CONTENTS

COMMERCIAL AIR TRANSPORT

GENERAL AVIATION

SPORT AVIATION / BALLOONS

ADDENDUMS and CORRECTIONS

(ALL TIMES IN THIS BULLETIN ARE UTC)

INCIDENT

Aircraft Type and Registration:	Avro 146-RJ100, G-JEAV (and others and Embraer 145)
No & Type of Engines:	4 Lycoming ALF502R-5 turbofan engines
Year of Manufacture:	1986
Date & Time (UTC):	17 January 2006 at 1600 hrs
Location:	Between Southampton and Manchester
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 37
Injuries:	None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	N/A
Commander's Flying Experience:	N/A
Information Source:	Aircraft Accident Report Forms submitted by pilots and subsequent enquires by the AAIB

Synopsis

AAIB Bulletin 4/2006, published in April 2006, documented numerous occurrences of flight control restrictions experienced during the winter of 2004/2005 on aircraft with non-powered flying controls. These events were believed to have been caused by the freezing of the rehydrated residues of thickened de/anti-icing fluids, that had accumulated in the aerodynamically 'quiet' areas of the elevator and aileron controls. The bulletin described the contributory factors involved and made safety recommendations, addressed to the Joint Aviation Authorities (JAA) and European Aviation Safety Agency (EASA).

In the winter of 2005/2006, many more events of control restrictions were reported to the AAIB, by UK operators of Avro 146/RJ and Embraer 145 aircraft types. These events are presented in this report, which re-states the safety recommendations made in AAIB Bulletin 4/2006.

The AAIB has repeatedly expressed its concerns to the UK CAA, the JAA and EASA, that effective measures to address the airworthiness concerns posed by the residues of thickened de/anti-icing fluid have yet to be implemented.

Flight control restriction events - winter 2005/2006

The most recent control restriction events reported to the AAIB are described in the attached tables. Table 1 presents the incidents to Avro 146/RJ aircraft and Table 2 the events to Embraer 145 aircraft.

	DATE	Aircraft Tail No./ Sector	INCIDENT DESCRIPTION	FINDINGS
1	27-Mar-06	G-JEAV Birmingham - Toulouse	During cruise at FL270, a/c was sluggish during an autopilot-controlled turn & failed to roll level out of the turn. 'AIL' warning caption appeared. On disconnecting autopilot, aileron controls were very stiff and resistant to movement, but the a/c remained controllable. Flight continued to destination & aileron controls became normal as conditions warmed. The takeoff and climb to FL150 were in wet conditions. AAIB File ref: EW/G2006/03/19	A/c had been parked on the ramp overnight, during which there had been significant rainfall. A glutinous opaque fluid was found in the control runs inside the wings after removing inspection panels. A/c had been previously de-iced on 22 March 2006.
2	27-Mar-06	G-JEAJ Southampton - Bergerac	Departed Southampton in rain (OAT +10 deg C). A/c climbed to FL270 with a/c & autopilot performing normally. A/c was accelerated to M 0.7 and on passing the French coastline the aileron trim caption illuminated for a short time. Later on when following an ATC instruction to change heading, the caption reappeared and the a/c failed to follow the flight director bars. When autopilot disconnected, ailerons were very stiff to operate. Aileron stiffness disappeared when descending through FL100.	
3	20-Feb-06	G-JEAY Southampton - Malaga	During cruise at FL270 with autopilot engaged, flight director gave a large right turn indication. When autopilot disconnected, a/c was found to be difficult to turn left & almost impossible to turn right. 'PAN' declared with request to route direct back to Southampton. A/c was descended into warmer air. Greater aileron control experienced from 4000 ft in the descent, but controls seemed very sloppy. AAIB File ref: EW/G2006/02/11.	Left & right ailerons inspected, panels 581 & 681AAB, 581/681ABB, 533 & 633AB, 533 & 633CB removed. Accumulations of de-icing fluid (rehydrated) found & removed on left & right ailerons beneath panels 581/681AAB & 581/681ABB.
4	15-Feb-06	G-JEAJ Southampton - Edinburgh	Takeoff & climb were uneventful. In level flight at FL140, with autopilot engaged, a/c started to sink (-300 ft/min) & then climbed at 500 ft/min. The autopilot was disengaged at FL142 and FL140 was regained, but it was noted that the controls were stiff. Control column & elevator trim wheel became 'locked'. Slight stiffness of aileron controls also noted. 'PAN' declared for 'no pitch control'. A/c was descended to FL60-70 by gentle reduction of engine power. At FL60 (OAT +3 deg C), controls gradually returned to normal. AAIB File ref: EW/G2006/02/05.	A/c had been parked outside in heavy rain overnight. On stand at Edinburgh de-icing fluid seen oozing from air-conditioning bay hatch, although the a/c had not been de-iced that day.
5	04-Feb-06	G-CFAA Madrid - Birmingham	Autopilot was disconnected at FL210 & a/c flown manually for an approach to Birmingham. Manual trim felt unusually stiff but the trim motor operated satisfactorily. Manual trim returned to normal on final approach. AAIB File ref: EW/G2006/02/16.	A/c Technical Log showed that the a/c had recently been de-iced with Type IV de-icing fluid.
6	20-Jan-06	G-MANS Inverness - London Gatwick	In cruise at FL270, aileron trim warning occurred in turn at a waypoint. Manual roll control was available, but abnormally heavy in both directions. No further aileron trim warnings after autopilot re-engaged. Aileron controls were rechecked when passing through 0 deg C level around 6,000 ft, when roll control was normal to the right, but still heavy to the left. Aileron control forces had returned to normal by 4,000 ft. AAIB File ref: EW/G2006/01/23.	

TABLE 1: Winter 2005/2006 Flight Control Restriction Events - Avro 146/RJ

	DATE	Aircraft Tail No./ Sector	INCIDENT DESCRIPTIONS	FINDINGS
7	17-Jan-06	G-JEAV Southampton - Manchester	On reaching FL220, altitude was captured & locked. Flight director however continued to show a fly-up indication, which was increasing. A/c then tried to climb to follow flight director. Autopilot was disconnected & a/c flown manually. A/c wanted to pitch up & when electric trim used to compensate, on every occasion the trim returned to its original position. The control column could be held forward using about three times the normal force, but the trim could not be adjusted to hold it there. Controls returned to normal in the descent. AAIB File ref: EW/G2006/01/14.	A/c was removed from service for investigation, which involved removing the elevators. When elevator trim rod fairings removed, significant accumulations of residues of thickened de/anti-icing fluid residues were found (Figure 1). In response to these findings, the a/c manufacturer issued All Operator Message 06/001V. The operator of G-JEAV instigated a fleet-wide check to remove trim tab fairings and inspect for and remove accumulations of fluid residues.
8	17-Jan-06	G-OZRH Paris CDG - Birmingham	During cruise at FL200 elevator trim began pitching a/c up & down, causing a slow but pronounced pitch oscillation. 'ELEV TRIM' caption appeared & trim movement confirmed on trim indicator. Oscillations continued, reaching a max. of +/-300 ft/min. Due to heavy windscreen icing, ice contamination of elevator circuit suspected & descent requested. 'PAN' declared as a/c not maintaining stable level flight. Speed reduced & autopilot disconnected. Strong resistance felt when attempting to move trim wheel. In descent a/c behaved normally & autopilot re-engaged. Oscillations returned when a/c leveled, so a/c flown manually. At FL130 in clear air & OAT 0 deg C, autopilot re-engaged with no oscillations. 'PAN' cancelled & landing uneventful. AAIB File ref: EW/G2006/01/13.	Significant quantities of de/anti-icing fluid residues found under elevator trim tab control rod fairings.
9	08-Jan-06	G-JEAV Bordeaux - Southampton	Takeoff was normal, with initial climb in icing conditions with moderate/heavy rain. In the autopilot-controlled climb in IAS mode, the a/c began to oscillate in pitch, causing the rate of climb to reduce to less than 500 ft/min. Autopilot was disengaged and both crew members expected abnormally stiff elevator controls, which was the case. Although elevator control was stiff, a/c remained controllable and climb was continued to FL280. Flight was continued to destination, with elevator control returning to normal at approximately 5,000 ft altitude. AAIB File ref: EW/G2006/01/07.	When a/c inspected at Southampton, 'significant' quantities of de/anti-icing fluid residues found. Elevator trim tab control rods found coated with fluid residues. See also item 5 above.
10	08-Jan-06	G-JEAV Southampton - Bordeaux	In an autopilot-controlled climb, the a/c had overshot the assigned FL270 by 100 ft, at which point the autopilot was disconnected & manual control assumed in an attempt to level off. The a/c felt 'tail heavy' & required the strength of both pilots pushing on the control column to level off, but the cleared level was still busted by 250-300 ft. Elevator trim position did not appear grossly abnormal; manual flying was very difficult, but the a/c was controllable. 'PAN' declared. Radar vectors requested for long final to configure early for landing. At approx. 5,000 ft elevator forces were normal again. AAIB File ref: EW/G2006/01/05.	A/c tail inspected at Bordeaux by an engineer using a 'cherry picker' hoist. Small patches of de-icing fluid residue found externally on control surfaces. Residues were cleaned off and further inspections requested on return to Southampton. See also item 5 above.
11	08-Jan-06	G-JEAJ Chambery - Southampton	Aileron trim warning occurred 15 mins into the cruise at FL270 (OAT -40 deg C) in clear conditions. The flight director commanded a right turn on passing over a waypoint but the autopilot did not respond & the a/c remained wings level. The autopilot was disconnected & a right turn attempted manually. The ailerons were found to be very stiff/almost jammed to the right, but a small amount of right roll was achieved (10 deg bank). The ailerons were also very heavy to the left. A descent was requested and immediately approved. A/c was descended to FL 230 (OAT -23 deg C), where the ailerons freed up, with no further warnings/incidents. Light icing experienced in the climb, but no icing at time of incident. AAIB File ref: EW/G2006/01/06.	Ailerons & elevators inspected for de-icing/anti-icing residue. Minor accumulations noted in aileron void areas. Ailerons & elevators & void areas flushed through with hot de-ice 25/75 mixture to remove residues.

TABLE 1 (cont.): Winter 2005/2006 Flight Control Restriction Events - Avro 146/RJ

	DATE	Aircraft Tail No./ Sector	INCIDENT DESCRIPTION	FINDINGS
1	15-Feb-06	G-EMBK Manchester - Edinburgh	A/c began oscillating in pitch shortly after establishing in the cruise at FL200. On disconnecting the autopilot, it was found that the control column could not be moved fore & aft. Memory drill for jammed elevator actioned, but both control columns remained immovable. A/c could be controlled in pitch by using the pitch trim control. 'PAN' call made to ATC, with a request for a gentle, continuous descent into Edinburgh. During the descent, some column movement became available & a landing was made with 22 degrees flap in accordance with QRH procedure EAP-87 - Jammed Elevator. Both control columns found to be fully free after landing. AAIB File ref: EW/G2006/02/04.	
2	15-Feb-06	G-EMBF Manchester - Dusseldorf	After level off at FL310 with autopilot engaged, a/c started porpoising with a rate of climb & descent of 1000 ft/min. Autopilot was disconnected, aircraft re-trimmed & autopilot re-engaged, after which the a/c began porpoising again & over a period of 1 ½ minutes reached a rate of climb & descent of 1,500 ft/min. When autopilot disconnected again it was noticed that there was only approximately one inch forward & aft movement of the control column. Elevator trim operation was normal. QRH procedure EAP-87 - Jammed Elevator consulted for approach & landing info, but it was decided not to disconnect the elevators. A/c was descended to FL280, as no longer RVSM compliant. Flight continued to destination using elevator trim to control pitch & further descent carried out into warmer air. Control column fwd & aft movement began to increase to a maximum of four inches fwd & aft as OAT rose above 0 deg C. Approach & landing were uneventful. AAIB File ref: EW/G2006/02/04.	When a/c inspected on stand, re-hydrated anti-icing fluid found in gaps between stabiliser & elevator control surfaces. The operator has since increased the frequency of inspection for fluid residues on the Embraer 145 fleet.

TABLE 2: Winter 2005/2006 Flight Control Restriction Events - Embraer 145

The symptoms reported are similar, in many of these cases, to those described in AAIB Bulletin 4/2006, which lists the control restriction events reported in the winter 2004/2005 period.

The AAIB had previously highlighted the problems caused by thickened fluid residues in AAIB Bulletins 12/2003 and 2/2004 published on 11 December 2003 and 5 February 2004, respectively.

Following the recent discovery of accumulations of thickened de/anti-icing fluid residues under the elevator trim tab rod fairings on Avro 146/RJ aircraft, Figure 1, the aircraft manufacturer issued an All Operators Message (AOM) 06/001V on 20 January 2006, recommending that operators inspect the area for fluid residues. A copy of the AOM was included in AAIB Bulletin 4/2006.

Figure 1

G-JEAV Left-hand elevator trim tab control rods, with fairing removed. Residues shown four minutes after re-hydration by water mist.

ERA Winter Operations Workshop

Recognising the lack of effective progress made by the industry in solving the problems posed by the rehydrated residues of thickened de/anti-icing fluids, the European Regions Airline Association (ERA) convened a Winter Operations Workshop on 11-12 April 2006. The purpose of the workshop was to find solutions to the safety problems caused by the thickened fluid residues and inconsistent standards of de/anti-icing service provision within Europe. The attendees included airline operators, aircraft manufacturers, JAA, EASA, de/anti-icing fluid manufacturers, de/anti-icing service providers, national airworthiness authorities and accident investigation authorities, including the AAIB.

The workshop reached consensus on a number of specific goals which needed to be achieved in order to ensure flight safety. A copy of the ERA newsletter describing these actions is attached to this bulletin for reference, Figure 2.

Discussion

The numerous incidents in the winters of 2004/2005 and 2005/2006 in the UK, of flight control restrictions believed to have been caused by the freezing of residues of thickened de/anti-icing fluids, show that this problem still has not been effectively addressed by the industry. This is a matter of concern, given that the potential dangers posed by such residues have been publicised by the AAIB, and other organisations. Experience has shown that the currently available thickened de-icing fluids, with their rehydratable residues, are not practically suited for use on aircraft with non-powered flight controls and continue to pose a hazard to flight safety through their ability to cause flight control restrictions.

european regions airline association

news

Experts unite to improve winter aviation safety

20/04/2006

Aircraft de/anti-icing experts are working together to plan vital safety improvements in this unregulated area.

A unique workshop arranged by the European Regions Airline Association (ERA), the Joint Aviation Authorities (JAA) and Swiss International Air Lines saw 65 delegates representing airlines, aircraft manufacturers, service providers, national authorities, the European Aviation Safety Agency (EASA), JAA, accident investigators, fluid manufacturers, flight and cabin crew unions and auditors meet in Basel, Switzerland, from 11-12 April.

The workshop set out to find solutions to the safety problems caused by thickened fluid residues and inconsistent standards of service provision within Europe.

Following detailed discussions the following goals were unanimously agreed upon:

- Type I de-icing fluid should be more readily available at more airports;
- Operators should be able to receive on demand the service they request, including two-step de/anti-icing;
- Service providers should be licensed and overseen by a regulatory body;
- De/anti-icing personnel should be licensed by a regulatory body;
- Consideration should be given to the certification of de/anti-icing products;
- A greater amount of independent research and development should be conducted into the behaviour of thickened fluids and the prevention of residue formation.

New UK Air Accident Investigation Board (AAIB) recommendations, presented at the workshop, clearly indicate it is time regulatory bodies within Europe took some responsibility and helped the industry by developing suitable legislative solutions. Operators have previously developed their own detailed and costly maintenance programmes to mitigate against the risks that exist from re-hydrating fluid residues. The problems, which include the freezing of flight control surfaces, have existed for more than nine years and delegates at the workshop were adamant that action needs to be taken immediately to reduce the likelihood of an accident.

ERA will use the workshop consensus to encourage national authorities to combine knowledge and resources and set a timetable for addressing these action points. ERA does not consider inaction to be an acceptable option.

NOTES FOR EDITORS
Founded in 1980, ERA is the recognised representative body for intra-European air transport. It currently represents 68 airlines and over 150 Associate and Affiliate members, including most of the principal airframe and engine manufacturers, suppliers and airports from throughout the area. For further information, please contact: Steve Garrett, Manager Operations and Safety | Tel: +44 (0)1276 485552 | Fax: +44 (0)1276 857038

Figure 2

It remains the AAIB's view that Regulators introduce, without delay, requirements for the properties of de/anti-icing fluids and how they are applied to aircraft, to ensure that acceptable standards of quality and safety are maintained.

Safety Recommendations

Flight control restrictions, on aircraft with non-powered flying controls, caused by the re-hydrated residues of thickened de/anti-icing fluids have been well documented in previous AAIB Bulletins. Despite this, recent events in the UK, in the winter of 2005/2006, have shown that the problem is still prevalent.

The safety recommendations issued by the AAIB in bulletin 4/2006 were intended to encourage the European Regulatory Authorities to address the problem, highlighted in AAIB Bulletins 12/2003 and 2/2004. A satisfactory resolution has yet to be achieved, therefore these safety recommendations are re-stated as follows:

Safety Recommendation 2005-135

It is recommended, that the Joint Aviation Authorities, in consultation with the European Aviation Safety Agency, issue safety documentation to strongly encourage operators of aircraft with non-powered flight controls to use Type I de/anti-icing fluids, in preference to 'thickened' fluids, for de-icing.

Safety Recommendation 2005-136

It is recommended that where the use of 'thickened' de/anti-icing fluids is unavoidable, the Joint Aviation Authorities, in consultation with the European Aviation Safety Agency, ensure that operators of aircraft with non-powered flight controls who use such fluids, invoke controlled maintenance procedures for the frequent inspection for accumulations of fluid residues and their removal.

Safety Recommendation 2005-137

It is recommended that the European Aviation Safety Agency introduce certification requirements relating to de/anti-icing fluids for use on aircraft with both powered and non-powered flight controls.

Safety Recommendation 2005-148

It is recommended that prior to the European Aviation Safety Agency assuming responsibility for operational matters within Europe, they consider the future need for the training and licencing of companies who provide a de/anti-icing service, so that anti-icing fluids are applied in an appropriate manner on all aircraft types, but specifically to ensure that the entry of such fluids into flight control mechanisms and control surfaces is minimised.

INCIDENT

Aircraft Type and Registration:	BAe 146, EI-CPJ
No & Type of Engines:	4 Lycoming LF507-1F turbofan engines
Year of Manufacture:	1994
Date & Time (UTC):	7 October 2005 at 1823 hrs
Location:	Runway 10, London City Airport
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 41
Injuries:	Crew - None Passengers - None
Nature of Damage:	None known
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	11,000 hours (of which 5,000 were on type) Last 90 days - 150 hours Last 28 days - 38 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During the landing roll, after the nose wheel made contact with the runway, the nose landing gear began a violent shimmy, which continued until the aircraft came to rest. During the ground roll, the nose wheel steering system was found to be ineffective. Initial examination revealed that the anti-torque links central pivot bolt was missing, although it was not determined whether this had had been a consequence of, or had precipitated, the shimmy. Later examination revealed that the nose wheel steering/friction damper breakout torque was some 34-40% of the specified value and the oleo inflation pressure some 28% above its specified value.

History of the flight

After a gentle touch down on Runway 10, the nose wheel started to vibrate as it made contact with the runway. When braking was applied to the main wheels, the vibration became severe; brake pressure was then reduced, but the vibration persisted and the nose wheel steering was found to be inoperative. Because of the severity of the vibration, the aircraft was brought to rest as quickly as possible, using moderate differential braking to maintain directional control, and the first officer transmitted a PAN call to ATC.

After having come to rest, the airport Rescue and Fire Fighting Service (RFFS) attended the aircraft and the commander was asked by ATC to communicate directly with them on 121.6 MHz. The crew then saw a fireman apparently attempting to communicate with the aircraft by means of a hand-held radio, but nothing of his message was heard on board the aircraft. He was asked to repeat his message, and, on that occasion, communications improved sufficiently that most of his message was received. An engineer then attended the aircraft and, after carrying out a visual inspection of the nose landing gear (NLG) climbed into the cockpit via the electronics bay and informed the crew that a bolt was missing from the torque link assembly. The aircraft was subsequently towed to its stand, and the passengers disembarked normally. The missing bolt was not recovered, despite an extensive search both at London City Airport and its departure airfield.

Aircraft examination

Detailed inspection of the NLG by the operator's line engineering staff, and later by specialists from the landing gear manufacturer, confirmed that the bolt which forms and the central pivot in the torque link assembly was missing. It was also established that after this bolt had detached, the upper half of the torque link had pivoted down such that its free end had come into contact with a shoulder on the lower (sliding) part of the landing gear. In doing so, it had become, in effect, a solid strut which had prevented the oleo from compressing during the roll out. As a consequence, the full weight of the nose, some 2.5 tonnes, had been supported by the trapped upper link.

Except for localised damage on the nose leg itself, caused directly or indirectly by the torque link disconnection, no damage was found either on the NLG assembly or in the nose wheel bay. The NLG was subsequently removed from the aircraft and taken to the manufacturer's facility where it was subject to detailed examination. No abnormalities could be found externally except for localised damage to the torque link components and adjoining parts of the landing gear housing, which had evidently occurred after, and as a direct consequence of, the bolt separation.

Subsequent checks carried out in a test rig revealed that the nose wheel steering/castering friction damper breakout torque was approximately 35-40% of the specified value. It was considered by the manufacturer that the effect of this would be to predispose the gear to a divergent shimmy oscillation, of the type which had occurred during the landing. Also, evidence was found of internal oil leakage past the seals of the oleo strut, and its inflation pressure was found to be approximately 28% above the specified value; apparently in compensation for the loss of oil from the working section of the strut. However, this was not considered to have been a causal factor in the violent shimmy or the loss of the torque link bolt.

