stringer supporting the cabin roof was 38 inches. The seated height of person of similar stature to the accident pilot was measured at 36 inches from the seat cushion (depressed) to the crown of his head).

Analysis

Overview

G-TWIG and its pilot both seemed to be operating well until the fifth sector of the day when, shortly after starting descent for Inverness at about 185 KIAS, the aircraft's rate of descent increased and it started to turn left. The aircraft struck the ground near the final radar return but almost 5,000 ft below it and on a heading at right angles to its intended track. The available evidence indicated that the aircraft struck the ground in a steep spiral dive to the left. The extreme fragmentation of the wreckage indicated a high impact speed, probably in the order of 350 kt. There were no radio messages from the pilot during the spiral dive.

Radar data analysis

The time of ground impact could not be established so analysis of the radar returns was the only method with which to estimate the likely flight path and deduce whether the aircraft flew directly from the last radar return to the point of impact or whether it flew a more circuitous route.

Loss of radar returns

Given the line of sight the radar heads had in the area of the accident, the radar tracks stop at a greater height than expected. In order to explain the sudden cessation of radar returns, the last few recorded points of primary and secondary radar are analysed separately.

Primary radar

The only source of recorded primary radar was the from the Tiree radar head. This indicated that Tiree detected a primary return from the aircraft one sweep after the final secondary return at FL81 which, given the Stornoway secondary radar track, is likely to have occurred at the time the aircraft was at approximately FL78. Tiree radar can 'see' down to at least 5,500 ft amsl at the accident location. The lack of further primary radar returns indicated that either the aircraft attitude at the time of the next sweep was such that it presented insufficient area to create a return, which is unlikely, or that the aircraft had descended below the Tiree line of sight limit in the 7.87 second interval between the sweeps. To descend from FL78 to 5,500 ft amsl in 7.87 seconds required a 1.2g downward acceleration (a person seated in the aircraft would experience -0.2g tending to lift them off their seat). This fact implies that the aircraft was providing a significant downward thrust.

Secondary radar

The first anomaly associated with the secondary radar data is that Stornoway was the only radar head to detect the aircraft at FL78. The explanations considered were as follows:

1. Random track drop. Radar occasionally drops aircraft tracks randomly. However, it is unlikely that two radars would randomly drop the track of the same aircraft. It is feasible that this is a product of interrogating the aircraft at the exact same time but this is also unlikely.
2. Antenna obscured. The secondary radar loses track of the aircraft if it is at an extreme attitude with the radar looking at a transponder blind spot above the aircraft or, when looking directly along the antenna axis from underneath the aircraft. Given that Kinloss and Tiree were looking at the aircraft from positions approximately 120º apart, it is unlikely that an extreme attitude could present the upper blind spot to both radars at the same time. If one of the radars was looking directly along the antenna axis

from underneath, it is unlikely that the other radar would simultaneously be looking at the transponder blind spot on top of the aircraft.

3. Transponder inoperative. Because their recorder clocks were not synchronised, the relative timings of the three radars sweeping the aircraft were unknown. It is possible that the transponder became inoperative just after the Stornoway detection at FL78 and just prior to the Kinloss and Tiree radar sweeps. The inoperative state is unlikely to have been directly linked to the primary causal factors of the accident because the loss of aircraft tracking occurred after the aircraft departed from its expected heading and altitude rate. However, the inoperative state could have been linked to a cascade of failures or to action as a result of dealing with other factors, possibly leading to the interruption of electric power.

The second anomaly is the lack of secondary radar returns below FL78. Explanations considered are as follows:

4. Transponder inoperative (as above).
5. The aircraft's descent rate was so high that it did not pass the reasonableness check of the altitude rate by the radar head. (If the reported altitude of an aircraft changes by 1,000 ft or more between consecutive sweeps the return is rejected and not transmitted to the control centre.) To meet this condition after the FL78 detection would require an average vertical acceleration to the impact point of approximately 0.7g or more (ie a person in the aircraft would experience +0.3g instead of the normal 1g). Whilst this does not require an acceleration force greater than gravity, it does not preclude it. However, it does require that normal wing lift forces are drastically reduced or no longer acting significantly upwards. Given the physical evidence of speed, this would imply a significantly nose-down or inverted attitude, or an airframe disruption such that the wings no longer imparted lift.