To date, no explanation has been found for the separation and loss of the torque link bolt assembly, nor has it been possible to determine whether the loss of the bolt was the cause, or a merely a symptom, of the shimmy which occurred during the landing. The NLG manufacturer is undertaking further detailed inspection of the unit concerned as it undergoes repair and overhaul, and an addendum will be issued to this report in the event that further information of relevance comes to light.

INCIDENT

Aircraft Type and Registration:	BAe 146-200, G-JEAY
No & Type of Engines:	4 Lycoming ALF502R-5 turbofan engines
Year of Manufacture:	1989
Date & Time (UTC):	13 April 2006 at 0640 hrs
Location:	Shortly after departure from Southampton
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - None Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Overheated vertical gyro unit
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	10,900 hours (of which 4,600 were on type) Last 90 days - Not known Last 28 days - Not known
Information Source:	Aircraft Accident Report Form submitted by the pilot and follow up inquiries to operator's maintenance organisation

Synopsis

Shortly after takeoff, a fault in the power supply to a 'vertical gyro' caused instrument malfunctions and an electrical burning smell throughout the aircraft. A PAN was declared and the aircraft returned to Southampton where an uneventful landing was made.

History of the flight

Shortly after departure from Southampton, the 'attitude' warning flag appeared on the Captain's Attitude/Direction Indicator (ADI) and, simultaneously, the TCAS failed. Both ADIs were selected to the No 2 system and the 'attitude' flag cleared; however, the TCAS remained inoperative. A few minutes later, an electrical burning smell became apparent on the flight deck and, at about the same time, the cabin crew called the flight crew to advise that they could smell something odd in the forward galley area. A decision was made to return to Southampton and, after declaring a PAN, an uneventful landing was made. Since the smell did not appear to be getting any worse, and there was no sign of smoke, the aircraft was taxied to a stand where the passengers disembarked normally.

Investigation by the operator's maintenance organisation identified a defective 'vertical gyro' in the avionics bay as the source of the problems. Upon replacement of this unit, both the TCAS and ADI faults cleared and the aircraft operated subsequently with no further problems being reported. The 'vertical gyro' was returned to the manufacturer for investigation, where a defect was found in the unit's power supply. This had caused its transformer and associated components to overheat. After replacement of the affected components, the unit was tested and performed to specification.

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

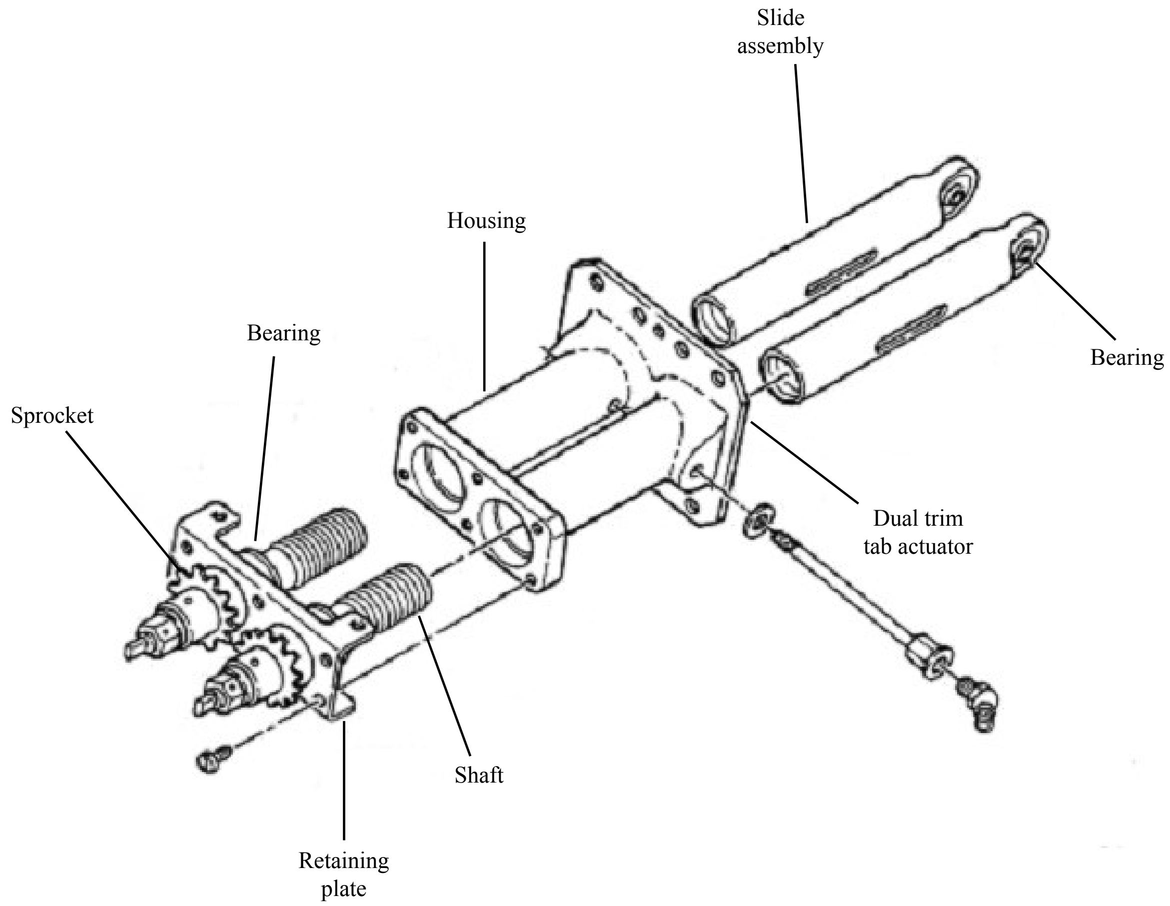

Diagram of elevator trim jack

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.

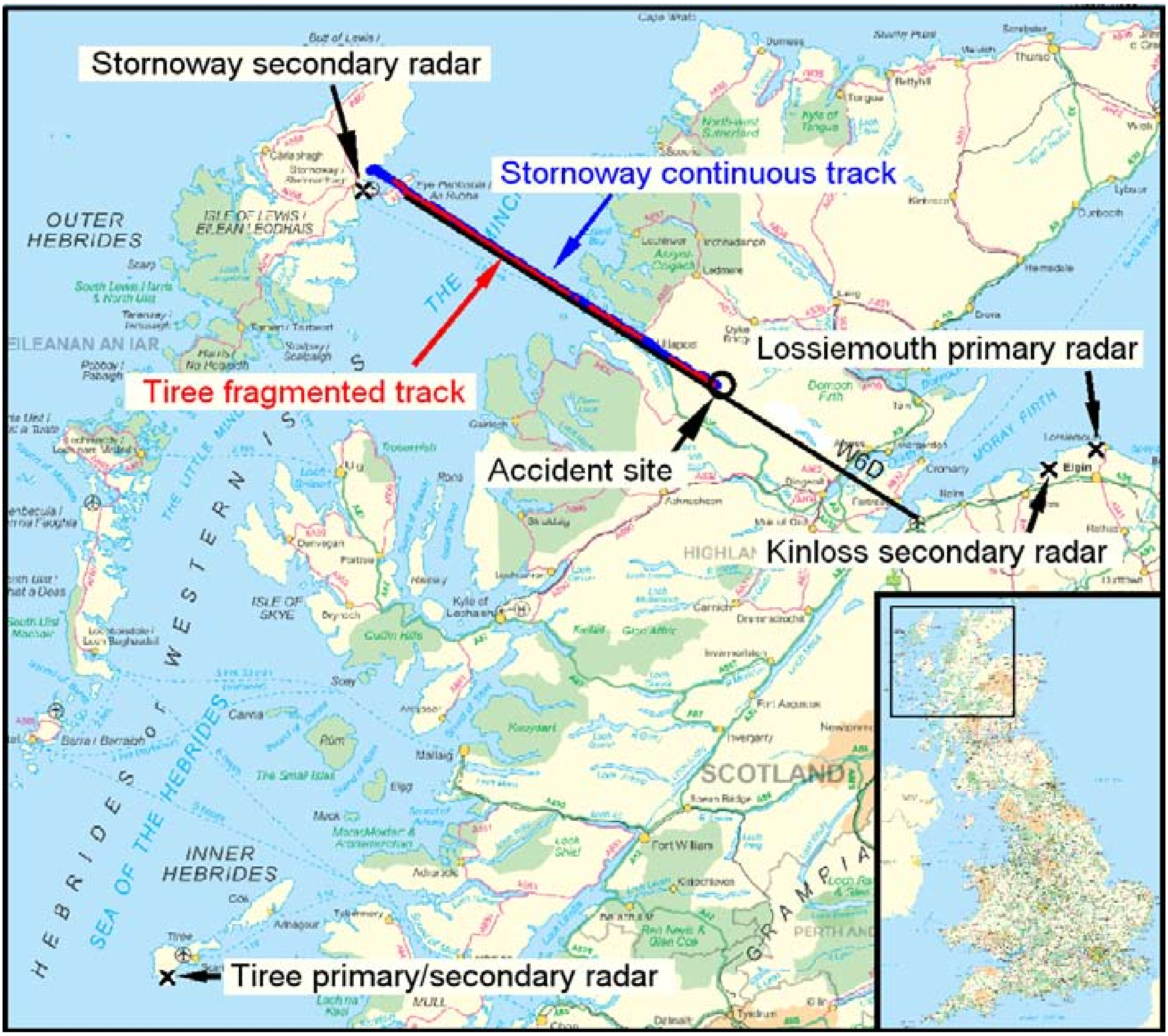

Figure 3

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.

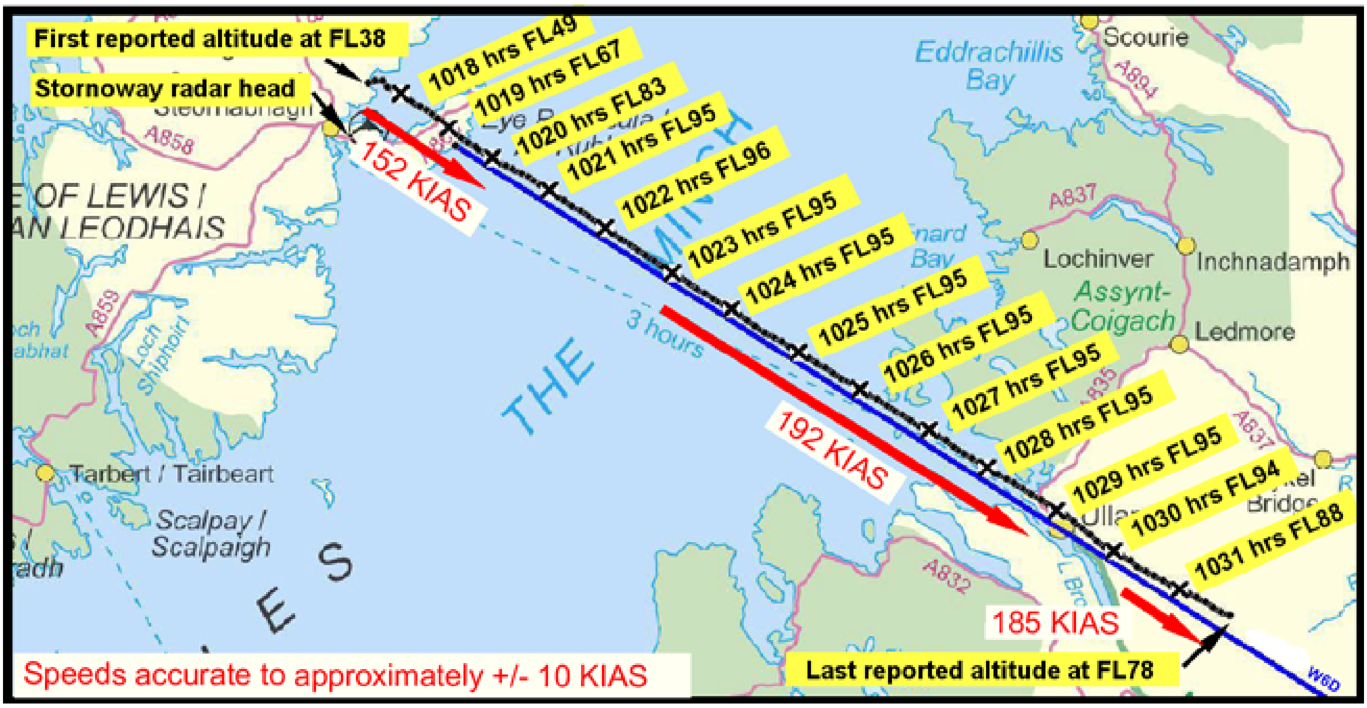

Figure 4a

The Stornoway secondary radar track with reported altitude

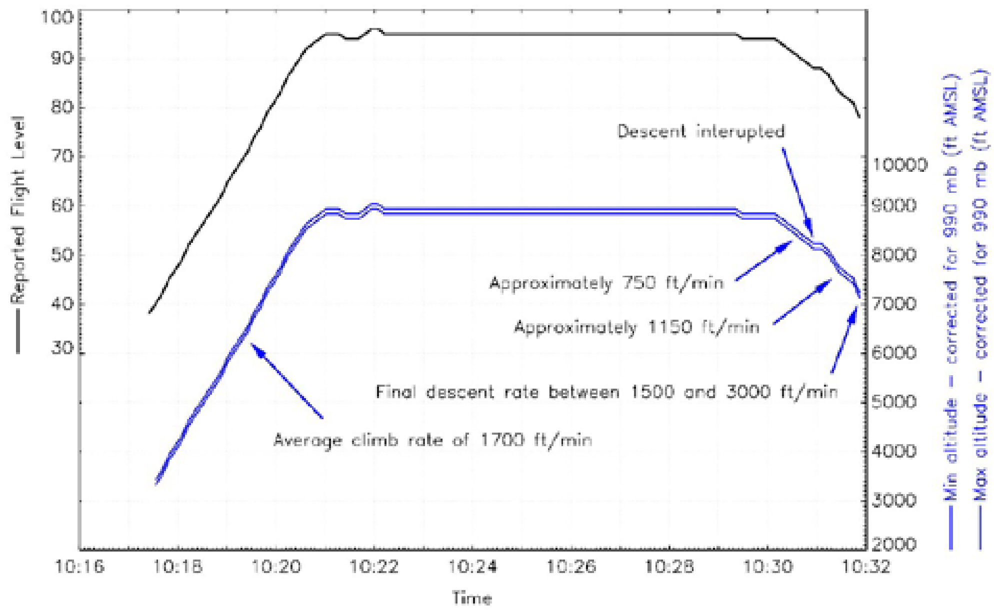

Figure 4b

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.

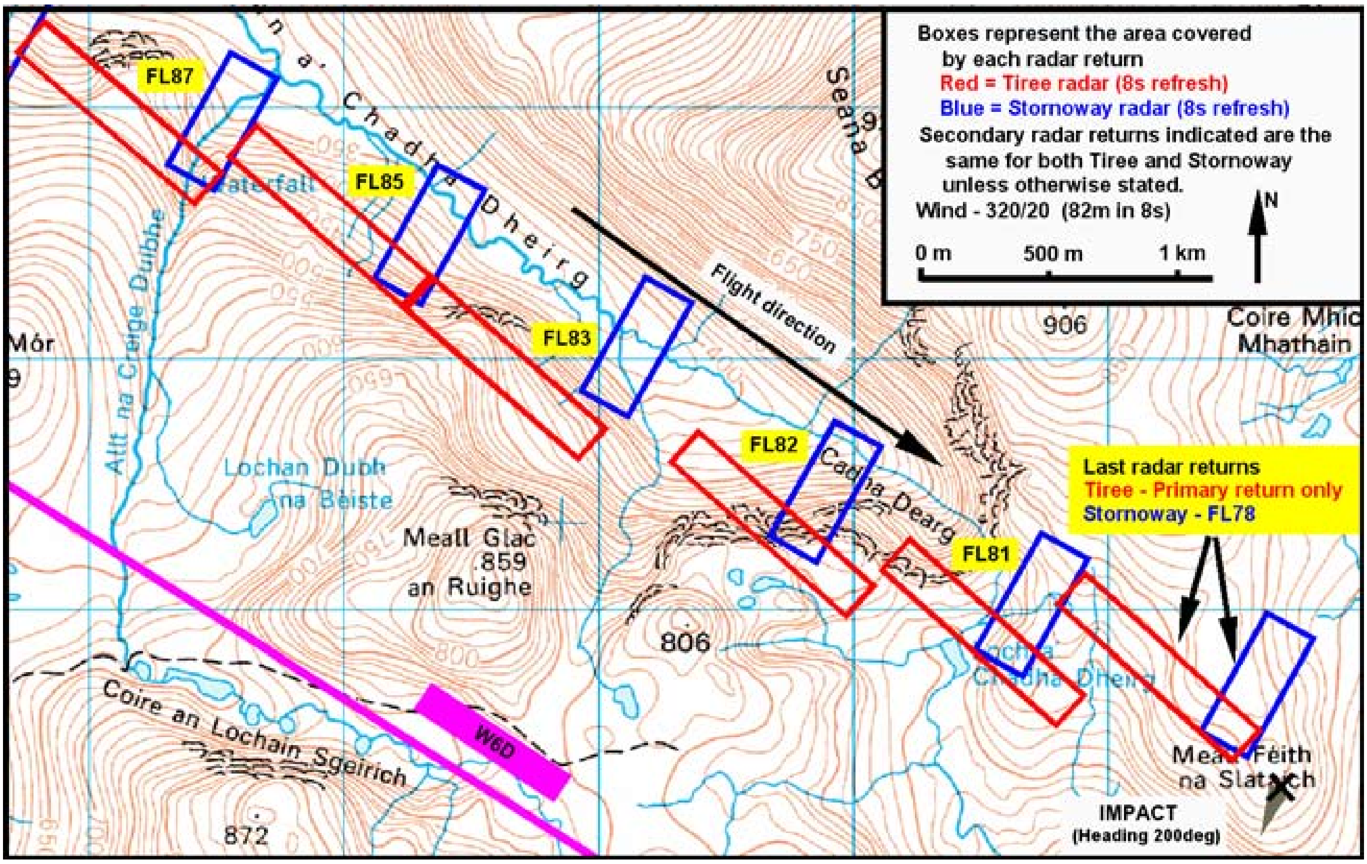

Figure 5

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

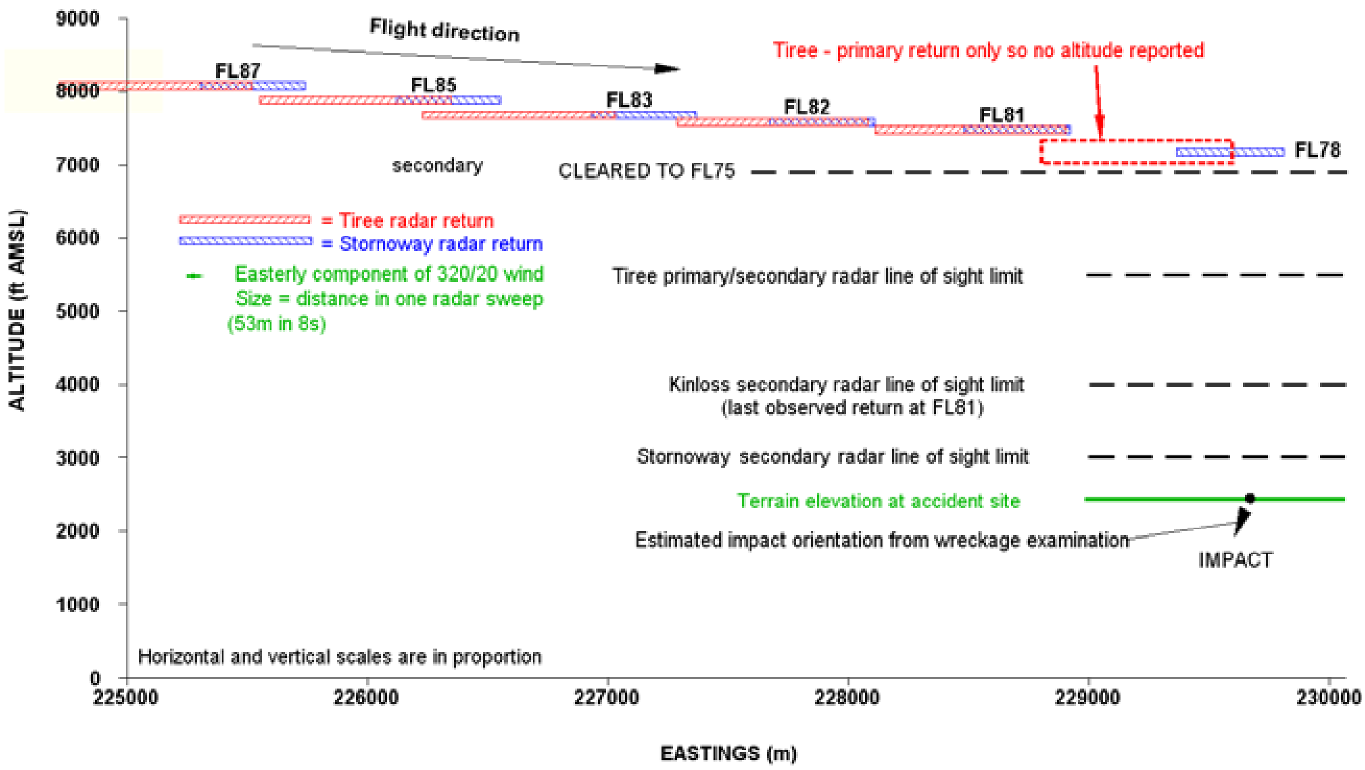

Figure 6

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.

ACCIDENT

Aircraft Type and Registration:	AS355F1, G-XCEL
No & Type of Engines:	2 Rolls-Royce (Allison) 250-C20F turboshaft engines
Year of Manufacture:	1985
Date & Time (UTC):	2 December 2003 at 1438 hrs
Location:	Hurstbourne Tarrant, near Andover, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 2
Injuries:	Crew - 1 (Fatal) Passengers - 2 (Fatal)
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	51 years
Commander's Flying Experience:	7,800 hours (of which 1,322 were on type) Last 90 days - 81 hours Last 28 days - 18 hours
Information Source:	AAIB Field Investigation

Synopsis

The helicopter was engaged on a post-maintenance test-flight following the fitment of a newly-overhauled main rotor gearbox and combining gearbox. Eyewitnesses heard unusual noises coming from the helicopter before the tail boom apparently folded forward around the cabin. The helicopter then fell to the ground, catching fire on impact. All three occupants received fatal injuries. Examination showed that the two gearboxes and the main rotor had detached before impact. Subsequent investigation showed that the left freewheel showed clear evidence of slippage under load; the right freewheel also showed signs of slippage but not to the same extent.

It is concluded that a series of freewheel slippages followed by aggressive re-engagements led to the structural failure. The reasons for the slippage however, cannot be proven conclusively. Although it was found that the rollers forming part of the freewheel mechanism had come from a manufactured batch that had been coated using an incorrect process, no laboratory testing could reproduce any greater tendency for such a coating to cause slippage. The helicopter manufacturer recorded five incidents of slippage under load, coinciding with the introduction of rollers from this batch. Satisfactory performance of the freewheels resumed following the removal from service of the incorrectly coated batch of rollers.

History of the flight

Maintenance work had been conducted on the helicopter requiring the pilot to spend two days completing engine ground run tests with the two engineers who had carried out the work. On the morning of the accident the pilot carried out a short flight to check that the helicopter's handling was satisfactory and to examine the extent of a torque difference between the engines that had been identified during the previous ground runs. The two engineers were on board for the uneventful 17 minute flight.

Adjustments were made to the helicopter, by one of the engineers, to rectify the difference in torque. About an hour after landing the helicopter, with the same pilot and engineers on board, departed for a further airtest. The purpose of the flight was to confirm that the adjustments to balance the engine torques had been successful.

The air traffic controller's log recorded that the helicopter departed Runway 07 at Thruxton at 1430 hrs. At the time there was a light easterly wind, with good visibility and a cloudbase about 1,200 ft above the airfield. The helicopter was seen to take off and appeared to be flying normally as it departed to the north-east.

Recorded radar data, between 1431 hrs and 1433 hrs, indicated that the helicopter maintained a steady track to the north-east flying at an altitude of approximately 2,000 ft amsl and at a speed of approximately 120 kt. Witnesses, 8 nm from the airfield, saw the helicopter fly overhead and heard it making a loud, and unusual noise, described by one as "a loud screeching mechanical noise". Another witness described seeing the whole helicopter shake. Witnesses then described seeing the tail of the helicopter fold forward against the side of the cabin, without fully separating, and the helicopter fall to the ground. There were variations in the witness accounts; some describing the tail folding to the right and others describing it folding to the left. One witness described seeing one of the main rotors "flip upwards" just before the tail folded.

The helicopter fell to the ground on the ridge of a small hill and caught fire. The emergency services were quickly on the scene; however, all three occupants had been fatally injured in the impact.

Helicopter description

The Eurocopter (Aerospatiale) AS355 series of helicopters were derived from the AS350 Ecurreil (Squirrel) helicopter but were fitted with two turboshaft engines in place of the single engine fitted to the latter. Known in the UK as the 'Twin Squirrel', the first models were equipped with Rolls-Royce (Allison) Model 250-C20 engines whilst later versions (AS355N) were fitted with Turbomeca Arrius engines. G-XCEL was fitted with Rolls-Royce engines. Of particular relevance to this accident is that fuel control in the Arrius engine is achieved by a full authority digital engine control unit (FADEC), whilst the Rolls-Royce engine uses a conventional hydro-mechanical system. Apart from the necessary changes to accommodate the different engine installations, the two helicopter models are essentially the same, particularly with respect to the main rotor transmission. The engines are mounted on the left and right sides of the main transmission deck and are referred to as left and right or No 1 and No 2 respectively.

The power output from each engine, in both helicopter variants, can be trimmed so that the total torque required for flight can be shared equally between the engines. This is commonly known as 'beep trim' and is adjusted by the pilot using a rocker switch on the collective lever. On the AS355N models (fitted with Arrius engines) this is purely an electrical signal working through the two

FADEC's. However, the Rolls-Royce Allison engines use an electromechanical trim actuator to mechanically move the fuel control settings. In both variants this is co-ordinated so that, for example, if the pilot increases torque on the right engine by moving the switch to the right it not only increases the power output of that engine, but decreases power from the left engine. Under certain circumstances it is necessary to perform a 'Power Assurance Check' on each engine. In this case one engine is trimmed to its maximum (or until a limiting parameter is reached) and the other simultaneously trimmed down to deliberately induce a large torque imbalance between the engines. Aircraft and engine performance figures are noted and checked against manufacturer's data in the Flight Manual. This is then repeated for the other engine. The Flight Manual includes graphs for performing the check either in-flight or on the ground, although it appears that the in-flight figures are more accurate.

Engine overspeed

Turbine engines can be subjected to an overspeed condition for various reasons, particularly in the free turbine application (see below). This can cause damage to the power turbine or even rupture of the turbine disc and consequent non-containment. In the case of the Arrius engine, the FADEC is programmed to completely shut down the engine at 115% Nf (power turbine rpm). However, in a twin-engine installation, if one engine has shut-down for any reason, overspeed protection is removed from the other engine and it is possible to burst the power turbine if a serious overspeed condition is also experienced on that engine.

The Rolls-Royce Allison engine has no specific overspeed protection device, but the manufacturer stated that the normal governing function of the Power Turbine Governor is sufficient to prevent an overspeed burst of the turbine. Data was presented from a test on a Model 250 engine in which the load was abruptly removed whilst the power turbine was delivering 100% torque. The turbine accelerated rapidly to 142% Np before settling back to a steady state 'no-load' condition of 114%. Since the overspeed peak was some 22% below the turbine's burst limit, it was considered that no additional overspeed protection was necessary.

Transmission description

Both types of engine use the 'free turbine' principle to extract power from the gas-generating module of the engine. The power turbine shaft, spinning at high speed, is connected to the engine's own reduction gearbox reducing the output speed to 6,016 rpm. A steel shaft then delivers the power to the helicopter's transmission via a flexible coupling sometimes called a 'Thomas' or 'Flector' coupling. Each Thomas coupling is connected to the input shafts of the Combining Gearbox, which is a separate module forming part of the Main Rotor Gearbox (MRGB). The Combining Gearbox combines the power output from both engines and delivers this to a single pinion gear, which mates with a bevel gear in the MRGB module. The tail rotor drive is also taken from this pinion (see Figure 1). An epicyclic gear within the MRGB, further reduces the rpm to a nominal 394, equating to 100% Nr (main rotor speed).

As is usual with helicopter transmissions, a freewheel mechanism is fitted at the input to the transmission (in this case the Combining Gearbox) for each engine in order to prevent the drag of a failed (or even seized) engine affecting the main rotor speed during single-engine operation or autorotation. In twin-engined installations, it also off-loads the first engine to be started, that would otherwise try to turn the second engine as well if a freewheel was not present.

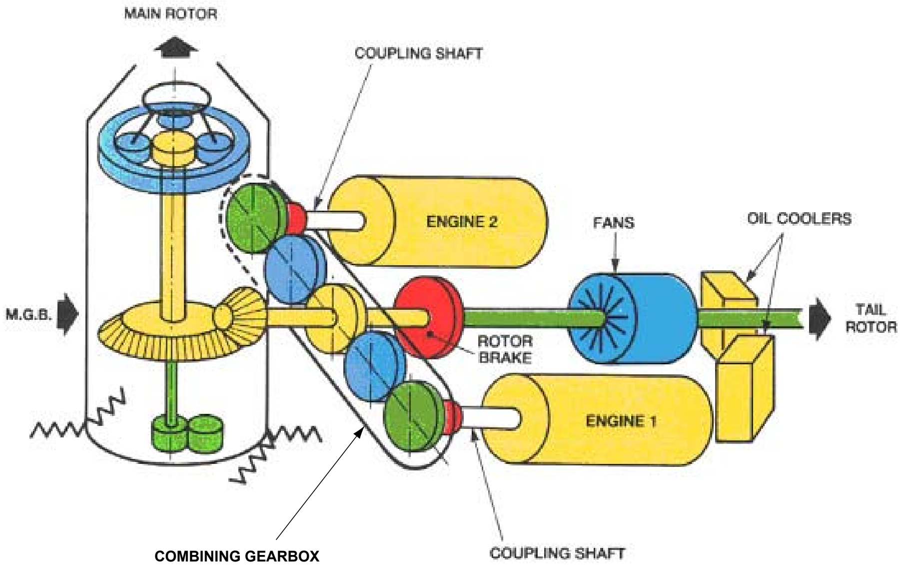

Figure 1

Schematic of AS355 engine/transmission layout

The MRGB/Combining Gearbox assembly is mounted on the helicopter structure by four rigid struts which react lift loads. All other loads and moments are reacted by a flexible mounting plate attached to the bottom of the MRGB.

Main rotor head description

The AS350/AS355 series of helicopters employ a 3-bladed main rotor constructed entirely of glass-reinforced composite materials. Similar material is also used in the main structural members of the main rotor hub which are referred to as the blade sleeves and the 'Starflex'. The 'Starflex' (see Figure 3) is the main hub component, since all loads pass through it. In addition to reacting the centrifugal and lift loads, it also transmits torque to the blades and acts as a spring in the blade

In the case of the AS355, the freewheels are effectively part of the input shafts to the Combining Gearbox and are of a type known as 'ramp and roller'. Referring to Figure 2, it can be seen that the driven shaft (coloured green) rotating clockwise, has a series of angled steps, called 'ramps', machined into it. Fourteen steel rollers (coloured red) engage in the ramps, enclosed by an outer race (coloured blue) which directly transmits torque to the transmission. A spring arrangement keeps the rollers pressed lightly against the outer race, when torque is not being transmitted, to ensure smooth engagement of the freewheel, particularly during start-up. During engagement, the rollers ride up the ramps and bear upon the outer race, allowing torque to be transmitted from each engine to the transmission. In cases where the transmission attempts to back-drive the engines, the rollers ride down the ramps and, spinning under the light spring pressure, no torque should be transmitted from the transmission to the engines. It should be noted that, in normal operation, drive from the engines to the transmission relies on a minimum level of friction between the rollers, the ramps and the outer race.

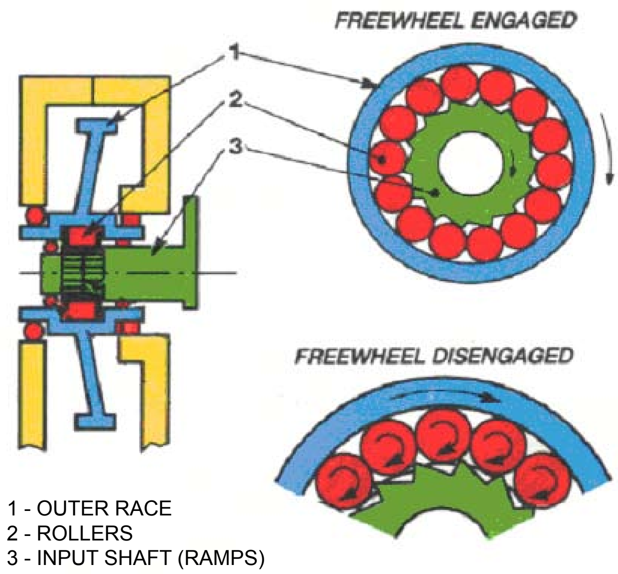

Figure 2

Principle of operation of 'Ramp and Roller' freewheel mechanism flapping sense. Thus it is rigid in all axes except flapping, when it acts as a flexible beam outboard of the laminated spherical bearing.

Maintenance history

G-XCEL had flown a total of 3,296 hours at the time of the accident. On 17 September 2003 it was presented for maintenance at a JAR-145 organisation based at Thruxton Aerodrome. The organisation was tasked with carrying-out a routine 100-hour check but, in addition, there was a requirement to change the Main and Combining gearboxes, which had reached their statutory overhaul life. The MRGB was overhauled by the UK agent for Eurocopter but the Combining gearbox had to be exchanged for an overhauled unit supplied by Eurocopter, Marignane. The two units were mated and fitted to G-XCEL.

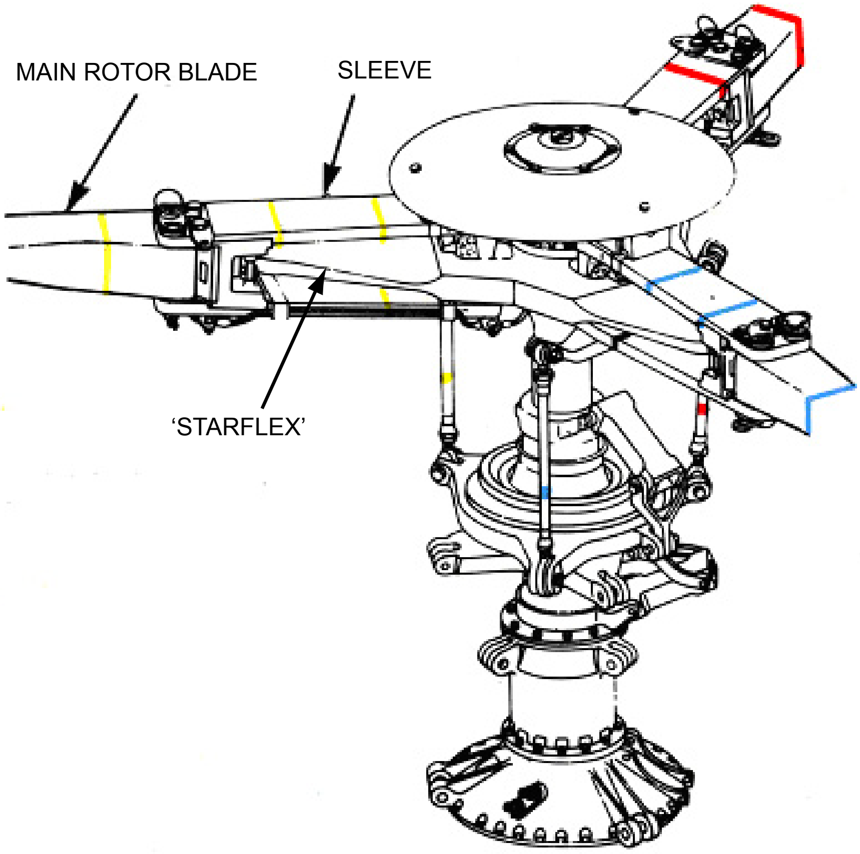

Figure 3

AS355 main rotor head

The day before the accident, the work was effectively complete and the helicopter engines were ground run; there was then a short test flight. This resulted in the following entry on the worksheet:

> *'Insufficient TQ (torque) crossover on ground governor beep test (Number one set too low')*

The rectification action, entered by the same engineer, was:

> *'3 Turns shortened on outer Ng (gas generator speed) cable at ball joint (below rotor brake) locked and torque sealed orange'*

Although both engineers involved in the maintenance of G-XCEL and the pilot sadly perished in the accident and so could not confirm it, one of the purposes of the accident flight was almost certainly to check that this adjustment had achieved the required effect. It was also possible that the pilot may have taken the opportunity to perform an in-flight power assurance check, which his company specified on a regular basis.

Examination of the accident site

The main wreckage was in a copse at the edge of a grass field near the village of Hurstbourne Tarrant, near Andover, Hampshire. The fuselage had landed inverted and there had been considerable burning on the ground. The entire primary structure was present at this location, excluding the MRGB, the Combining Gearbox and the main rotor. These were found, in an unburnt condition, 20 m south-west of the fuselage. All three rotor blades were attached to the hub, although the blade sleeves had become delaminated. None bore evidence of significant leading edge damage indicating very little or no rotation at impact with the trees and ground. It was clear that the MRGB had detached shortly before the fuselage hit the ground due to failure of the four support struts. Both the fuselage and MRGB appeared to have cut vertical paths through the trees indicating little, if any, forward speed. The outboard, flexible, parts of two of the 'Starflex' arms were missing from the main rotor, whilst the third, although present, had also fractured.

The two missing portions of 'Starflex' were found in a relatively compact debris field which lay immediately before the main wreckage. Approximately 100 items were found to have detached from the helicopter prior to impact; these were recovered from an area measuring some 100 m long by 140 m wide. In addition to the 'Starflex' pieces, the debris generally comprised pieces of engine and transmission fairings, contents of the cabin, including a seat cushion, and a 'chin' window transparency. The largest piece was the complete under-fuselage fairing immediately aft of the transparency.

Site examination conclusions

The helicopter had clearly suffered a structural break-up in the air. There was no doubt that the main rotor transmission had detached, probably fairly late in the break-up sequence. Surprisingly, the distribution of wreckage was unable to confirm eyewitness reports that the tail boom had folded, since components such as the empennage and the tail rotor were found with the main fuselage in roughly their correct orientation. It was concluded that the tail boom had not completely detached and had followed the fuselage down, perhaps even resuming its normal position as the two components fell to earth. Certainly, the manufacturing joint of the tail boom was found separated from the fuselage, with compressive buckling on the left side and shear failure of the rivets on the right side, suggesting that the tail boom had failed by bending to the left.

Information from Eurocopter suggested that the release of the under-fuselage fairings, window and cabin contents were consistent with very high vibration levels. The remaining debris comprised what would have been expected as a consequence of 'tearing-out' of the main transmission. At the time, no explanation was forthcoming for the in-flight failure of the 'Starflex' arms, since it was reported that, even with extreme main rotor coning due to low rotor rpm, the 'Starflex' had never been found to fail.

Detailed examination of the wreckage

The wreckage was transported to the AAIB facility at Farnborough. In order to determine the reason for the MRGB detachment, attention focussed on this component and it, together with the combining gearbox, were shipped to Eurocopter in France for strip examination under strict supervision by the AAIB and BEA (the French equivalent of the AAIB). In addition, the remains of the MRGB mounting structure were removed from the fuselage deck and also despatched. Metallurgical examination quickly discounted any anomalies with these latter components, such as missing fasteners or material defects, as having contributed to the detachment.

The 'beep trim' actuator was recovered and it was found that the left engine had been trimmed fully back and the right consequently trimmed fully to maximum.

The first component to be stripped was the combining gearbox. After the casing was split, it could be seen that it was in good condition internally. However, when the two freewheels were extracted, it was obvious that the ramps associated with the left unit were in a highly distressed state, consistent with slippage under load (see Figure 4). There was evidence of wear, overheating and material build-up on the ramps. The rollers too, whilst not showing significant wear, were discoloured due to overheating. The outer race, under moderate magnification, appeared to be normal. The right freewheel bore none of these signs and was, at first, thought to be completely normal. Subsequent comparison with in-service units however, later suggested that the slight polished band on the ramps was not normal for an almost new assembly and that this had probably also slipped, but not to the same extent as the left freewheel. Subsequent strip examination of the MRGB revealed no anomalies with the rest of the transmission.

The broken 'Starflex' was also examined. Eurocopter advised that the fracture faces, which ran roughly at 45º to the axis of the arm across half the section and at 90º across the other half, were indicative of a mixture of torque and vertical bending being involved in their failure. No further explanation of the reason for failure could be offered at that stage.

Metallurgical examination of the freewheels

The AAIB employed the services of a consultant in tribology (the study of friction, wear and lubrication of bearings) to assist in the laboratory examination of the freewheels. There was no doubt that the left unit distress had been caused by slippage under load. Indeed, it was possible to discern impact marks from rollers on adjacent ramps caused by the rollers being violently 'spat out' of engagement and striking the face of the ramp behind them. The depth of the wear on each ramp was in the order of

Figure 4

Left input shaft showing wear and overheat damage to ramps of the freewheel

40-50 microns. Although an attempt was made, it was not possible to determine categorically the severity of any re-engagement by examination of the indentations. However, the remains of the 'Thomas coupling' bolts, which were still retained in the combining gearbox input flange, bore signs of deformation suggesting that at least a 250% over-torque had occurred on both sides. This figure was arrived at through tests and calculations carried out by Eurocopter, early in the helicopter's service life, and is normally used for assessing damage caused by events such as main or tail rotor strikes.

Further consideration of the marks on the right freewheel also concluded that this had slipped, but to a much lesser degree than the left.

The consultant tribologist calculated that, given the profile of the ramps and other dimensions, a minimum friction coefficient of 0.062 is required to prevent slippage. In his opinion, a minimum coefficient of 0.1 would therefore be desirable to allow for a reasonable margin of safety. At any value less than 0.062, slippage will occur. Such slippage could be inherently unstable inasmuch as lubrication could actually be improved for perhaps a few seconds due to oil entrainment velocity. This reduction in friction would allow the power turbine to accelerate. However, after this, friction could build again to the critical value due to heating and scoring of the surfaces, causing re-engagement which could potentially be quite aggressive.

Some concern was raised that graphite grease was used when assembling the gearbox, mainly to lubricate bolt threads, and that this could alter the friction coefficient of the freewheel components if the grease were to contaminate them. Analysis of the oil samples taken during the strip examination subsequently revealed no evidence of grease contamination of the oil.

Metallurgical examination did not, at this stage, reveal any material or dimensional abnormalities with the freewheel components.

Previous instances of freewheel slippage and remedial actions

Following the discovery of the distressed left freewheel, Eurocopter provided the investigation with details of five instances of freewheel slippage, all occurring within a period of about 18 months prior to the accident to G-XCEL. All these incidents had occurred to the AS355N model fitted with Arrius engines. Four of the helicopters were new whilst the other had been fitted with a new MRGB and combining gearbox two operating hours prior to the incident. It is apparent that Eurocopter had linked these with freewheel slippage only after the fourth incident (on 10 November 2003). The first three incidents, commencing in April 2002, had simply been recorded as overspeed shutdowns. With no physical signs of distress of the freewheels, and having verified that there were no dimensional anomalies, problems with the FADEC or wiring were suspected and therefore it was these that became the focus for investigation. However, after the fourth incident, in which an overspeed shutdown of one engine was followed by an overspeed burst of the other, resulting in a heavy landing, a problem with freewheel-slippage under load was suspected. Even then, no physical evidence was noted on the freewheels themselves.