Potential explanations for the accident

The evidence from the accident site indicated that the aircraft had struck the ground in a steep, left wing low attitude, on a track some 90° to the right of the track towards Inverness, at a speed well in excess of the maximum permitted. The most logical explanation for its disappearance from radar was a very high rate of descent.

In attempting to evaluate what might have happened to induce this high-speed dive, three categories of causal factors were considered: an aircraft defect, an environmental factor and a piloting factor.

Aircraft defects

There was no evidence of an in-flight fire or explosion. The possibility of an in-flight structural failure was eliminated by the fact that all the extremities of the aircraft were accounted for and the wing was structurally intact at impact. However, it was not possible to be so certain about the forward baggage doors although, as a causal factor, the possibility of a door becoming detached, penetrating the windscreen and incapacitating the commander, seemed remote. The airspeeds probably achieved prior to impact would have been well in excess of the maximum permitted and the associated control forces would also have been abnormally high. However, in the event that the commander was able to make a significant control input, it is probable that the aircraft would have suffered an in-flight structural failure.

The fragmented nature of the wreckage meant that it was difficult to establish with confidence the operating state of some of the aircraft systems. For example two gyroscope rotors were recovered; one bore evidence of circumferential s coring whilst the other did not. Thus the evidence that one of them was rotating at the time of the impact, when it came into violent contact with its casing, was countered by the absence of such evidence on the other. Whilst this was most probably an oddity of the impact, it put in mind at least the possibility of a failure of the pneumatic supply to one or all of the relevant instruments. If such an event occurred, in addition to presenting misleading information to the commander, it is likely that the autopilot would make erroneous control inputs to the aircraft. For example, if the attitude indicator drifted to the extent that it gave a false nose-up indication, the autopilot would apply a nose down correction, which could result in an excessive rate of descent. If the aircraft was flying in IMC, then the commander might not immediately recognise that something was wrong. However, such a scenario would likely result in a relatively gradual departure from the intended flight path; the available evidence suggests a more dramatic event.

Similarly, it was not possible to establish, with certainty, that electrical power was available on the aircraft, although the fact that the transponder was operating during the early part of the descent suggests that it was. In any case, failure of the electrical system would not logically be followed by a sudden loss of control.

Investigation of the propeller hub components led to the conclusion that both propellers struck the ground at similar blade pitch angles and, as a consequence, with essentially symmetrical engine power applied. The nature of the evidence was such that the derived blade angles (approximately 55° in both cases) were subject to potentially large errors. Whilst this reduces confidence in the airspeed calculations, it at least suggests the engines were developing a significant amount of power, rather than flight idle power. If the propeller blade angles were at 55°, the impact speed may have been close to 400 kt.

Investigation of the pitch trim system revealed that the elevator trim actuators were near their fully nose-down positions whereas the appropriate setting for the weight and balance conditions was 0.125 in from the fully nose-down position. There are only three possible reasons for the as-found positions of the actuators: the commander trimmed to this position; a fault in the electric trim system caused an uncommanded trim input; or there was a fault in the autopilot. There appears to be no logical reason why the commander would trim to such a nose-down setting at the normal airspeed used in a descent. However, the as-found trim setting may have been appropriate to some higher airspeed. It was not possible to discount an electric trim system malfunction although flight tests indicated that the control forces could have been overcome with little difficulty. Similarly, the most serious potential fault in the autopilot, a spurious nose-down input followed by failure to disengage automatically when the pitch angle exceeded 21° nose-down, could not be discounted. If that had happened, the commander would have had to overcome the force of the servo motor in addition to the aerodynamic force. Whilst this force may have been significant, possibly in excess of 40 lbf, the commander would have had the option of switching off the autopilot and manually re-trimming the aircraft. Switching off the autopilot via the electrical master switch might explain why the aircraft's secondary radar return was lost but it does not explain why only one more primary return was received. Moreover, had the commander been combating a run-away trim system, it seems likely that he would also have reduced engine power and rolled the aircraft's wings level to recover from a dive.