Eurocopter examined their records to see whether any changes had been made in the previous 18 months to any of the processes affecting the friction environment of the freewheels. They found that, in November 2001, they had changed the supplier of the preservative fluid used when delivering new or overhauled gearboxes from their factory in Marignane. Although the fluid was to the same specification as before, and no chemical differences were identified, it was considered that it could have affected, in some unexplained way, the friction coefficient between the rollers and the ramps or outer race. In normal use some preservative fluid remains in the MRGB and Combining Gearboxes, becoming progressively diluted with the normal running lubricant. It was therefore reasoned that only gearboxes with very low running times were vulnerable, explaining why gearboxes with higher service times, although delivered with the same preservative fluid, had not experienced problems. The fifth incident (on 19 November 2003) was a tethered ground test to evaluate a newly-developed flushing procedure for the gearboxes to hasten dilution of the preservative oil into the lubricant. It also apparently demonstrated that the procedure was not effective, since an engine still suffered an overspeed shutdown.

Accordingly, Eurocopter prepared an 'Alert Telex' No 63-00-21 for distribution to all operators of the AS355E/F/F1/F2 and N as well as military variants. This communication which, according to Eurocopter, had first been drafted on 19 November 2003, eventually grounded any MRGB or Combining Gearboxes which were new or newly-overhauled ex-Marignane and which had run less than 10 hours. Again, according to Eurocopter, identifying the affected units and routine delays with DGAC (the French equivalent of the Civil Aviation Authority) approval, translation etc meant that this was not issued until 8 December 2003, six days after the accident to G-XCEL but some three days prior to the discovery of the damage to the freewheel described above. The combining gearbox fitted to G-XCEL would have been grounded under the instructions in the Alert Telex. On 11 December 2003 the DGAC, on behalf of the European Aviation Safety Agency (EASA), issued Emergency Airworthiness Directive (AD) UF-2003-464, making the requirements of the Eurocopter Alert Telex mandatory.

The Alert Telex was soon revised to Revision 1 on 19 December 2003 to include cleaning instructions for the bevel gear module of the MRGB (after which they could be returned to service). It is therefore clear that Eurocopter were still convinced at that time that the root cause of the slippage problem lay with the change of preservative fluid. They still felt however, unable to develop a flushing procedure for the combining gearbox. This followed a further test on 3 December 2003, on the combining gearbox from the 19 November 2003 slippage event which had been stripped-down and cleaned before being re-assembled without preservative fluid. When this experienced a freewheel slippage, yet another test was performed on the same gearbox, this time with grease contamination of the freewheel deliberately introduced. When this test, which took place on 18 December 2003, did not result in a slippage event, Eurocopter concluded that lubricant contamination was not responsible and started further investigation of the freewheel components themselves.

At a meeting with the AAIB and BEA (and later promulgated to operators by Revision 2 to the Alert Telex dated 4 February 2004) Eurocopter advised that they had discovered another change to the manufacturing process that had occurred before the first recorded overspeed incident. This concerned the freewheel rollers themselves which had historically been manufactured by a large German company specialising in bearings and precision machining. Between approximately 1980-1983 they had supplied a large number of rollers to Eurocopter and these were used for subsequent production and overhaul. The rollers were supplied in an uncoated, ‘as-ground’ surface finish.

In 1995, Eurocopter’s stock of the rollers became depleted and they entered into dialogue with their German supplier to manufacture a new batch. It is apparent that Eurocopter asked that these rollers should be supplied with a thin surface coating of zinc phosphate (also known as the ‘Bonderite’ process). The purpose of this was to impart an increased surface roughness to the rollers during the early hours of operation. The high quality surface finish, as delivered, had been found to be prone to occasional slippage under low torque conditions, apparently during first engine start using a new freewheel in cold conditions. They also requested a quotation from the German company to rework the remaining rollers from the original batch with this process. Later, the German company also requested a very minor change to the angle of the chamfer at the ends of each roller for ease of production and this was agreed by Eurocopter.

The subsequent quotation acknowledged that the purpose of the process was to increase the surface roughness of the rollers. However it appears that, whilst the order for new rollers was accepted by Eurocopter, the quotation to rework the existing stock was not since, in 1997, Eurocopter sent the remaining rollers from the initial batch to a local metal finishing company to have the Bonderite process applied. The change was introduced by Eurocopter modification 077159 and all subsequent new and overhauled freewheels used rollers to this standard until 2001, when rollers from the new batch, delivered with a phosphate coating already applied were used instead. An initial consignment of 5,000 of the new rollers was delivered to Eurocopter in July 2000 followed by a second, in two batches, delivered in November and December 2003.

Roller coating anomaly

In January 2004, as part of the investigative work described earlier, it was found that, with the new batches, the roller drawing instructions had not been followed and that a coating of manganese phosphate had been applied. Under its proprietary name of 'Parco Lubrite', and others, this process claims to reduce wear during running-in of machinery, particularly since its large grain size (compared with zinc phosphate) and relative softness can trap oil, which can be squeezed out under high contact pressures – sometimes called the 'sponge theory'. No such properties are claimed for zinc phosphate, which is mainly used as a surface preparation prior to painting but can also bring benefits when forming sheet metal components under high pressures. The unauthorised change in process would not have been detectable by simple visual comparison between correct and incorrect applications.

Eurocopter have also advised the AAIB that, in addition to the coating being of an incorrect chemical composition, it was also thicker than the dimension specified on the drawing (2-5 microns) by a factor of 3 or 4. The German company dispute this, saying that the term 'thickness' is ambiguous and open to interpretation. They define 'thickness' as the increase in overall roller diameter after coating divided by 2 whereas Eurocopter define it by sectioning the specimen and microscopically examining the surface coating as well as the parent material which has been chemically altered. Because either phosphating process etches material *into* the surface as well as depositing it on the surface, the latter approach will give a coating thickness reading greater for two otherwise dimensionally identical items. The German company assert that their coating met drawing thickness requirements and furthermore that rollers coated by Eurocopter's process suppliers did not. Tests on bare rollers manufactured by them and subjected to zinc phosphating, by the same suppliers used by Eurocopter, have suggested that the process was achieving almost no deposition of zinc phosphate on the surface; only a slight etching, effectively roughening the parent steel, was achieved.

Since Eurocopter are the sole supplier of rollers to overhaul and repair shops, limiting affected gearboxes to those overhauled at Marignane was no longer valid, as defective rollers would have been supplied to agencies worldwide. Accordingly, Revision 2 of the Alert Telex grounded any overhauled, repaired or newly-manufactured Combining Gearboxes from *any* source, which had run less than 10 hours. It also mentioned a modification number (077212) which introduced rollers subsequently produced correctly to the drawing requirements. Gearboxes with this modification embodied were permitted to return to service and this was the only action deemed necessary by Eurocopter to 'unground' combining gearboxes affected by Alert Telex 63-00-21.

Testing of freewheel rollers

The reason for retaining the 10 hours threshold, even though its original technical justification had been based on a rationale involving dilution of preservative fluid, was questioned. To this end, Eurocopter embarked on a series of tests in which a MRGB and combining gearbox were connected to a rig capable of driving both input shafts in a manner similar to the two engines. The purpose of the tests was to examine the different behaviour of zinc and manganese phosphate coatings with time of operation in freewheel mode. One freewheel was equipped with manganese-phosphated rollers and the other with zinc-phosphated rollers. The assembly was then subjected to a typical engine start sequence (one freewheel engaged and the other disengaged) followed by the second 'engine start' with both engaged. This was followed by a simulated shutdown sequence. The selection of which 'engine' was started and shutdown first was alternated between the two. After a period of time the test was interrupted and the freewheels disassembled to measure the surface roughness and percentage of coating/iron visible on the surface. The freewheels were then re-assembled and the test resumed, followed by another examination. Accomplishing this many times enabled a graph to be produced showing how the ratio of the surface coating to the amount of base metal (Iron) on each type of roller varied with a number of typical duty cycles, translated into time for which the freewheels had rotated. This graph is reproduced in Figure 5. From this it can be seen that the zinc phosphate coating wears away very rapidly, reaching a figure of 35% visible iron after about 3 minutes of rotation time. The manganese phosphate coating wears much more slowly, reaching the same ratio after about 19 minutes.

It is Eurocopter's considered view that this figure of about 35% of base metal visible, *for either type,* is critical; above that figure, slippage under load is unlikely whilst below that figure it is possible. This percentage was reached after about 3.5 minutes of rotation time for the zinc-phosphated rollers but the manganese-phosphated rollers did not reach the 'critical percentage' until about 19 minutes. They also related these figures to the known history of slippage events, for which the precise operating times and sequences were recorded since the majority took place under their own flight test operations. This comparison enabled a chart to be plotted, relating slippage occurrences to time of freewheel operation since new. From this it was determined that the slippage events all took place within the range of about 100-700 seconds of freewheel rotation time once fitted in the helicopter.

A new set of rollers using both types of coating was then subjected to the normal bench running regime that all gearboxes are subjected to prior to release from the

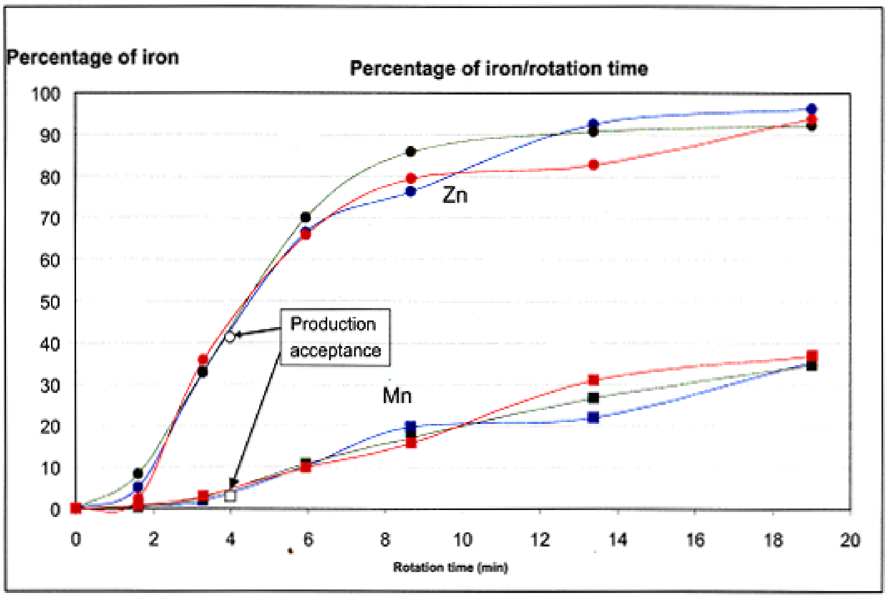

Figure 5

Graph of results from rollers with Manganese and Zinc Phosphate coatings showing percentage of base metal (Iron) visible on the surface plotted against freewheel rotation time

Eurocopter factory. This was found to equate to four minutes of freewheel rotation time, at which time the percentage of Iron visible on the zinc-phosphated roller surface was measured to be about 40%; only some 4% was visible on manganese-phosphated items. From this it was concluded that, when the bench running time is added to the normal post-installation ground running before flight torques are applied, the surface iron/zinc phosphate ratio is comfortably above 35% and slippage will not occur. With manganese phosphate, however, slippage under load is possible for another 10 minutes or so of freewheel rotation time. Eurocopter calculations showed that this equated to about 3 hours of helicopter operation and that, after applying a safety factor of roughly 3, manganese-phosphated rollers, which had run for more than 10 flight hours, could remain in service.

The tests run contrary to the observations made by the German company described earlier, in which they assert that rollers processed by Eurocopter's supplier had almost zero percentage of zinc phosphate visible on the surface before any wear process took place. As discussed later, it remains Eurocopter's position that the percentage of zinc on the surface is not relevant, and that rollers coated to their specification had been proven, by experience, to perform satisfactorily.

Roller manufacture

The German company which manufactured the rollers is a long-established specialist in bearing design and manufacture. Indeed, they are regarded as a '*supplier'* to Eurocopter, since the roller production drawing belonged to them (they would technically be a '*subcontractor'* if they were working to a Eurocopter drawing). The drawing clearly stated the requirement for 'Bonderite 880 phosphating using the Eurocopter process'. The company was not, however, involved in any of the design processes of other components of the freewheel. As an experienced and capable manufacturer of freewheels for other applications (including automotive), they have expressed the opinion that they would normally prefer to at least be fully consulted on the overall design of the assembly and at best be given responsibility for the design.

After the final grinding process, the rollers, accompanied by a routing card which specified the process, were shipped to the company's process shop for phosphating. The person preparing the card had annotated it with the letters PHS, indicating that the parts required phosphating and included the word 'Bonderite' in a remarks section to indicate that it was to be zinc phosphate. Unfortunately, the operator responsible for applying the coating, who was familiar with the manganese phosphate process, since his company produced many components finished in this manner, did not recognise the significance of the word 'Bonderite' and applied the process with which he was familiar. Indeed, it would appear that the company had seldom, if ever, used zinc phosphate before and that their phosphating bath would have required draining of the manganese and re-filling with zinc phosphate solution to fulfil the requirement. This however, did not happen.

The German company supplied a full and frank description of the circumstances which led to the error however, they strongly refute that the incorrect coating could have been responsible for freewheel slippage. In support of this assertion, they provided the AAIB with the results of a series of friction coefficient tests they had conducted (post discovery of the error) in which uncoated specimens, manganese, and zinc phosphate coated specimens were compared. The tests, which measured conventional dynamic friction coefficients of the specimens in lubricated and un-lubricated conditions, were combined with a special static test in which rollers finished in the different ways were loaded between two metal blocks. This attempted to simulate the contact conditions between the freewheel ramps and the outer race. Neither type of test revealed any large differences between the various finishes and the dynamic friction coefficient remained comfortably above the minimum 0.1 value in each case. The company also disputed the theoretical claims made for manganese phosphate in reference works and advertisements for the process, including the 'sponge theory' described above.

In support of their assertion, that some factor other than the incorrect chemical composition of the coating was involved in the freewheel malfunction, they commissioned a wide-ranging report from two German tribological engineering consultants. This report looked at both the theoretical merits and demerits of the 'ramp-and-roller' type of freewheel in helicopter applications as well as a critique of the AS355 design based on 'reverse-engineering' a particular specimen they had acquired. The report had several conclusions, but in particular, the observation was made that the 14-roller design resulted in close-packing of the rollers such that, if one were to be transiently 'spat-out' of engagement (an event acknowledged to be possible or even probable), it could collide with its neighbour. It could then cause this to disengage and so forth around the group, resulting in complete disengagement of the freewheel. In addition, the report concluded that, because of the high contact pressures when the freewheel is engaged, *any* coating could increase the tendency to slip under load.

It is clear, however, that Eurocopter are satisfied that the erroneous coating was responsible for the onset of freewheel slippage under load problems which started in April 2002. This equates to no serious cases of freewheel slippage experienced over a period of some 22 years with some 690 helicopters delivered plus at least 800 overhauled combining gearboxes using replacement rollers. The only problems, according to Eurocopter, were the isolated cases of slippage on first start-up in cold conditions which led to the introduction of Bonderite coating of rollers in 1997. During the next 5 years, no problems were reported. Furthermore, since the issue of Revision 2 of Alert Telex 63-00-21, in February 2004, which allowed operators to return to service gearboxes which had been previously grounded on the proviso that they replace rollers with less than 10 hours flying time with correctly coated items, the AAIB are not aware of any more in-flight cases of freewheel slippage. This equates to some 28 new helicopters delivered and 112 overhauled combining gearboxes. Thus it would appear that, over a period of approximately 18 months, five cases of single engine overspeed shutdowns, an uncontained engine failure leading to an accident, a further non-fatal accident (see below) and, finally, the accident to G-XCEL all occurred. This coincided with the introduction of rollers coated with manganese phosphate.

Quality Assurance issues

The German company has an excellent reputation and Eurocopter had experienced a long and satisfactory working relationship with them in dealing with many other components as well as freewheel rollers. This clearly influenced the Eurocopter's approach to quality assurance.

There were minimal physical checks carried out on the delivered rollers because it seemed inconceivable to Eurocopter that such a relatively simple component could have been defective. Quality assurance procedures and requirements, contained in various documents, are used when obtaining relevant approvals, both for aviation and non-aviation-specific tasks. However, these tend to be written in general terms.

For example, EASA regulation 1702/2003 Part 21 para 21A requires that:

> *'an approved organisation, its partners, suppliers and subcontractors must demonstrate that it has, and is able to maintain, a quality system which ensures that each product or part conforms to the applicable design data and is in a condition for safe operation'.*

It does not prescribe in detail how the organisation should construct such a system. Organisations may chose to audit suppliers (who themselves should also conduct internal audits) or physically inspect a sample or 100% of the components supplied. The latter, theoretically, should guarantee that defective components do not enter service and is known as 'quality control'.

Manufacturing industry however, has generally been moving away from 'quality control' in favour of auditing their own, or a supplier's, production process. Such an approach would thus be termed a 'total quality assurance' philosophy. The problem is that, under a 'total quality assurance' system, isolated human error, such as occurred in this occasion, may not be picked up until a component malfunctions in service. In aviation this can have catastrophic results.

A further contributory factor could have been the time that elapsed between the first discussions about the possibility of producing the new batch of rollers (including the zinc phosphate coating requirement) and the actual delivery. As stated earlier, documentary evidence has been supplied showing that, in 1995, the purpose of zinc-phosphating was understood by the German company to be 'to induce surface roughening of their roller finish'. Verbal evidence has also been given suggesting that, at that time, the German company queried the requirement because the capability to apply zinc phosphate was not available at their premises. They were assured by Eurocopter however, that it *was* necessary. Had manufacturing commenced shortly after this dialogue, the 'unusual' nature of the process may have alerted the German company to the possibly that they needed to acquire new equipment and certainly a different phosphating solution from their usual manganese process and the error would not have been made. However, it appears that a further five years elapsed before production actually commenced. During that time personnel aware of earlier discussions may have left the company or been moved elsewhere, and the significance of the coating was overlooked. By the time the rollers were manufactured the German company had not acquired the capability for zinc-phosphating.

Eurocopter were evidently operating under a 'total quality assurance' philosophy regarding the rollers. There seems to have been little verification that the product they were receiving conformed to drawing. Additionally, no auditing of the actual roller production process was carried out as they had an expectation that their supplier, by virtue of their reputation, would produce a quality product.

AAIB has received comments from both parties as to where, in their opinion, the other has failed to follow quality assurance procedures. It is felt that to explore these in greater depth in this report however, could be judged as inappropriate and not immediately relevant to flight safety.

However, the observation is made that, given the very long period of time and the changes made between the two production runs of the rollers, both parties would have been well advised to have physically checked samples in greater depth before releasing and accepting the items, regardless of whether such inspection was strictly required or not. To have completely verified all aspects of the manufacturing process (eg material specification, hardness, dimensions, coating thickness and composition) would have required destructive laboratory work on a sample. Tests on such a low-cost item would almost certainly have revealed the incorrect coating.

Additional case of freewheel slippage

Another accident had occurred to an Austrian-registered AS355F1 helicopter, which was damaged beyond economic repair on 3 December 2002, following an autorotative landing. An investigator from Eurocopter assisted the Austrian investigation, on which no report has subsequently been published. The Austrian pilot reported that, whilst performing a routine power assurance check, the crew heard a 'metallic bang' followed by a hammering noise and vibration was felt through the flight controls. Thinking that the noise appeared to have come from the rear of the helicopter, he rapidly closed both power levers and entered autorotation. Because of the nature of the terrain however, the helicopter rolled to the right on touchdown and the main rotor blades hit the ground; nobody was injured.

Examination of the helicopter revealed that an engine oil cooler heat exchanger was loose; all eight nuts mounting it to the airframe were loose and one was missing. Rocking the assembly by hand produced a hammering noise and it was believed, at the time, that this had been responsible for the noise. It was therefore concluded that failure to tighten the nuts during the 1,000-hour check, which the helicopter had just undergone, was the cause of the accident. Although the transmission was not strip-inspected as part of the investigation, both freewheels were turned by hand and found to operate smoothly. After being pronounced an economic total loss, the helicopter was presented to a museum in Vienna and prepared for display.

After the accident to G-XCEL, the Eurocopter Air Safety Investigator, being aware of the eyewitness reports of loud unusual noises, and also recalling that the Austrian helicopter had had a recent replacement of the combining gearbox, endeavoured to re-visit the helicopter in the museum and enquired about running time of the gearbox since overhaul. After some delay, he was advised that it had run less than one hour and he was allowed to remove the combining gearbox for examination. Although not as severe as the damage found on the left freewheel of G-XCEL, sufficient evidence was found on one freewheel to show that slippage had occurred and the rollers were coated with manganese phosphate from the batch supplied by the German company.

Discussion and Conclusions

Structural break-up of the helicopter

Although the precise forces and moments involved in failing the helicopter structure have not been quantified, calculation has shown that, if the engine affected is neither automatically nor (rapidly) manually shutdown, rapid re-engagement of a slipping freewheel has the potential to cause structural failure of the tail boom. Defining such forces is difficult because the exact timeframe over which the re-engagement occurs has a significant effect on the torque felt through the transmission and by the airframe; an instantaneous re-engagement would theoretically generate an infinite load. Physical examination of the components could not refine the time parameter, but calculations suggested that a re-engagement occurring over a fraction of a second could cause structural airframe damage. Moreover, if there were multiple re-engagements, at a frequency approaching the natural frequency of the tail boom, then the time period could be even longer than that needed for a single event.

No signs of roller imprints were found on the freewheel outer race. Additionally, other components such as the engine drive shafts, had not failed. It was therefore concluded that over-torque values generated by the shock of re-engagement could not have approached the very high figure necessary to fail the tail boom in a purely static manner. The deformation of the Thomas coupling input flange bolts, however, did suggest that the over-torque was at least 250% for both engines. It is therefore considered that the interaction of the two freewheels, alternately engaging and disengaging, may have created a dynamic situation of alternating applications of high torques (effectively a severe vibration) which compromised the structure of the tail boom.