Environmental factors

The aircraft was probably in icing conditions although it may not have been accreting ice. In those conditions the aircraft's anti-icing systems should have been operating and, if there was an ice build up of between ¼ and ½ an inch on the leading edges of the wings, the commander should have been able to operate the de-icing boots without any adverse effect. He should also have been aware of the attendant warnings in the Operations Manual. The reduction in aircraft speed that could accompany an ice build up may be reflected in the radar data if the commander had selected maximum cruise power on the engines. There was no indication of any significant turbulence and the commander of another aircraft which was following the same route at FL75, some 25 minutes astern of G-TWIG, reported experiencing smooth conditions. Moreover, there were no thunderstorms in the area which might have produced a lightning strike. Therefore, severe atmospheric conditions seem an unlikely explanation.

Collision with an object, perhaps one penetrating the windscreen leading to pilot incapacitation, was considered but there was no evidence of any other 'foreign' objects, including birds, within the wreckage. AAIB experience indicates that collision with any sizeable object leaves identifiable traces within the aircraft so this also seems an unlikely explanation.

Piloting factors

The commander was due to leave the company in just over a week's time to join a larger short haul jet operator. In doing so, he would have been leaving behind two and a half years of enjoyable flying on turboprop aircraft, operating passenger and freight flights on a regional network. At his request, he had changed the standby duty, for which he was rostered on the date of the accident, with the F406 five-sector duty that had been allocated to another pilot. In view of his comments that he might not enjoy such flying in the future, it is understandable that the commander might have wished to make the most of any remaining opportunities. The commander's private life was happy and company staff at Stornoway described him as being in his normal, jovial mood. They also remarked on his conscientious approach to his duties. There was no evidence in his training records of any difficulties during his conversion or recurrent training and, by all accounts, he was fit and able, with an exciting future ahead of him. Equally, the aircraft type was not known to display any characteristics which could place particular demands on a pilot. G-TWIG's take off from Stornoway was unusual but the commander had flown a similar manoeuvre at least once before with no adverse effect on the aircraft. Also, it would not have been the first time that a pilot had performed an eye catching departure in an empty, light aircraft. Consequently, there was no reason why the commander might have taken his own life, either deliberately or inadvertently through some form of unauthorised manoeuvre.

The climb and subsequent cruise at FL95 seem to have been unremarkable and all the commander's radio calls were lucid and calm. He did not transmit an emergency call and he gave no indication of any problems. He missed one radio call towards the end of the cruise phase but this may have been when the aircraft was in a known radio blind spot or when he was listening to the Inverness ATIS frequency. His acknowledgement of the ATC clearance for the aircraft to descend from FL95 to FL75, his final radio call, was delivered in a clear, unhurried voice.

The aircraft had returned from Stornoway 1,000 ft above the level it had cruised at on the outbound leg. On both sectors the commander would have had the cabin heating on. However, there was no evidence from the post mortem that the commander had been incapacitated by fumes.

If the elevator trim had malfunctioned in the early stages of the descent, it would have been possible for the commander to overcome the nose-down trim forces; moreover, he could have stopped an electric trim runaway by isolating electrical power to the trim motor. It is not known how manageable the control forces would have been at speeds above the maximum permitted but the commander could have used the elevator trim wheel to assist with recovery from a high speed dive.

If the aircraft's attitude been disturbed by an encounter with localised turbulence or vertical windshear, the pilot had sufficient skill and experience to recognise an 'unusual position' and take the appropriate recovery action. That would probably have been to throttle back both engines, roll the wings level and ease the aircraft out of its dive. However, both engines were still developing significant power at impact, the wings were not level and the dive angle was about 70°. These parameters were inconsistent with an attempted recovery.

One plausible causal factor for this accident could be that the commander was affected by a sudden mental or physical incapacitation that manifested itself in involuntary movements. For instance, if the aircraft had entered a localised vertical air current leading to a negative g excursion, even if his seat harness was securely fastened, it is possible that this unusually tall pilot could have struck his head on a hard stringer supporting the cabin roof about two inches above his head. He was almost certainly wearing a communications headset which might have given some cushioning to the crown of his head but a hard impact on an unprotected region of his skull could have been temporarily debilitating. A severe encounter could have rendered him unconscious and if he started to regain consciousness, any involuntary arm and leg movements might have been sufficient to 'upset' the aircraft. Amongst other control inputs, involuntary movements might explain why the electric elevator trim operated to near its full nose-down extent. The commander was not heard to make any emergency radio call, although the frequency was briefly blocked after the aircraft had disappeared from the radar screen, and there were no signs that he was attempting to recover from the steep, spiral dive.

Conclusion

During a gentle descent from FL95 to FL75 in instrument meteorological conditions G-TWIG rapidly entered a dramatic and sustained manoeuvre from what initially appeared to be controlled flight at normal descent speed. Despite a determined and thorough investigation, because there was insufficient evidence from which to draw a firm conclusion, the cause or causal factors for this rapid deviation from controlled flight could not be identified.

Safety Recommendations

Internationally agreed standards did not require G-TWIG to carry either a flight data recorder or a cockpit voice recorder but the investigation of this accident would have been greatly enhanced if audio and basic flight parameter recordings had been available.

For accidents where there has been extensive disruption of the aircraft, it may not be possible to determine the causal factors from wreckage analysis and witness evidence alone. Yet with aircraft of G-TWIG's weight category undertaking commercial air transport, installing a traditional flight data recorder, with its array of remote sensors, would be impractical and economically unacceptable. An alternative and potentially more practical solution would be to record the activity of the pilot(s), flight controls, flight instruments and instrument panel selectors using imagery techniques. The addition of audio recording to the image recording system would enhance the availability of evidence for accident and incident investigation. However, before appropriate recording equipment can be developed, a minimum performance specification must be developed. To that end, in the report on the accident to G-BGED (AAIB Bulletin 11/2005) the AAIB made the following recommendation:

Safety Recommendation 2005-062

It is recommended that the European Aviation Safety Agency [EASA] develop standards for appropriate recording equipment that can be practically implemented on small aircraft.'

Also, two safety recommendations, 2004-084 and 2004-085, were made as a result of the investigation into the accident to helicopter G-CSPJ (AAIB Bulletin 1/2005), and these are reproduced below:

'Safety Recommendation 2004-084

The Department for Transport should urge the International Civil Aviation Organisation (ICAO) to promote the safety benefits of fitting, as a minimum, cockpit voice recording equipment to all aircraft operating with a Certificate of Airworthiness in the Commercial Air Transport category, regardless of weight or age.'

'Safety Recommendation 2004-085

The Department for Transport should urge the International Civil Aviation Organisation (ICAO) to promote research into the design and development of inexpensive, lightweight, airborne flight data and voice recording equipment.'

In a letter to the AAIB, dated 14 October 2004, the Department for Transport gave its full support to these recommendations.

With EASA assuming responsibility for matters of airworthiness within the European Community, the following two recommendations were made in the G-BXLI report (AAIB Bulletin 1/2006):

'Safety Recommendation 2005-100

The European Aviation Safety Agency should promote research into the design and development of inexpensive, lightweight, airborne flight data and voice recording equipment.'

'Safety Recommendation 2005-101

The European Aviation Safety Agency should promote the safety benefits of fitting, as a minimum, cockpit voice recording equipment to all aircraft operated for the purpose of commercial air transport, regardless of weight or age.'

Recommendations 2005-100 and 2005-101 are appropriate to this accident. As yet, no response to these recommendations has been received from the EASA.