Another possibility, suggested by Eurocopter, is that the over-torque, caused by re-engagement of the freewheels, could interact with a transient loading of the 'Starflex', caused by rapid lowering of the collective lever by the pilot attempting to enter autorotation. Calculations suggest that the 'Starflex', normally carries a safety factor of 7 (ie would require 7 times the torque output available from the engines to fail it). For a very brief moment during rapid lowering of the collective lever, this is reduced to a factor of 2.7 - fairly close to the over-torque value witnessed by the flange bolts. In other words, the combination of over-torque and flight stresses interacted for an instant and caused failure of the 'Starflex'. The severe vibration could then have failed the tail boom.

Although it has not proved possible to establish the precise sequence of break-up, this could be regarded as largely academic, since it appears that, on Rolls-Royce-engined AS355 helicopters, at least, in-flight slippage of freewheels must be avoided because of the potential to result in catastrophic failure of the helicopter's structure, howsoever that occurs.

There is little doubt that structural damage due directly to freewheel re-engagement was avoided, in the five cases of freewheel slippage under load known by Eurocopter that occurred prior to the G-XCEL accident, by the fact that the helicopters involved were all powered by Arrius engines. This engine reacts to overspeed of the power turbine (resulting from freewheel slippage) by immediately shutting-down the engine. The Rolls-Royce (Allison) engines of G-XCEL continued to run, albeit with the gas generator effectively at an idle condition, but with the power turbine spinning at the 114% while the off-load condition persisted. The kinetic energy in the system was therefore high when the re-engagements occurred. This is also probably the reason why the accident to the Austrian helicopter, although powered by the same engines as G-XCEL, did not have the same tragic outcome. It appears that the Austrian pilot, alarmed by the noise of what was probably a malfunctioning freewheel, rapidly closed both throttles and entered autorotation. There may also have been an element of good fortune, as such events probably have a random element in relation to the severity and timing of the re-engagement. There is little information concerning precisely how the pilot of G-XCEL reacted to what may have been similar cues to those presented to the Austrian pilot, although the radar trace suggests he initiated a descent, possibly with a view to performing a forced landing. There is no pilot drill for such an eventuality and, bearing in mind how quickly the situation can develop from onset to catastrophic failure, there appears to be little scope for devising one.

It was noted that in both the Austrian accident, and at least some of the five previous incidents of freewheel slippage, the pilots were flying with deliberate torque difference between the two engines. It is also evident that the pilot of G-XCEL was doing the same, probably as a power assurance check. Perhaps, contrary to expectations, it was the engine freewheel carrying the *least* torque which bore most evidence of slippage and re-engagement. However, tribological opinion suggests that this is likely - the lower engagement forces of the freewheel transmitting the lower torque could be more prone to the stimuli, such as vibration and transient rpm variations, which tend to momentarily unload the freewheel and could trigger slippage. Alternatively, Eurocopter believe that the right freewheel, carrying the majority of the flight torque, was the first to slip and transferred the load to the left freewheel which in turn also slipped. As stated previously, it is then possible that both freewheels entered a cycle of slippage/ re-engagement creating an oscillation in yaw at a frequency which compromised the tailboom structure.

The effects of the manganese phosphate coating

It has not yet been possible to reproduce, under test conditions, any greater tendency for manganese phosphate coated rollers to slip out of engagement compared with those zinc-phosphated. Indeed, conventional friction measuring tests suggest that there is little significant difference between not only the two different coatings but also uncoated rollers. Against this is the practical experience that serious slippage problems were only encountered when a batch of manganese-phosphated rollers were inadvertently used in AS355 freewheels. Eurocopter are of the opinion that the environment (eg vibration and transient torque levels) within the freewheel may be too complex to be replicated by standard test methods.

Eurocopter have accepted that the Bonderite process, as applied to their specification, was in practice achieving almost no deposition of zinc phosphate on the roller surface. They believed it was achieving a thin, but 100% coating, since their testing of freewheels equipped with rollers of the two different types was predicated on both phosphate coatings having 100% coverage at the start of the tests. The German manufacturer asserts, therefore, that it was the presence of a coating *of any type*, irrespective of chemical composition, which caused the problem; that is to say it was purely fortuitous that problems were not encountered with the zinc-phosphated rollers because the Bonderite process specification was actually achieving only a slight etching of the surface, not a coating.

In response, it remains Eurocopter's position that if the German company had correctly followed the drawing instructions they too would have arrived at the same finish which was proven to be effective. The same process had been applied to freewheels used in Gazelle helicopters and reportedly given satisfactory performance - this represents decades of flying and millions of hours of service.

The satisfactory performance of rollers both uncoated and coated with zinc phosphate over many years must be acknowledged. However, the freewheel has demonstrated that it is very sensitive to changes in tribological conditions which are not fully understood or measurable by conventional techniques. Its performance may also be compromised by small variations in dimensional tolerances. The following Safety Recommendation is therefore made:

Safety Recommendation 2006-070

It is recommended that the European Aviation Safety Agency, together with Eurocopter, review the design of the AS355 helicopter freewheel to ascertain whether it can be made more tolerant of variations in dimension or tribological performance of its components.

Although Eurocopter have indicated that they do not intend to perform any further tests in support of this investigation, it is possible that they, or their German supplier, may do further work to resolve the inevitable dispute resulting from the errant batch of rollers. If such work results in significant new information, the AAIB will publish it in a future issue of the AAIB Bulletin.

Manufacturer's response to air safety incidents

There was a time interval of some 18 months between the first incident, of what is now considered to be a number of incidents associated with freewheel slippage, and issuance of the first Alert Telex and associated Airworthiness Directive which grounded gearboxes at risk. The unit fitted to G-XCEL would have been one of the latter. The explanation of events offered by Eurocopter for this interval is not untypical of the way industry operates generally, with the major period of time being consumed by an incomplete understanding of the true nature of the problem (which was not thought to be a high-risk event) followed by partial recognition of the basic underlying cause coupled with experience of its potential to result in (non-catastrophic) damage.

After the 10 November 2003 accident at their own premises, it was clear that not only was there a problem with freewheel slippage but also a potential for a double engine failure occurring. The manufacturer realised the need to consider urgently what appropriate safety actions should be taken.

Firstly, they needed to establish which helicopters were at risk and this, in itself, required a connection to be made between the earlier incidents of engine overspeed shutdown with the accident. This led them to conclude that only new or newly-overhauled gearboxes with less than 2 hours running time seemed to be affected by the problem. Presumably, a check on the worldwide experience then indicated that it was only components from their own facility which were affected. Eurocopter were then faced with the decision of whether to ground all such units pending identification of the problem and a solution to return them to service. They chose not to do this, still believing that a slipping freewheel would most likely result in an engine overspeed shutdown (all the incidents, they believed at the time, were to Arrius-engined helicopters) or at worst a double engine failure followed by an autorotative landing.

It is clear that there was the intention that, when the appropriate safety action was communicated, it would also contain the remedy to return affected components to service. Eurocopter were initially focussed on the theory that tribological alteration brought about by the change in supplier of the gearbox preservative fluid was responsible. Even though no chemical or other causes were identified with this change, it was decided that this must have been a factor and therefore an experiment was conducted in which a new 'flushing' procedure was developed to remove as much of the preservative as possible before filling with lubricant. This unsuccessful test resulted in another overspeed shutdown during the tethered ground test on 19 November 2003. It was only with the 18 December 2003 test, with grease deliberately introduced into the freewheel, that Eurocopter finally concluded that lubricant contamination was not responsible and looked in greater depth at the freewheel components themselves.

At any stage the decision could have been made to urgently ground all affected gearboxes, but it was not until 8 December 2003 when the first issue of Alert Telex 63-00-21 effectively did this, stating that Eurocopter were trying to develop an improved flushing procedure to disperse the preservative. It was obviously not deemed to warrant immediate action, for it took 19 days from the unsuccessful tethered test to issue of the Alert Telex.

The manufacturer has to make a judgement, balancing risk against economic factors and also his reputation. Sometimes that judgement can be flawed or based on incorrect information. Eurocopter had notified the 10 November 2003 accident to the BEA (the French equivalent of the AAIB), who did not become involved, primarily because the helicopter was destined for a military customer and was operating under the manufacturer's temporary flight test registration. Thus investigation rested with Eurocopter and the DGAC and the former provided AAIB with a copy of a presentation given to DGAC on 26 November 2003. This largely summarised the history of engine overspeed events leading up to the accident, gave details of the action plan they intended to follow, which has been described above and culminated in the 18 December test which finally convinced them that lubricant contamination was not responsible for the slippage events.

There is no indication from the presentation that a discussion or risk assessment was conducted to consider all the potential consequences of freewheel slippage. Presumably it was assumed that the 'worst case' scenario was the 10 November 2003 accident, which involved no personal injury. The effects of aggressive freewheel re-engagement and different behaviour of the Allison engine, which had no overspeed shut-down protection, were apparently not explored. Since no minutes were kept, or at least available, there is no record of the DGAC reaction to the presentation and no discussion about the timescale for possible airworthiness action. Therefore, it must be assumed that they were content with Eurocopter's proposals.

Were manufacturers and regulatory authorities to approach the issue of identification of technical problems through to airworthiness actions on a more formal basis, this might, apart from subsequently providing firm evidence should such actions prove to be flawed, result in a more robust exploration of potential consequences at the time. Therefore the following Safety Recommendation is made:

Safety Recommendation 2006-071

It is recommended that the European Aviation Safety Agency ensure that manufacturers and those responsible for regulatory oversight of manufacturers, document the decision-making process resulting from identification of an in-service problem through to issuing airworthiness action.

Conduct of the Investigation

This report will be published more than two years after the accident to which it refers. It has been necessary to exceed the nominal target time to publication, however, because of the extremely complex nature of the technical investigation and the requirement to prepare and assess a wealth of test and theoretical evidence presented by the two principal manufacturing companies involved. It had been hoped that this might resolve the conflicting conclusions reached by each company's evidence but this ultimately was not possible. With no immediate prospect of resolution, it was decided that the facts and opinions of both parties should be described without a conclusion as to whose is correct. The AAIB wish to thank both companies for undertaking this work and sharing their results with the investigation team.

ACCIDENT

Aircraft Type and Registration:	Cessna 152, G-BWEV
No & Type of Engines:	1 Lycoming O-235-L2C piston engine
Year of Manufacture:	1979
Date & Time (UTC):	29 April 2006 at 1055 hrs
Location:	Compton Abbas Airfield, Dorset
Type of Flight:	Training
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Collapsed nose landing gear, damaged propeller, shock loaded engine
Commander's Licence:	Student pilot
Commander's Age:	40 years
Commander's Flying Experience:	40 hours (of which 37 were on type) Last 90 days - 13 hours Last 28 days - 5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The aircraft landed fast and bounced before landing again on the nosewheel. The nose landing gear collapsed causing the propeller to strike the ground.

History of the flight

The student pilot reported that whilst on finals to land the aircraft was blown off the runway centreline. The student regained the centreline but stated that in doing so he failed to monitor the airspeed. The aircraft landed fast and bounced. The student states that instead of going around he attempted to force the aircraft back onto the runway, landing on the nosewheel. The nose gear immediately collapsed causing the propeller to strike the ground. The aircraft slid to a halt but remained upright. The student was uninjured and after shutting down the aircraft he was able to vacate normally through the left door.

ACCIDENT

Aircraft Type and Registration:	DH82A Tiger Moth, G-ACDJ
No & Type of Engines:	1 de Havilland Gipsy Major 1C piston engine
Year of Manufacture:	1933
Date & Time (UTC):	18 August 2005 at 1034 hrs
Location:	Remenham (Berkshire), near Henley-on-Thames
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - 1 (Fatal) Passengers - 1 (Fatal)
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	61 years
Commander's Flying Experience:	289 hours (of which 107 were on type) Last 90 days - 9 hours Last 28 days - 2 hours
Information Source:	AAIB Field Investigation

Synopsis

During a pleasure flight in good weather conditions the aircraft was observed to enter a spin to the right from which it did not recover. The pilot and passenger both sustained fatal injuries. Despite extensive investigation, the cause of the accident could not be established.

History of the flight

On the morning of the accident, the aircraft had been flown from its maintenance base to White Waltham, in order that some associates of one of its owners could be taken on some short local flights. The accident happened on the second of these flights. As is customary in the Tiger Moth, the passenger was in the front seat and the pilot in the rear. Both were wearing glass-fibre flying helmets with intercom microphones and headphones, enabling them to speak to each other and to communicate with Air Traffic Control.

The aircraft was observed to start up, taxi normally and take off without incident. It then flew west to the River Thames and over Henley-on-Thames, before adopting a north-easterly track. Witnesses described seeing the aircraft on this track, and hearing the sound of the engine reduce markedly, after which the aircraft entered a steepening turn to the right. The aircraft was observed descending rapidly in a tight 'spiral' before hitting the ground in a field just south of the village of Remenham. The field (Figure 1) was large and unobstructed, with a slight slope and a surface mostly of rough pasture. The description of the descent and subsequent examination of the wreckage showed that the aircraft struck the ground in a spin to the right.

Figure 1

Photograph showing accident site

Members of the public were soon at the crash site and the emergency services were called. The pilot was conscious and lucid; the passenger was alive but unconscious; both had extensive injuries. An air ambulance helicopter from White Waltham and a police helicopter, which was also equipped as an air ambulance, both landed at the accident site. Paramedics treated the pilot and passenger at the scene, and the two helicopters took them to local hospitals. The pilot was able to communicate clearly during his treatment and transfer to hospital. The paramedic asked him questions about the flight and the accident, but he had no recollection of it. Both the pilot and passenger died of their injuries in hospital.

Pilot information

The pilot obtained his Private Pilot's Licence in 1995, having flown a total of 57 hours on Piper Cherokee aircraft. He flew regularly in the years that followed, and began to fly tailwheel aircraft such as the Piper Cub and the de Havilland Tiger Moth. He was a member of a syndicate which owned the accident aircraft and had flown it regularly since the summer of 2001. In 2005, he completed a biennial check and a renewal of his Single Engine Piston class rating with an examiner, flying a Piper PA-22 Caribbean. The examiner described the pilot as being "an average pilot with a good attitude towards flying", going on to state that he was "a steady pilot who achieved a reasonable standard of flying and knew his limitations".

During the renewal flight, the examiner put the aircraft into a spin, and the pilot recovered with the examiner talking him through the recovery. The recovery was correct with no problems. The examiner then suggested that the pilot should carry out a spin entry and recovery, but the pilot declined, saying that he was not keen on spinning. The syllabus for the renewal flight did not require spinning to be undertaken.

Aircraft information

G-ACDJ was first registered on 6 February 1933 having been built at de Havilland's site in Edgware. During 1990 and 1991 the aircraft was subject to a major overhaul, and a new certificate of airworthiness was issued on 17 October 1991. The engine was removed and overhauled to 'zero time' in July 1993.

Key information for the support and continued airworthiness for Tiger Moths, such as modifications and inspections, is published by de Havilland Support in a series of Technical News Sheets (TNS). Whilst there are modifications that date from 1933, the TNS system has been actively updated in recent years. There is also a Gazette which is issued for the guidance of operators and engineers of de Havilland aircraft and engines and this is distributed to all TNS subscribers.

Some examples of Tiger Moths have anti-spin strakes and auto-slats fitted, however these are not mandatory and were not fitted to G-ACDJ.

The aircraft had been subject to a 150 hour inspection on 20 July 2005 and an annual inspection the day before the accident. At the time of the accident 7,520 aircraft hours and 769 engine hours had been logged.

Meteorology

An aftercast supplied by the Met Office indicated that at the time of the accident a very slack airflow was affecting south-east England, with haze thinning between 1000 hrs and 1100 hrs, after which the visibility was 12 to 18 km, the sea level pressure was 1013 mb and the cloud was one or two octas of cumulus, with a base at 4,500 ft. The wind and (calculated) temperature are shown in Table 1.

Radar data

Radar recordings of the Tiger Moth's flight were consistent with witness recollections. The recordings showed that the aircraft's ground speed decreased by approximately ten knots over a period of several minutes during the latter part of the flight, but prior to the accident manoeuvre. At about 1031 hrs, the aircraft was recorded entering a right turn of slightly more than 360°. Radar contact was then lost as the aircraft descended above the accident site.

The recording also contained data relating to the flight of the Air Ambulance helicopter which attended the scene. Although the Tiger Moth was not equipped with an altitude-reporting transponder, the base of radar cover was established reasonably accurately by comparing the primary radar return of the helicopter with its Mode C altitude reporting[1]. This indicated that the base of primary radar cover at the accident site was approximately 800 ft amsl.

Examination of the wreckage at the crash site

The aircraft wreckage was contained within a small area consistent with a low impact speed and typical of a spinning accident. The left tip of the horizontal tail plane had dug into the ground, and the wooden fin post had broken so that the fin and rudder were angled to the left of the aircraft. One blade of the wooden propeller had broken away from the hub and lay next to the aircraft's nose, and the tip of this blade (20 cm in length) had been thrown 17 m forward of the aircraft's nose. Scuff marks, consistent with propeller rotation, were clearly evident on the blade that had broken away. No such scuff marks were found on the other blade, or the spinner. It was concluded that the engine was probably rotating at low speed at the time of the impact.

Footnote

[1] Mode C is a means by which an aircraft transmits its altitude such that it can be displayed alongside the aircraft's primary radar return on the ATC radar display.

Height (ft agl)	Wind Direction (° True)	Wind Speed (kt)	Temperature (°C)	Dew Point (°C)	Relative Humidity (%)
Surface	Variable, mainly easterly	5	25.5	14	49
500	100	5-10	24	12.5	49
1,000	100	5-10	20.9	10.9	53
2,000	100	10	18.4	9.9	58

Table 1

The nose of the aircraft had impacted the ground causing significant damage to the engine and the forward fuselage. Both lower mainplanes were damaged along their leading edges, and the upper mainplanes and the fuel tank had been thrown forward in the impact. The fuel tank was damaged and was leaking but was still about 20% full approximately 90 minutes after the accident.

A preliminary check on the continuity of the controls to the ailerons, rudder and elevator made at the wreckage site showed that there was no disconnection in any of the three primary flying controls prior to the impact.

The right hand lap straps of the 'Sutton harnesses' for both occupants had failed in the webbing material. The attachment cable for the rear occupant's shoulder straps had failed in overload and the fuselage structure in the vicinity of the front occupant's shoulder harness attachment cable had been disrupted. Thus both shoulder and lap restraint had been compromised for both occupants.

Detailed examination of the wreckage

Engine

The engine was removed from the wreckage and taken to a maintenance facility which had extensive experience with Gipsy Major engines. The strip inspection and examination included the carburettor and the magnetos as well as an internal mechanical inspection. Apart from the damage caused by the impact, nothing abnormal was found and the engine appeared to have been serviceable prior to the impact.

An attempt to assess the throttle position at impact was inconclusive since the throttle pushrod had been damaged extensively in the impact.

Fuel and fuel system

The fuel tank on the Tiger Moth is situated between the two upper mainplanes and forms the centre section of the upper wing. On the underside of the tank was a fuel ON/OFF valve and this was connected to a lever, the 'cock', in the cockpit by a series of pushrods and cranks. A mandatory modification to incorporate a locking device for the fuel ON/OFF cock had been incorporated in June 1999. The pushrods had been heavily deformed in the accident; however it was considered likely that the fuel ON/OFF valve was open at impact. An analysis of the fuel confirmed that it was AvGas 100LL and that it was fit for purpose.

Aircraft structure

The fabric covering material was removed from much of the aircraft and the structure was inspected. Included in the inspection were control hinges, primary structural members and bracing wires. The airframe appeared to have been in a serviceable condition prior to the accident, and there was no evidence of an in-flight malfunction or failure.

Flying controls

The primary flying controls consist of rudder, elevator and ailerons, the latter are on the lower mainplanes only.

The lower end of the rear occupant's control stick on the Tiger Moth is attached to aileron control cables and these cables form a closed loop system that runs between two sprocket wheels, one inside each of the lower mainplanes. The two parallel cables are attached to lengths of chain through adjustable and wire-locked turnbuckles such that the chains sit on the two sprocket wheels. When the control stick is moved sideways, the cables move causing the sprocket wheels to rotate and pushrods attached to the sprocket wheels move the ailerons. The sprocket and chain assemblies are effectively built into boxes, with the upper surface being formed by fabric, the lower surface by two aluminium cover plates on the wing lower surface and the sides are wood.

In 1943 the Air Ministry, on behalf of the de Havilland Aircraft Company, introduced Mod 125 to:

> *'introduce an improved aileron sprocket chain guide arrangement to reduce the possibility of the chain riding on the sprocket due to sagging of slack cables, and a reduction in the length of the slot in the cockpit floor to prevent the chain shackles riding on the sprocket when the control column is in the fully over position. The modification includes the deletion of the existing fixed chain guard and replacement by a spring guard and the introduction of Guide Plates to prevent chain sag'.*

TNS No 5 for the Tiger Moth issued in January 1990 listed three CAA mandatory modifications, and Mod 125 is included on this list.

A pair of wooden stops are attached to the underside of the fuselage beneath the control column, to reduce the length of the aileron slot, and hence the aileron movement. Whilst the underside of the fuselage of G-ACDJ was disrupted as a result of the impact, both stops were found to be present and their length and the likely gap between them were consistent with Mod 125.

The two cover plates were removed from the lower surface of each lower mainplane and the fabric was cut away from above the aileron control mechanisms. The aileron box in the right wing was found to be intact and the chain was properly located on the sprocket wheel. However, in the left wing the aileron box had been disrupted, most probably in the impact, and there was a crack up to 6 mm wide on the forward side of the box. The spring guard was flattened and the chain was derailed from the sprocket and sitting around the inner part of the sprocket assembly – see photograph in Figure 2.

Mod 125 also requires the fitting of a chain guide plate in both lower mainplanes. This plate is 18 cm long and has a shallow inverted channel section. It is attached to the wing lower surface structure by four wood screws and it requires spruce packing of the correct thickness to be inside the section to ensure the correct gap between the guide plate and the plane of the sprocket wheel. On G-ACDJ the guide plate in the right lower mainplane was found to be securely attached, however the guide plate on the left lower mainplane was found attached but with no evidence of any packing strip, and with the

Figure 2

Photograph showing derailed aileron chain in lower left mainplane three retaining screws only part way in (Figure 3). The fourth retaining screw was found loose inside the box structure. Further inspection of the guide plate on the left wing revealed no evidence of any of the screws that secure the packing strips to the wing structure. This would suggest that the packing pieces were not present prior to the impact, and hence the plate might not have been securely in place before the accident.

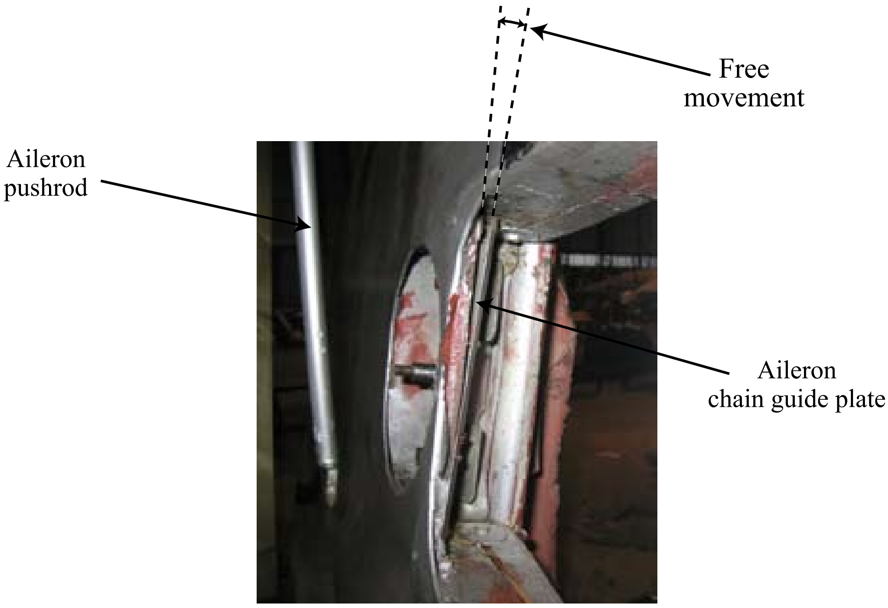

Figure 3

Photograph showing loose guide plate in lower left mainplane

Inspection of the chains, sprockets, guide plates and the loose screw showed no evidence of any marks that would indicate a control problem. Attempts were made to derail the chain from the sprocket assembly under a variety of conditions. Even with the flattened chain guard and low cable tension the chain would not come off the sprocket wheel. Also, with the chain derailed as found on the left mainplane, the shape of the crank and sprocket assembly was such that some restricted movement of the aileron did occur.

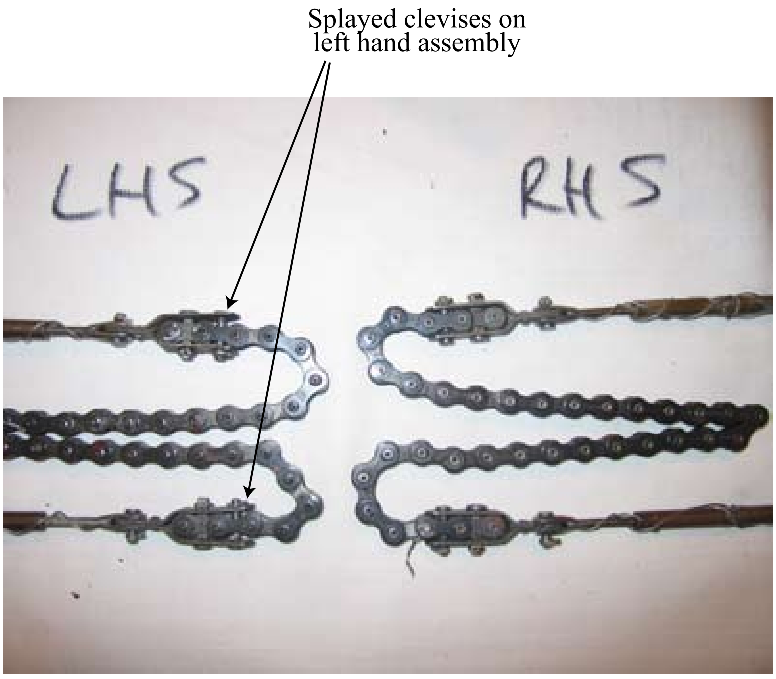

Figure 4

Photograph showing left and right hand aileron chains.

The left and right chains were compared, see Figure 4, and the clevises on the left chain were found to be splayed, consistent with a significant load being applied. The bracket which attaches the rear spar of the lower mainplane to the fuselage was found to have suffered a significant upward load, thus supporting the evidence that the left wing, including the aileron cable, was subject to an abnormally high load in the accident.

Further investigation of the flight control system, in particular the rudder, elevator and the mechanical linkages under the cockpit floor, revealed no evidence of foreign objects or control restrictions which might have caused a control problem.

Aileron system inspections

The aileron system on G-ACDJ was checked as part of both the 150 hour inspection on 20 July 2005 and the annual inspection on 17 August 2005. Interviews with the maintenance engineer and the signing licensed engineer confirmed that the cable tensions, the integrity of the cable assembly and the aileron movement were satisfactory on both occasions. However neither of the engineers checked the integrity of the guide plates as part of these inspections.

The aileron systems in two other Tiger Moths were inspected and in one of the aircraft there were no guide plates fitted. Whilst it is clear from Technical News Sheets that the fitting of guard plates is part of a mandatory modification, it would appear that there has been more than one instance of inadequate inspection of guide plates on Tiger Moths.

Pathology

An expert in aviation pathology carried out post mortem examinations on both the pilot and passenger. He concluded that both had died as a result of multiple injuries sustained in the accident. Toxicological tests revealed nothing of significance in either case.

Examination of the pilot identified pre-existing medical conditions, affecting his heart and brain. The heart was found to have approximately 70% occlusion (narrowing) of coronary arteries, and the pathologist reported that this degree of abnormality was sufficient to produce: *'an abnormal heart rhythm, chest pain, collapse, or even sudden death'*.

However, no evidence of an acute coronary event was found. The pilot had undergone extensive cardiological review in 2004 following an Electrocardiogram (ECG) examination but had been assessed as fit to hold a Class 2 medical certificate [1].

A tumour (meningioma) was found adjacent to the frontal lobe of the pilot's brain. A consultant neurologist with experience of aviation medicine was asked to give an opinion on this tumour, and he reported that: *'this meningioma with surrounding oedema could well have caused an epileptic fit, which… would lead to a sudden incapacity. It is possible that it could have caused some more longer term personality change, but I suspect, given its unilateral nature and relatively small size that this would not be the case. Family members may be able to give more information on this possibility'*.

The pilot's family reported that there had been no change in the pilot's personality in the months before the accident. The pathologist indicated that whilst it would be unlikely for a private pilot with an undiagnosed meningioma to suffer a first epileptic seizure during the brief time in a given year that he was involved in operating an aircraft, the possibility could not be excluded.

The examination also identified minor injuries to the pilot which suggested that the pilot's left hand was on one of the aircraft controls at the time of impact, and therefore, that he was not unconscious.

Harnesses inspection and webbing material testing

Sutton harnesses were fitted to the aircraft and each occupant's harness consisted of two lap and two shoulder straps made from canvas webbing reinforced locally with leather. Set within the leather

Footnote

1 Class 2 medical certificates are commonly held by holders of Private Pilot's Licences. Professional pilots are required to hold Class One certificates, which have more stringent requirements.

reinforcements were a series of eyelets and to secure the harness an occupant threaded a pin through the appropriate eyelet from each of the four straps before securing the pin with a sprung clip. The shoulder straps were fixed to the aircraft by a cable running across the fuselage, and the lap straps were attached to the fuselage.

Sutton harnesses were the subject of the following TNS:

a) TNS 37 issue 2 in 2000: A CAA mandatory TNS which specifies the fitting of higher strength transverse cables for the attachment of shoulder straps.

b) TNS 33 issue 2 in 2002: A CAA mandatory TNS which specifies a nine year harness life from initial fitment. Since production of Sutton harnesses had ceased many years ago, replica harnesses, known as 'alternative' harnesses, had become available and were described in Mod No 160 issue 2 in 2002. As part of the certification process for the alternative harnesses ultimate load testing was required to confirm that the harnesses met the original specification.

The fitting of the higher strength cables to G-ACDJ was documented in the log book and dated September 2001. The attachment cables were inspected and, apart from the overload failure for the rear cable, they appeared to have been in good condition prior to the accident and they both had valid part numbers.

Whilst the harnesses on G-ACDJ were installed before the alternative harness certification date they were effectively exactly the same as the certificated alternative parts. The original harness was designed to '*keep the wearer firmly in his seat*' when subject to certain loads and the relevant drawings dated 1943 called for '*Khaki webbing of tensile strength not less than 1,100 lbs approximately 3/32 inch thick*'. As such the harness was not part of an integrated crashworthy aircraft design in which energy absorption and survivable space were considered to the extent that they are for more modern aircraft.

As a result of the failure of the webbing material in both right lap straps the harnesses were removed from the wreckage for further examination. To ascertain if the webbing material had performed to its specification various samples from the harnesses fitted to G-ACDJ were subject to ultimate load tests and the results were compared to the data from the harness certification tests that were performed in December 2001. In the tests all the samples were from the same batch of webbing material. The strength of the webbing material declines with age due to a variety of factors including wear, humidity and any high loads encountered in service. The results of the three tests of samples from G-ACDJ all exceeded the manufacturer's 1943 specification.

Additional information - spinning

A spin is a manoeuvre in which an aircraft describes a descending spiral, in a stalled condition, whilst yawing, pitching, and rolling simultaneously throughout. In a spin, an aircraft loses height rapidly, but airspeed is low.

In order for an aircraft to enter a spin, certain criteria must be met. First, the aircraft's wings must be stalled. To achieve this intentionally, the aircraft must be pitched nose up, usually, by the pilot moving the control column rearwards and holding it in a rearwards position. Yaw must also be present as the wing stalls, or approaches the stall. In aircraft such as the Tiger Moth, this yaw may occur as a result of deliberate pilot control input or as a result of an absence of accurate control of the aircraft to arrest undesired yaw, particularly if one wing drops approaching a stall, which is common. Some aircraft, notably some with swept wings, exhibit different characteristics in this respect.

Another circumstance in which yaw must be controlled is following changes in power. When power is reduced, a Tiger Moth will yaw and then roll to the left. The pilot must apply right rudder to prevent this yaw, if balanced flight is to be maintained.

Some aircraft require constant application of pro-spin controls to maintain a spin, and recover as soon as the controls are released. Other aircraft types continue spinning, even if the controls are released, and require the correct action to be taken to recover to normal flight.

As the aircraft exits the spin manoeuvre, the speed increases rapidly, and the aircraft enters a steep dive. Recovery from this dive involves significant loss of height.

Some accounts of the characteristics of the Tiger Moth suggest that the early stages of a spiral dive are remarkably similar to a spin. However, the low speed of the accident aircraft at the time of impact indicated that the aircraft was spinning, and not in a spiral dive, prior to impact.

The investigation made use of a Pilot's Assessment of the Tiger Moth aircraft, written by a professional military test pilot for the Royal Australian Air Force Museum. This document gave a thorough description of the aircraft and its characteristics. In the section *'Spinning'*, the report stated:

> *'The effect of abandoning the controls during the spin was examined during one left and one right spin. For each direction of spin, releasing the controls did not effect a recovery after a further four turns…'.*

It may be inferred that positive action on the controls is necessary to effect a recovery from a spin in the Tiger Moth.

Another report, commissioned following a fatal accident to a Tiger Moth in Australia, stated:

> *'It is difficult to get the DH82 to enter a fully developed spin without applying and maintaining application of a lot of rudder whilst keeping back pressure on the stick'.*

Recording equipment

The aircraft was fitted with equipment, carried in a case behind the rear seat, which was capable of recording images from cameras fitted around the aircraft and sound from the interphone and VHF radio onto a small cassette tape. This equipment was used by the company which sometimes used the aircraft for pleasure flights, to provide passengers with a recording of their flights. Prior to the accident flight, the equipment had not been activated.

Analysis

From the engineering investigation, it appears that the aircraft was serviceable before the flight with no pre-existing defect which contributed to the accident, and that no defect occurred during flight which caused the aircraft to enter the spin.

The pilot was correctly qualified to carry out the flight and had reasonable prior experience on the aircraft.

Whilst not in very current flying practice, he had renewed his Single Engine Piston rating with an Examiner, approximately six weeks before the accident.

The weather conditions were entirely suitable for the intended flight and the pilot would have had uninterrupted visual contact with his environment and the ground beneath him, with a good horizon as a reference.

The flight appeared to have progressed normally until the aircraft had passed over Henley-on-Thames. Following analysis of the radar recordings, and with the assumption that the aircraft may have lost height in the right turn recorded on radar, it may be estimated that the Tiger Moth was at an altitude of approximately 800 ft plus the height lost in this turn, if any, prior to its final manoeuvre. The elevation of the ground at the accident site was approximately 180 ft, and less in the river valley between the accident site and Henley-on-Thames.

The first significant event immediately prior to the accident was the reduction in engine power, described by the witnesses. This reduction in power may have resulted from a reduction in the throttle setting by the pilot, or could have been caused by some failure of the engine or its systems. The engineering investigation did not identify any reason why the engine should have failed, but the possibility remains that a failure occurred which could not be identified in the post-accident investigation, or that carburettor icing (which may leave no trace for accident investigators) might have caused the engine to lose power.

Carburettor icing is usually associated with a gradual power loss and rough running, and although the aircraft's average groundspeed (derived from radar) had reduced gradually in the period leading to the accident, the manner of the change in the engine note, which the witnesses described as being quite sudden and definite, suggested that the change in power was not caused by carburettor icing. Moreover, the ambient conditions were such that there was not a high risk of carburettor icing at cruise power. Had the pilot identified that the engine was gradually losing power, and decided to land as a precaution against a total power loss, it seems reasonable to expect that he would have made a radio call to inform others that he was carrying out a forced landing, and that he would have used the remaining power to fly a controlled circuit of a possible landing site prior to commencing a circuit to land.

After the power reduction, the aircraft entered a turn to the right and then began descending. When power is reduced, the effect of the propeller slipstream and engine torque causes the Tiger Moth to yaw and roll to the left. Therefore, there must have been a control input to cause the aircraft to turn to the right. Given that the Tiger Moth does not enter a spin readily, it must also be concluded that a control input was made which caused the spin entry. These control inputs may have been deliberate, for example, an entry into a right turn to manoeuvre for a forced landing, or may have been unintentional, for example, caused by incapacitation, or an input made by the passenger following recognition of the pilot's incapacitation. If the control inputs were deliberate, mis-handling (itself perhaps caused by distraction or partial or subtle incapacitation) could have caused the aircraft to depart into the spin.

The pathology report indicated that the pilot had two medical conditions, either of which could have caused sudden incapacitation. The fact that the pilot was conscious and lucid when the rescuers arrived at the accident site indicates it is unlikely that he had suffered a major epileptic or cardiac event, but it does not entirely exclude the possibility of a transient episode causing partial incapacitation.

In the event of incapacitation of the pilot, the passenger might have attempted to gain control of the aircraft and carry out a landing. However, she would first have had to establish that the pilot was incapacitated, and as the pilot was seated behind the passenger, incapacitation which caused him to lose consciousness would not have been immediately apparent to the passenger, except that the pilot would not have been able to communicate by intercom. In the event of such communication ceasing, the passenger might have concluded that the intercom system had failed or that the pilot was occupied with tasks which prevented his conversing, rather than coming immediately to the conclusion that he had become incapacitated.

It is noteworthy that this pilot, who had significant coronary artery disease, had been pronounced fit following investigation of his abnormal ECG, and this reflects the imperfect nature of some medical screening tests.

If the passenger had identified that the pilot had become incapacitated, it is possible that she might have attempted to gain control of the aircraft. However, she had received no flying training, and would not have known how to fly the aircraft. It is considered that an untrained individual would not be able to carry out a safe landing in these circumstances, and any attempt to take control of the aircraft would be likely to result in loss of control.

Once the aircraft was established in the spin, reports indicate that recovery action would have been necessary to regain 'normal' flight. One of the first consequences of such recovery would be an increase in the aircraft's forward speed, and the manner of the impact suggests that the speed was very low, and therefore it seems that recovery action was not being taken.

Both occupants died from multiple injuries. Whilst the lap straps failed in both the harnesses, tests concluded that the webbing material met its design specification. It is thought likely that the accident would not have been survivable had the harnesses remained intact and secured, although this is a somewhat subjective view based on a discussion with the aviation pathologist.

The impact with the ground was the most likely cause of the derailed chain and the flattened spring chain guard. This was substantiated by the significant damage to the left lower mainplane, the fact that the system was inspected the day before the accident and the absence of any reported defect on the day of the accident. Even if the left aileron chain had become derailed in flight it would seem likely that the pilot would have retained some aileron control due to the shape of the crank on the sprocket wheel, or the aileron would have adopted a constant position as a result of floating up under aerodynamic loads. Adequate control of the aircraft would have been available in both of these scenarios.

The absence of any of the wood screws for the packing strips and the lack of any evidence from inspection records would strongly suggest that the packing strips were not present and that the left plate had been loose, but attached, prior to the accident. No evidence of a problem with the flying controls could be found. It is therefore unlikely that the loose left guide plate contributed to the accident. As a result of the high probability that the left aileron guide plate was loose prior the accident, the following Safety Recommendation is made.

Safety Recommendation 2006-055

It is recommended that de Havilland Support remind pilots and maintainers of Tiger Moths of the importance of the embodiment and periodic inspection of the mandatory modifications for the aileron system described in Technical News Sheet No 5.

Conclusions

Witness accounts and radar evidence, together with the results of the wreckage analysis, allowed the investigation to determine the aircraft's final manoeuvres with some accuracy. However, it was not possible to determine a cause for the reduction in engine power or for the aircraft's entry into the spin. A significant number of theories might be constructed to account for these events, but none stands out as more or less probable than the others.

It is notable that the recording equipment fitted to the aircraft would, had it been activated, have provided very valuable evidence to the investigation, and might have allowed the cause of the accident to be determined.

INCIDENT

Aircraft Type and Registration:	DR 107 One Design, G-IIID
No & Type of Engines:	1 Lycoming O-360-A4N piston engine
Year of Manufacture:	2005
Date & Time (UTC):	21 April 2006 at 1700 hrs
Location:	Tatenhill, Staffordshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to undercarriage, main gear bent, tailwheel detached, fuselage tubing damage near gear attach point
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	5,700 hours (of which 11 were on type) Last 90 days - 147 hours Last 28 days - 31 hours
Information Source:	Aircraft Accident Report Form, and follow up correspondence and photographs submitted by the pilot

Synopsis

The aircraft was damaged in a ground loop as directional control was lost after the pin securing the tailwheel to its cantilever spring detached. This then allowed the tailwheel to detach from the aircraft.

History of the flight

Whilst backtracking to clear the runway for an approaching aircraft, the tailwheel detached from its supporting spring, making a loud scraping sound and rendering it impossible for the pilot to steer the aircraft normally. After running straight initially, the aircraft veered towards the left side of the runway; possibly, the pilot suggests, as a result of uneven braking. The pilot was aware of raised lighting units at the runway edge and was also concerned that the aircraft might nose over if it ran off the paved runway and onto the adjoining soft ground. His attempts to keep the aircraft on the runway, however, provoked a ground loop to the right. As the aircraft swung through 90°, it started to 'hop' on its left wheel and tilted sufficiently to bring the left wing tip into light contact with the ground. It finally came to rest after having yawed through 180° from its original direction of travel.

The pilot reported that when he examined the aircraft, he found that the pin or bolt (he was unsure which) securing the tailwheel assembly to its cantilever spring, was missing. He tried to locate the missing item but was unsuccessful, and consequently the reason for its loss could not be established. A post-incident photograph provided by the pilot, showing the tailwheel in situ held by a temporary pin, showed no deformation of relevant areas around the hole for the missing pin.

ACCIDENT

Aircraft Type and Registration:	Europa, G-BWZT
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	1997
Date & Time (UTC):	5 March 2006 at 1220 hrs
Location:	Crowfield Airfield, near Ipswich
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - 1 (Minor) Passengers - 1 (Minor)
Nature of Damage:	Fuselage fractured ahead of fin
Commander's Licence:	Private Pilot's Licence
Commander's Age:	63 years
Commander's Flying Experience:	285 hours (of which 12 were on type) Last 90 days - 3 hours Last 28 days - 3 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot, and a statement by the aircraft passenger

Synopsis

Whilst carrying out a practise stall the engine began to misfire. Relevant cockpit actions did not cure the misfiring but the engine did start to run more normally during the recovery to Crowfield Airfield. The aircraft became high and fast on the approach and, when it was clear that a safe landing was unlikely, the pilot applied full power to go-around. As the aircraft turned downwind it was clear that the engine was not providing sufficient power to maintain height and speed so a forced landing was carried out into a field. The occupants received only minor injuries but the aircraft was extensively damaged during the landing.

History of the flight

The pilot, who owned the aircraft, was flying a local sortie from Crowfield Airfield. He was accompanied by a passenger who also held a PPL, but who was unfamiliar with the aircraft. The weather was fine but cold, with a surface temperature of about 0ºC and the surface wind was from 320º(M) at 18 to 20 kt. The grass runway at Crowfield is orientated 31/13 and 768 m in length.

Pre-flight actions and checks were carried out, including a check of the fuel from both drain points. The fuel tanks were approximately two thirds full. With all engine indications normal, the aircraft took off and was operated between 800 ft and 1,500 ft in the local area.

After some general handling the aircraft was climbed to about 4,000 ft with the intention of conducting a stalling exercise. Whilst carrying out a stall, and with the aircraft in a high nose attitude at a low power setting, the engine began to misfire. The pilot levelled the aircraft and increased power, but the engine did not respond correctly. The rpm was seen to fluctuate between about 4,400 rpm and 4,900 rpm, with associated 'surges' of power. The pilot selected the reserve fuel tank but this made no noticeable difference. At some point the electric fuel pump was selected on, though the pilot was unable to say exactly when this happened. The pilot also cycled the propeller control and, although this made no immediate difference, the engine did then start to run more normally. A recovery to Crowfield was initiated, with the propeller pitch set to full fine. The pilot requested a priority landing because of the rough running engine but did not declare an emergency.

The aircraft arrived over Crowfield at about 3,000 ft, positioned to the north of the airfield on the 'dead side' of Runway 31. The pilot joined the left hand circuit crosswind, descending to about 2,000 ft at the start of the downwind leg. By the time the aircraft was on base leg it was at about 1,000 ft but the speed was too high to allow selection of flaps, which were eventually selected when the aircraft was on finals. The aircraft crossed the threshold at about 100 kt, and it was clear then that a safe landing on the grass runway was unlikely. The pilot selected full power and the engine appeared to respond. As the aircraft climbed, the pilot retracted the flaps and commenced a turn to the left, intending to fly a tight low-level circuit. Soon afterwards, it became clear that the engine was not producing sufficient power to maintain height and speed and that a forced landing would be necessary. A suitable field lay ahead and the aircraft was landed downwind into it, heading about south-south-east, at an estimated 55 kt IAS. The aircraft ran on smoothly for a while but the nose wheel 'dug in' after about 50 or 60 m and the aircraft pitched forward and yawed through 180º before coming to rest.

The pilot and passenger, who were both wearing four point harnesses, received only minor bruising and were able to vacate the aircraft without difficulty. The aircraft suffered extensive damage to the aft fuselage, engine cowling and spinner, undercarriage and left wing.

Comment

This accident highlights the dangers of relying on an engine which is of doubtful reliability. As the aircraft arrived overhead the airfield at about 3,000 ft, a full forced landing pattern was an option and, had the aircraft been established at the required gliding speed, the pilot may arguably have been better placed to assess, and allow for, the wind effects. Additionally, being overhead his home airfield, he would have been in a familiar situation which it would be expected he had practised several times before.

As the aircraft commenced its downwind leg higher than normal, and with excess speed, the pilot was in a less familiar situation, particularly since it would be difficult to dissipate this energy in the relatively strong tailwind. In this situation an assessment of the wind effect and aircraft's energy levels would have been more difficult until relatively late in the attempt to land.

The intended tight, low level, circuit with a relatively strong wind and suspect engine would have been a demanding manoeuvre and not without considerable risk. The pilot is to be commended for making the quick decision to force land ahead when the engine lost power again and not to attempt to return to the airfield.

ACCIDENT

Aircraft Type and Registration:	Europa XS tri-gear, G-FELL
No & Type of Engines:	1 Rotax 912-UL
Year of Manufacture:	1998
Date & Time (UTC):	28 April 2006 at 1300 hrs
Location:	Upfield Farm, near Newport, Gwent
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Nosewheel detached, port wingtip scratches, prop damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	59 years
Commander's Flying Experience:	742 hours (of which 145 were on type) Last 90 days - 17 hours Last 28 days - 8 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The aircraft touched down to the left of the runway in gusty wind conditions and the nose landing gear leg detached.

History of the flight

The pilot flew the aircraft from North Weald, Essex, to a farm strip at Upfield, Gwent. Before departure, he obtained a weather forecast for Cardiff Airport, which was the nearest airport with such information available; he was not able to obtain a report directly from the farm.

On arrival at Upfield Farm Runway 05 was in use. The surface wind was estimated to be from 010º at 10 kt and the pilot reported that the wind was gusty. The runway had a recently constructed concrete surface, which was 640 m long and 10 m wide. At some points along the edges of the concrete strip there was a drop down of a few centimetres to the surrounding grass.

The pilot made an approach to Runway 05 but during the flare experienced gusty conditions. The left mainwheel touched down to the left of the runway surface and some 15 cm below the concrete. The propeller struck the edge of the concrete but the pilot was not aware of this at the time. He applied full power to go around but the aircraft landed heavily on rough ground to the left of the runway and the nose landing gear leg detached. The pilot and his passenger were wearing full shoulder harnesses and were not injured in the accident.

ACCIDENT

Aircraft Type and Registration:	Evans VP-1 Series 2, G-EVPI
No & Type of Engines:	1 Volkswagen 1834 piston engine
Year of Manufacture:	2004
Date & Time (UTC):	6 April 2006 at 1030 hrs
Location:	Deanland (Lewes), East Sussex
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to right wing, propeller and landing gear
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	52 years
Commander's Flying Experience:	445 hours (of which 42 were on type) Last 90 days - 13 hours Last 28 days - 0.5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During takeoff the aircraft deviated to the right, left the runway and struck the airfield perimeter fence. Insufficient control inputs had been applied to counteract a tendency for the aircraft to rise and move to the right as the tailwheel was raised.

History of the flight

On a calm clear day, with the wind reported as being from 240° at 5 kt, the pilot lined up to take off from Runway 24 at Deanland Airfield, East Sussex. The initial takeoff roll of the tail-wheeled aircraft was normal and as takeoff power was applied, the tailwheel was raised. The aircraft then deviated to the right and left the grass runway, before making contact with the airfield perimeter fence, causing damage to the right wing, propeller and the landing gear. The pilot, who was wearing a four-point harness, was uninjured and exited the aircraft normally.

The pilot stated that this aircraft, as the tailwheel rose off the ground, had a tendency to rise up and move to the right, requiring correction by applying some forward stick and left rudder control input. In a full and frank statement the pilot felt that he had applied insufficient control inputs to counteract this characteristic of the aircraft. He also stated that a contributory factor could have been that this was only his second flight of the 'season', with just 0.5 flying hours completed in the last 28 days.

ACCIDENT

Aircraft Type and Registration:	Grob G109B motorglider, G-KNEK
No & Type of Engines:	1 Grob 2500-E1 piston engine
Year of Manufacture:	1986
Date & Time (UTC):	29 April 2006 at 2045 hrs
Location:	Currock Hill Gliding Club, Northumbria
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Collapsed undercarriage, damage to propeller and minor damage to lower cowl
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	24 years
Commander's Flying Experience:	96 hours (of which 19 were on type) Last 90 days - 27 hours Last 28 days - 22 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The handling pilot was flying from the right seat, which was unusual for him, and meant that the control column and airbrake lever were in the opposite hands compared to when flying from the left seat. During a glide approach for a straight-in landing on Runway 06, with the airbrakes in, an undershoot began to develop. His unfamiliarity with flying from the right seat resulted in the pilot initially applying inappropriate control inputs, which increased the rate of descent. The aircraft touched down heavily on rising ground in the Runway 06 undershoot.

ACCIDENT

Aircraft Type and Registration:	Grumman AA-5B, G-BXTT
No & Type of Engines:	1 Lycoming O-360-A4K piston engine
Year of Manufacture:	1978
Date & Time (UTC):	1 April 2006 at 0907 hrs
Location:	Tatenhill, Staffordshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Propeller damaged, engine shock loaded, nose landing gear damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	220 hours (of which 74 were on type) Last 90 days - 0 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot had not flown for three months so he decided to carry out some circuits for practice. The weather conditions were clear with good visibility; the surface wind was from 250º at 15 kt. Runway 26 was in use at Tatenhill, this has an asphalt surface 700 m long and 28 m wide.

Following a successful circuit and 'touch and go' the pilot carried out a second approach and landing. The aircraft bounced on touchdown, porpoised and then ballooned. The pilot applied full power and attempted to go around. As he carried out the go around the aircraft banked to the left and descended towards a cultivated field to the left of the runway, where he then landed. The pilot was wearing a lap and shoulder strap and was not injured in the accident.

Propeller strike marks were found on the runway surface during the subsequent inspection. It is possible that propeller damage sustained on landing affected the aircraft performance during the attempted go around.

ACCIDENT

Aircraft Type and Registration:	Piper PA-28-181 Archer 2, G-EMAZ
No & Type of Engines:	1 Lycoming O-360-A4M piston engine
Year of Manufacture:	1981
Date & Time (UTC):	4 September 2005 at 1221 hrs
Location:	Irish Sea, 5 nm north-west of Strumble Head, Pembrokeshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - 1 (Fatal) Passengers - 1 (Fatal)
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	63 years
Commander's Flying Experience:	Approx 150 hours (of which approx 45 were on type) Last 90 days - Not known Last 28 days - Not known
Information Source:	AAIB Field Investigation

Synopsis

The pilot and his passenger were returning to Cardiff Airport, in G-EMAZ, from Weston Aerodrome, near Dublin, Ireland. The aircraft had not contacted Cardiff ATC at its ETA, therefore overdue action was initiated 30 minutes later and the London Area Control Centre was notified. The subsequent Search and Rescue operation used British and Irish lifeboats, search and rescue helicopters and a RAF Nimrod aircraft.

Aircraft wreckage and two bodies were found that night by the lifeboats 11 nm north of Strumble Head, near Fishguard, Pembrokeshire, having drifted with the tide for 10 hours. It was later confirmed that the wreckage was from G-EMAZ.

History of the flight

The pilot and his passenger departed Cardiff Airport, in G-EMAZ, on 1 September 2005 for Kilkenny, Ireland at the start of a weekend of flying touring. At 0958 hrs on 4 September 2005 the pilot filed a flight plan for his return flight to Cardiff, with a planned takeoff time of 1030 hrs. The flight was expected to take 2 hrs, with an endurance of 4 hrs. The flight planned route was to fly south from Weston Aerodrome along the east coast of Ireland to Wexford, on the south eastern coast of Ireland, across the St George's Channel to Strumble Head, Pembrokeshire and then via Carmarthen, to Cardiff. The intention was to fly the route under VFR.

Prior to departure the aircraft refueller at Weston

Aerodrome saw the occupants of the aircraft, who both appeared to be well. G-EMAZ departed Weston Aerodrome at 1113 hrs. The flight through Irish airspace was uneventful.

At 1146 hrs the pilot made an initial call to London Area Control Centre (LACC) but was told to standby. At 1148 hrs LACC asked him to pass his message. The pilot informed LACC of his aircraft type, the number of persons on board, that he was en route from Weston to Cardiff, and that he was currently east of Wexford at an altitude of 3,800 ft. LACC asked him to advise when he was at the FIR boundary. (The FIR boundary is 30 nm north-west of Strumble Head.)

At 1201 hrs the pilot was contacted by LACC and asked if he had crossed the FIR boundary. He replied that he was "crossing now". He was informed by LACC that he was under a Flight Information Service and that there was no known traffic to affect him.

At 1218 hrs he was asked by LACC for his ETA at Cardiff. He replied "Thirteen decimal two zero zulu". LACC asked "was that thirteen hundred" to which he replied "Thirteen decimal two zero." LACC informed him that "the airways time was presently twelve eighteen hours" to which he replied "that will be, sorry, "fourteen decimal two zero." This was the last radio contact with the pilot of G-EMAZ. At 1229 hrs LACC called the pilot of G-EMAZ to clarify his ETA at Cardiff as 1420 hrs, to confirm that he was not flying direct and to ask if he was going sightseeing. There was no reply to this call or to the subsequent two blind calls made by LACC to G-EMAZ.

Search and rescue operation

The Manual of Air Traffic Services Part 1, Section 5, Chapter 3, provides guidance for the actions to be taken when an aircraft is overdue. For aircraft equipped with a radio, the aerodrome controller should initiate preliminary overdue actions no later than 30 minutes after the next expected reporting point. If no news is received after the preliminary actions have been completed, or if one hour has elapsed since a position report should have been received, or the fuel carried by the aircraft is considered to be exhausted, whichever is the sooner, then the controller at the destination aerodrome should inform the Area Control Centre (ACC) that the aircraft is fully overdue.

The ETA at Cardiff, from the pilot's flight plan, was 1313 hrs, although his last radio call had estimated an ETA of either 1320 hrs or 1420 hrs. Cardiff ATC commenced preliminary overdue action on G-EMAZ at 1343 hrs. This action involved informing the LACC Supervisor of the overdue aircraft, and this was accomplished at 1350 hrs.

At 1358 hrs the Distress and Diversion (D & D) cell at RAF West Drayton, Middlesex, was informed by the LACC that R/T contact with G-EMAZ had been lost whilst it was over the St George's Channel. A radar replay request was made. All information was then passed to the Aeronautical Rescue and Coordination Centre (ARCC) at RAF Kinloss, Scotland.

One hour after G-EMAZ's flight planned ETA, at 1413 hrs, Cardiff ATC initiated full overdue action and the LACC Supervisor was again informed. Coordination of the Search and Rescue (SAR) operation was now transferred to the ARCC. At 1520 hrs three rescue helicopters commenced a search for the aircraft and were later followed by a RAF Nimrod. Two lifeboats were launched at 1600 hrs. Initially, they were sent to the aircraft's last certain position, which was at the FIR boundary in the middle of the St George's Channel.

Having analysed the recorded radar data the D & D cell were able to pass a more accurate last known position of G-EMAZ to the ARCC. Tidal data was then applied to this position by the Maritime and Coastguard Agency and the search area was then transferred to the north of Strumble Head.

At 2215 hrs, at a position 11 nm north of Strumble Head, the lifeboat crew smelt fuel. A life jacket was then found, followed shortly thereafter by other pieces of wreckage and the remains of the pilot and his passenger. These were identified to be from G-EMAZ. Additionally, a large number of bird feathers was also found amongst the debris.

Radar information

National Air Traffic Services provided secondary radar information for G-EMAZ from two radar sources: from Mount Gabriel, County Cork, Ireland and from Burrington in Devon. Examination of the radar recordings and the information encoded in it enabled the flight profile to be reconstructed, up to the point at which radar contact was lost.

The recorded radar information indicates that G-EMAZ coasted out at 1143 hrs just north of Wexford. The radar trace continued until 1148 hrs when radar contact was temporarily lost. The next radar contact was at 1159 hrs when G-EMAZ was in the middle of the St George's Channel, just prior to the FIR boundary. There was then another break in radar contact from 1201 hrs to 1204 hrs. The remainder of the radar trace was continuous until radar contact with G-EMAZ was lost at 1220:47 hrs, 5 nm north-west of Strumble Head, with an indicated height of 2,200 ft. (See Figure 1: Radar Plot).

Between 1204 hrs and 1214 hrs G-EMAZ was at an altitude of approximately 3,500 ft with a ground speed of 80 kt. At 1214 hrs the aircraft descended to 3,200 ft, as it did so its ground speed increased to 100 kt. G-EMAZ then flew level, maintaining approximately 100 kt, for 4 mins until it entered a rapid descent at 1220 hrs. As it

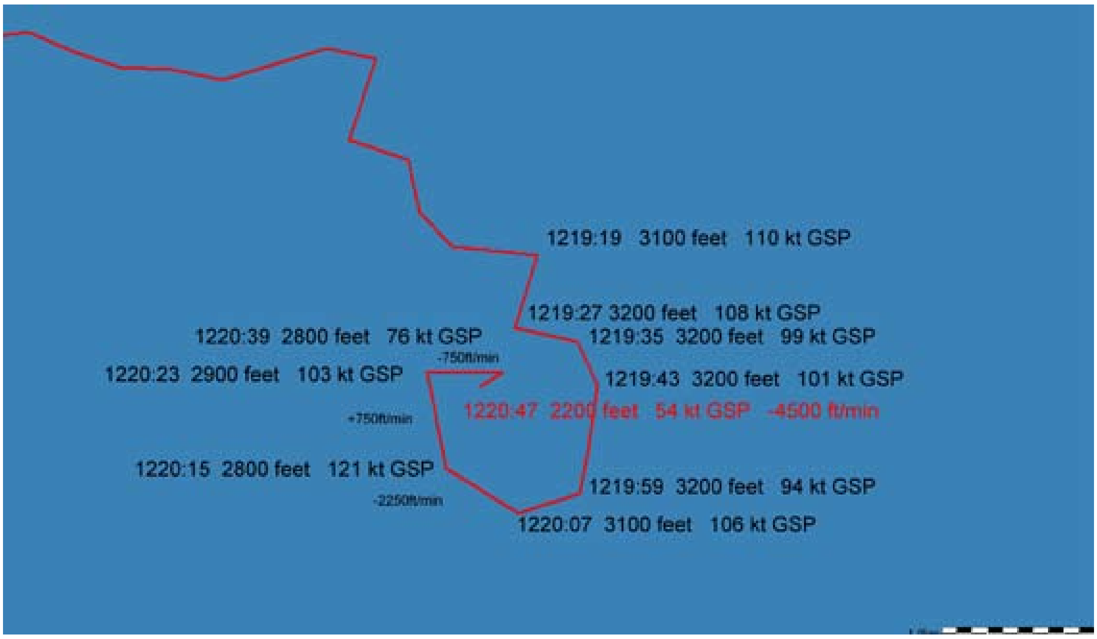

Figure 1

Radar Plot

entered the descent its ground speed initially increased to 120 kt, followed by a rapid decrease. This rapid reduction in ground speed can be attributed to the increasing angle of descent.

The aircraft's initial track over the Irish Sea was on a relatively straight course of 112º(T), towards the Strumble navigation beacon. At 1217 hrs the aircraft turned left onto 052º(T) and held this track for 24 sec before turning right on to 091º(T), this track was maintained for approximately one minute. The aircraft's track then became erratic, with at least four large heading changes occurring over a period of about one minute.

At 1219:35 hrs, the aircraft entered a right turn through approximately 140º over a period of 40 sec: this equates to a turn rate of 3.5º/sec. The aircraft then commenced its rapid descent whilst turning very quickly through a further 150º to the right. The radar trace was then lost.

Weather

An aftercast was provided by the Met Office. The synoptic situation at 1200 hrs showed an area of low pressure lying just south-west of Ireland feeding a light, unstable, southerly flow over the route flown by G-EMAZ, with a trough line lying from the Channel Islands through Barnstable in Devon to Wexford in Ireland. It was estimated that the cloud would have been broken or overcast stratus with a base of 1,000 ft amsl and with a surface visibility of 3,000 to 4,000 m in mist or haze. Continuous cloud was expected up to approximately 3,000 ft with layered cloud above. The weather was likely to have been showers of rain. The surface wind was expected to have been from 130º at 12 to 15 kt, with gusts to 25 kt; the wind at 4,000 ft was expected to be from 160º at 10 to 15 kt. The mean sea level pressure was 1016 mb.

Recordings of the weather radar indicate that there was a line of showers extending from Strumble Head across the St George's Channel to Wexford.

Another aircraft was also flying east bound over the Irish Sea, via Strumble Head, at 3,500 ft and about 15 mins ahead of G-EMAZ. The pilot of this aircraft reported that the weather conditions across the Irish Sea were marginal for flight under VFR. He reported that the cloud base was approximately 1,500 ft amsl and the top of the first layer of cloud was approximately 3,000 ft, with layers of cloud above.

Pilot's details and flying experience

The pilots flying log-book was not recovered. It is believed that it was on board the aircraft at the time of the accident. The hours quoted are therefore approximate and have been estimated using other sources of information.

The pilot conducted training for his Private Pilot's Licence (PPL) on PA-38 (Tomahawk) and PA-28 (Warrior) aeroplanes between 2003 and 2004. The pilot successfully completed his skills test on 13 July 2004 and was issued with his PPL on 4 August 2004 having recorded 75 hours of flying. His flying instructor had assessed him as a consistently solid, average student. The pilot purchased G-EMAZ around April/May 2005 and had recorded approximately 45 hours flying in it prior to the accident. His passenger had not had any pilot training and would not have been able to offer any assistance in flying the aircraft.

Part of the PPL syllabus includes an appreciation of instrument flying. During this element of the syllabus the student pilot has his external vision artificially restricted so as to simulate flying in IMC. During the PPL skills test the pilot is required to demonstrate a turn through 180º using 15º angle of bank, under simulated

IMC, in order to demonstrate that he can safely regain VMC if he inadvertently encounters IMC.

Medical information

The pilot held a current JAA Class II medical certificate with limitations requiring him to fly by day only, due to the fact that he had colour blindness. He was also required to have near vision lenses available while flying.

The post mortem examination, carried out by a consultant aviation pathologist, revealed that the pilot and his passenger had died instantly from multiple injuries resulting from a high speed impact with the sea.

Further examination of the pilot, and consultation with his doctor, indicated that he had a complex medical history. Traces of a prescribed drug were discovered, the concentration of which is thought to have been at a therapeutic level. The pilot had been taking this drug for many years and it is believed that he did not suffer from any untoward side effects. It is unlikely that the presence of this drug played any role in the accident, but the possibility could not be excluded. The CAA was aware of the pilot's condition for which the drug was being taken, but they had not been informed that he had actually been prescribed the drug. Had they been so they would not have issued a medical certificate for him to fly due to the possible multiple side effects associated with this treatment.

In 2001 the pilot was admitted to hospital having suffered a possible fit. The discharge summary stated there was insufficient evidence to label him as epileptic. At his initial CAA medical he declared that he suffered from vertigo and dizziness but had not suffered from fitting. While there is a possibility that the pilot might have suffered a similar episode of altered consciousness at the time of the accident there was no evidence to indicate that this had occurred nor that it might have caused the accident.

Engineering

Wreckage recovered by the Fishguard lifeboat was identified as coming from G-EMAZ, although there was very little of the aircraft to conduct any meaningful technical investigation. The largest pieces were an intact (but buckled) seat and a pair of chocks with the aircraft's registration painted on them. The remainder comprised a few fragments of interior trim and carpet. The pilot's flying licence, in a plastic wallet, was also recovered. Some months later a tyre and inner tube, still inflated but with the wheel completely corroded away, was washed-up on the Irish east coast: it may have come from G-EMAZ as it was of the right size and type, but it was not possible to confirm this.

The tiny amount of wreckage recovered did, however indicate that the aircraft had been travelling at a high speed when it struck the water since the degree of disruption to the airframe and the occupants was clearly immense. The damage was far more than would be expected had the aircraft been ditching after, say, an engine failure or even a failure to recover from a spin.

The aircraft which had been fairly recently acquired by the pilot, had been surveyed by a professional company prior to purchase. The surveyor's report, which described the aircraft's condition in great detail, was made available to the investigation and concluded that it was 'considered to be in a very good physical condition, taking into account its age and specification'.

The report also noted the relatively high specification of the avionics equipment, including an autopilot and Global Positioning System. The pilot was described by his instructors as enthusiastic and keen to improve his knowledge. However, they believe that he would not have had the knowledge to operate the autopilot and global positioning system effectively.

The aircraft's documentation, as examined by the surveyor, was also found to be in order.

Analysis

Radar information

The radar information suggests that the flight profile was normal until 1217 hrs. G-EMAZ had been maintaining a relatively steady track of 112º(T) but then turned left onto 052º(T) before reversing the turn to the right onto 091º(T). Approximately one minute later the aircraft's track became erratic, with at least four large heading changes occurring over a period of about one minute. At 1219:35 hrs, the aircraft entered a right turn through approximately 140º over a period of 40 sec. It is possible that at this point the pilot was attempting to maintain or regain VMC, by turning away from poor weather using the technique he had learnt during his PPL training. The aircraft then entered a rapid descent and turned very quickly through a further 150º to the right. The radar trace was then lost. The aircraft appears to have entered a steep spiral dive from which it did not recover.

Spatial disorientation

With the reported weather at the altitude at which G-EMAZ was flying over the St George's Channel it is highly likely that the aircraft encountered cloud. Whilst in cloud it would have been necessary for the pilot to fly by sole reference to the flight instruments.

Although the pilot had received basic instrument flying familiarisation training, his experience level made it unlikely that he would have been able to accurately control the aircraft in IMC, let alone recover from an unusual manoeuvre such as a spiral dive. Moreover, there is a psychological difference between performing a pre-planned manoeuvre in an artificial environment, with an instructor in the aircraft, and performing it having inadvertently entered IMC, with no instructor present to assist the pilot if he encounters difficulties. With the absence of outside visual references, physical sensations can produce compelling perceptions of the aircraft's attitude and manoeuvres that differ markedly from those indicated by the flight instruments and spatial disorientation can occur. This tends to be more likely when recent and/or total instrument flying experience is low and in a high stress situation, such as inadvertent entry into IMC by a relatively inexperienced pilot.

In the event of inadvertent entry into IMC it would be appropriate to maintain a moderate airspeed while attempting to regain VMC or, having done so, while manoeuvring to remain clear of cloud. The characteristics of the final flight path, particularly the high airspeed, the rapid descent and the high rate of turn, were consistent with the effects of spatial disorientation. It is thus considered possible that the accident may have resulted from loss of control due to spatial disorientation following inadvertent entry into IMC.

Bird strike

When the lifeboat crewmen discovered the limited flotsam they found a large number of bird feathers amongst it. Most of them were small though there were a few large ones. It is thought that the smaller ones may have come from a pillow that might have been on board the aircraft. The larger ones are thought to have come from the numerous large sea gulls that were in the vicinity.

It would be most unusual for a bird strike to occur to an aircraft at 3,200 ft whilst in cloud and, even had such a bird strike occurred, it should not have caused the pilot to loose control of an aircraft of this type. Moreover, any bird remains are unlikely to have remained with the limited flotsam that had drifted some way from the original point of impact but were more likely to have remained attached to the major structure of the aircraft. It is therefore considered unlikely that the aircraft was affected by a bird strike.

Discussion

The National Transportation Safety Board, in the USA, have published a report on weather related flying accidents: "*Risk Factors Associated with Weather Related General Aviation Accidents*". Two of its conclusions were:

> *Pilots who start flying earlier in life are at a lower risk of being involved in a weather related General Aviation accident than those who start flying when they are older, and age at first certificate is a better predictor of future accident involvement than age at time of flight.*

> *The observed connection between age and accident risk in this study is not likely due to physical aging issues, but to other factors associated with the age at which a person starts flight training.*

Conclusions

The aircraft's last manoeuvre, derived from the radar recordings, was a rapid descent as it turned quickly to the right. The aircraft appears to have entered a steep spiral dive which led to a high energy impact with the surface of the sea.

It is considered likely that the aeroplane had inadvertently entered IMC on its planned route. While attempting to regain VMC the pilot lost control of the aircraft, possibly as the result of spatial disorientation.

The circumstances of the accident to G-EMAZ could also be explained by some form of brief and temporary incapacitation of the pilot, brought on by a medical or toxicological reason, without this necessarily leaving any evidence.

ACCIDENT

Aircraft Type and Registration:	Piper PA-28RT-201, G-MERL
No & Type of Engines:	1 Lycoming IO-360-C1C6 piston engine
Year of Manufacture:	1979
Date & Time (UTC):	10 April 2006 at 1725 hrs
Location:	Cardiff Airport
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Bent propeller, scraped engine cowling and nose landing gear doors
Commander's Licence:	Private Pilot's Licence
Commander's Flying Experience:	1,625 hours (of which 1,230 were on type) Last 90 days - 1.5 hours Last 28 days - 1 hour
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The nose landing gear collapsed following a normal landing. An examination of the aircraft after the accident revealed no obvious fault that would have prevented the landing gear from extending, or the indicating lights from illuminating.

History of the flight

On returning to Cardiff Airport, following an uneventful flight to Bristol Filton, the pilot was instructed to orbit in the local area before being cleared to join the circuit on the base leg. The aircraft was established on the final approach to Runway 30 at a speed of 75 to 80 kt with two stages of flap (25º) selected. As the aircraft entered the flare the pilot became aware of a beeping noise that she thought was the stall warner. She checked the air speed, which was satisfactory, and continued with the landing. The aircraft landed normally on the mainwheels and as the nose was lowered it sank onto the ground. The pilot made the aircraft safe and then with the passenger vacated the aircraft through the normal exit.

The airport fire service responded to the incident and helped in the recovery of the aircraft by raising the nose and pulling the nose landing gear into the extended position. When the pilot later entered the aircraft she noted that the landing gear lever was in the extended position.

Aircraft damage

The damage was restricted to a bent propeller blade and abrasion damage to the engine cowling and nose landing gear door. The engineer who undertook the assessment was of the opinion that the damage was consistent with the nose being lowered gently onto the runway. The engineer also inspected and tested the undercarriage operating and warning system and could find no faults or obvious reason as to why the nose gear would have collapsed.

Aircraft information

The aircraft is equipped with a tricycle retractable landing gear, operated by an electrically driven hydraulic pump. In flight the landing gear is held in the retracted position by hydraulic pressure acting on the jacks. The landing gear selector handle is mounted on the instrument panel. The position of the gear is indicated by three green lights that illuminate when the landing gear is down and locked. A red light illuminates when the gear is in an unsafe position. The red light and a warning horn operate if the power is reduced below 14 inches of manifold pressure and the landing gear has not reached the down and locked position. The landing gear warning horn emits a 90 Hz beeping sound, whereas the stall warner emits a continuous sound.

The aircraft is also equipped with a backup gear extender which automatically lowers the landing gear, independently of the landing gear selector, when the aircraft speed drops below 95 kt with the engine power set at idle. The actual extension speed varies between 75 and 95 kt and is dependent on the altitude, airspeed and engine power due to propeller slipstream effects. The system operates by sensing the static and dynamic pressure at a probe mounted on the side of the fuselage. This operates a pressure switch that releases the hydraulic pressure in the jacks, thereby allowing the landing gear to extend, under gravity, to the down and locked position.

Comments

It would appear that the pilot misinterpreted the undercarriage warning horn as the stall warner and consequently landed the aircraft with the nose landing gear in an unsafe condition. Consideration was given to the aircraft landing with the gear selector in the UP and DOWN positions. Had the selector been left in the UP position then the backup system would have automatically extended the landing gear. However, with power applied during the descent, the automatic lowering of the landing gear and operation of the warning horn might not have occurred until the aircraft was in the flare and the throttle was moved to the idle position. It is then possible that whilst the main landing gear had sufficient time to extend, and lock, the nose leg was still moving into the downlock when the wheel made contact with the ground. It is also possible that the selector had been moved to the DOWN position, but that the nose leg failed to engage the downlock. In that case, the warning horn would have operated when the power was reduced below 14 inches. With both scenarios at least one of the green landing gear indication lights would not have been illuminated during the approach and landing.

The pilot considered herself to be very conscientious and meticulous in undertaking her pre-landing checks. However, she believes that on this occasion it is probable that she did not observe three green lights before landing the aircraft.

ACCIDENT

Aircraft Type and Registration:	Replica SE5A, G-BMDB
No & Type of Engines:	1 Continental Motors Corp O-200-A piston engine
Year of Manufacture:	1988
Date & Time (UTC):	22 April 2006 at 1325 hrs
Location:	Boscombe Down Airfield, Wiltshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Propeller not repairable, minor damage to engine cowlings and wing tip
Commander's Licence:	Private Pilot's Licence
Commander's Age:	74 years
Commander's Flying Experience:	1,307 hours (of which 638 were on type) Last 90 days - 8 hours Last 28 days - 4 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Following engine start the pilot removed the wheel chocks and took them to an area where chocks could be left. While the pilot was away from the aircraft it slowly moved forward and started to turn, during which time the left wing touched the ground and the aircraft tipped onto its nose.

History of the flight

The aircraft, which is not fitted with a park brake, was parked with chocks in place on the grass at the side of Runway 23. The pilot started the engine and set the engine rpm to a slow idling speed. The operation of the airfield does not allow aircraft chocks to be left on the grass so the pilot removed them from the aircraft's wheels and carried them to an area where they could be left. On turning back towards the aircraft, the pilot saw that it was slowly moving from the grass to the tarmac runway. On reaching the tarmac the aircraft started to turn in a circle. The left wing tip touched the ground and, when facing east, which put the aircraft in a crosswind position, it tipped onto its nose.

The pilot, in a frank and honest statement, said that in his assessment the accident was the result of his rush to get airborne before the airfield's ATC opened. This resulted in him not tightening the throttle friction nut sufficiently which allowed the throttle to vibrate towards the open position.

ACCIDENT

Aircraft Type and Registration:	Scheibe SF25B motorglider, G-BLZA
No & Type of Engines:	1 Sauer 1800 ESI piston engine
Year of Manufacture:	1970
Date & Time (UTC):	4 March 2006 at 1000 hrs
Location:	2.5 miles WNW of RAF Halton, Buckinghamshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Loss of propeller
Commander's Licence:	Private Pilot's Licence
Commander's Age:	70 years
Commander's Flying Experience:	1,927 hours (of which 219 were on type) Last 90 days - 6 hours Last 28 days - 4 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and examination of propeller and engine by the AAIB

Synopsis

Whilst at 1,000 ft on the downwind leg of the circuit of Runway 02, the pilot experienced rapidly increasing airframe vibration; approximately five seconds later the engine stopped suddenly. The pilot noticed that the propeller was no longer attached to the engine and landed successfully on an alternate runway. Investigation revealed that the loss of the propeller was due to the fatigue failure of the bolts securing the propeller back-plate to the crankshaft.

History of the flight

On the day prior to the incident flight the aircraft had been flown without problems for 1 hour 10 minutes in air temperatures of -10°C but, as the aircraft was taxiing, a clattering noise was heard from the engine. An inspection after shutdown showed that the starboard exhaust baffle appeared to be loose.

The incident pilot, together with an engineer, inspected the engine the next day and, after finding no further faults, re tightened the exhaust baffle. Following a 10 minute ground run, the pilot decided to take off and fly a circuit to confirm that the source of the rattle had been rectified. Whilst at 1,000 ft on the downwind leg of the circuit for Runway 02, the airframe began to vibrate severely and, after approximately five seconds, the engine stopped. Realising that the propeller was no longer attached to the engine, the pilot carried out a successful emergency landing on Runway 06. On inspection, the starter ring gear and generator pulley were found to have fallen into the lower engine cowling.

Propeller installation

The aircraft was fitted with a Sauer 1800 ESI piston engine, and is the only SF25 motorglider on the UK register fitted with this engine type. It had been installed by the engine manufacturer in December 2002 and had operated for 310 hours prior to the incident flight. The Sauer 1800 ESI is approved for operation with two propellers types, one manufactured by Mt Propellers (the type fitted to 'ZA), the other manufactured by Hoffman Propeller GmbH. The Hoffman propeller is directly attached, together with the starter ring gear and generator pulley, to a flange on the engine crankshaft by six bolts. The 'Mt' propeller requires the use of an adaptor, or back-plate, to accommodate the wider pitched bolt holes of the 'Mt' propeller, Figure 1. This is secured by six bolts to the crankshaft flange; the propeller is then secured to the back-plate with six additional bolts. The use of a back-plate in the 'Mt' installation also allows a spinner to be fitted.

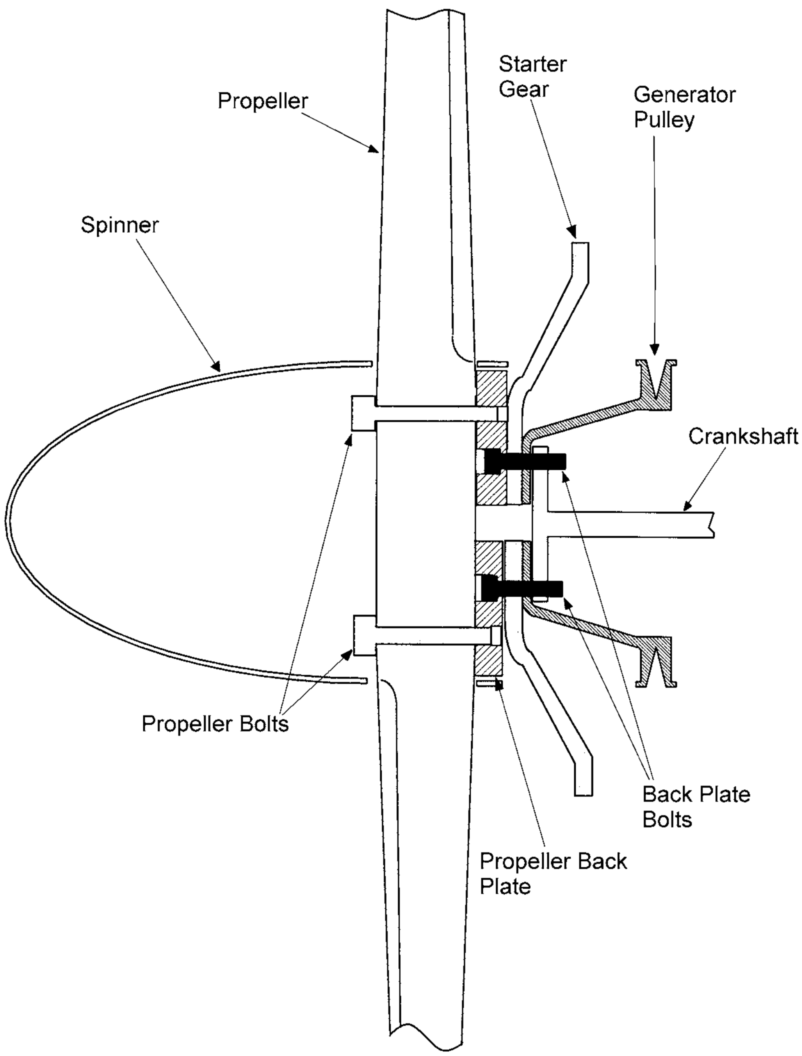

Figure 1

Diagram of 'Mt' propeller attachment to Sauer 1800 ESI engine, G-BLZA

Investigation

This event was the first propeller loss for this engine type. Initial inspection revealed that the bolts holding the back-plate, starter ring gear and generator pulley to the crankshaft had failed. The propeller, together with spinner and back-plate, was located several days after the event and these, and the remains of the bolts held in the crankshaft, were examined in detail. The propeller was found to be securely attached to the back-plate, with all bolts correctly torque tightened and wirelocked; the remains of the bolts which held the back-plate to the crankshaft were also found wirelocked.

The aircraft operators confirmed that the installation of the propeller had been carried out by the engine manufacturer and that, since installation, routine torque checks of the propeller attachment bolts, as specified in the CAA LAMS document, had been carried out. However, there was no specific requirement to check the back-plate bolts and these had not been checked since being installed. The back-plate bolts specified by the engine manufacturer are 'M 8.8' type, with an installation torque of 20 Nm; these bolts are manufactured from medium strength carbon steel with a minimum tensile strength of 120,000 psi.

All six of the failed bolts were 8 mm in diameter, with the corresponding holes in the back-plate being 8.1 mm in diameter. Four of the bolt heads were marked *'s 8.8'* and were unthreaded along the first 1.8 mm of the shank. The remaining two were marked *'e D 8.8'* and were unthreaded for the first 6.5 mm of the shank. Two adjacent bolts marked *'s 8.8',* had failed approximately 5 mm along the shank from the head, with the remaining four failing at approximately 17 mm. The fracture surfaces of each bolt showed clear signs of high cycle fatigue across approximately 95% of their surface areas.

The remains of the bolt shanks retained by the crankshaft flange were also examined and found to be between 17 mm and 18.5 mm long. Four of the shanks had failed in fatigue, and matched the four longer bolt heads from the propeller; measurement gave a complete bolt length of approximately 36 mm. The remaining two shanks showed signs of overload failures, which did not match the failure surface of the two shorter bolt heads. Further measurements indicated that approximately 13 mm was missing from each bolt shank. Given that these two bolts had initially failed by fatigue closer to the bolt head than the remaining four bolts, the portion of their shanks retained by the crankshaft would have projected approximately 13 mm further forward than the other four shanks. Distortion of two bolt holes on the starter ring gear indicated that after separation of the propeller, the ring gear had been held in place for a short while by these two longer shanks, until the rotational forces on the gear caused overload failures. The bores of the bolt holes in the back-plate, used to secure the plate to the crankshaft, showed evidence of damage caused by bolt threads.

On examination by the manufacturer, the engine was found to be fitted with spark plugs of a shorter reach than those specified. This can cause minor torque fluctuations in operation. The operators confirmed that they had originally ordered the long reach spark plugs specified by the manufacturer but, when the original plugs were removed, they were found to be the short reach type. The operators therefore installed new spark plugs of the same type as those they had removed, assuming them to be the correct plugs.

Analysis

Damage to the bores of the back-plate holes, caused by the bolt threads, showed that there had been relative movement between the propeller assembly and the crankshaft. It was also apparent that the drive to the propeller was being transmitted across the threaded portion of the bolts where their cross sectional area is at its minimum. The damage also indicated that the torque loading of the bolts was insufficient to prevent movement of the back-plate. This may have been the result of either insufficient installation torque or a 'backing off' of the bolts in operation, possibly due to the differential contraction of the back plate, starter gear and generator pulley in the low temperatures experienced on the pervious days flight, or both. The possibility of minor torque fluctuations, as a result of operating with spark plugs of the incorrect reach, may also have been a contributory factor to the failure of the bolts.

Safety actions

As a result of this incident the engine manufacturer has incorporated the following changes to the 'Mt' propeller installation for this engine type.

- Replacement of the current bolts with items that are unthreaded for the first 10 mm, thus preventing contact between the back-plate hole bores and the bolt threads
- Changing the specification of the bolts from 'M 8.8' to 'M 10.9'; this gives a 25% increase in their minimum tensile strength to 150,000 psi
- Increasing the installation torque of the back-plate bolts to 25 Nm

As a result of these measures, it is not considered necessary to issue any formal safety recommendations at this time.

ACCIDENT

Aircraft Type and Registration:	Slingsby T67B, G-BLTU
No & Type of Engines:	1 Lycoming O-235-N2A piston engine
Year of Manufacture:	1985
Date & Time (UTC):	20 February 2006 at 1325 hrs
Location:	13 miles north of RAF Marham, Norfolk
Type of Flight:	Training
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to landing gear, propeller, engine and structure
Commander's Licence:	Private Pilots Licence
Commander's Age:	34 years
Commander's Flying Experience:	1,430 hours (of which 68 were on type) Last 90 days - 8 hours Last 28 days - 8 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and AAIB inquiries

Synopsis

As a result of a reduction in engine power, possibly caused by carburettor icing, the pilot was unable to maintain height and therefore made a forced landing in a recently harrowed field. During the landing roll the nose wheel dug into the soft earth causing the nose leg to break and the aircraft to nose over coming to rest inverted.

History of the flight

The pilot departed from RAF Wyton on a three hour navigation exercise around the south-east of England and was receiving a Flight Information Service from Marham on 124.15 MHz. Approximately 45 minutes into the flight, and whilst flying straight and level at approximately 1,100 ft, the pilot noticed a reduction in the engine rpm from the cruise setting of 2,300 rpm. As the pilot was checking that he had not inadvertently knocked the throttle lever, the engine rpm decayed towards 2,100 rpm. The pilot selected the electrical fuel pump ON and confirmed that the fuel pressure was in the green (normal) zone. However, the engine rpm continued to decrease so the pilot contacted Marham and informed them that he had a rough running engine and requested a heading to Marham, which was 18 nm away. At this stage the pilot stated that the throttle was fully forward, the mixture was fully rich and he believes that he set the carburettor heat to ON. During the turn towards Marham the engine rpm decreased to around 1,700 rpm and the height reduced to 800 ft. The pilot realised that he could not maintain height and made a distress call on 124.15 MHz, which was acknowledged by Marham. The pilot stated that a landing into wind would have entailed descending towards trees which he was not sure he would clear and, therefore, he elected to land in a field with a 90º crosswind. He selected full flap and turned off the fuel cock and then held the aircraft in the flare for as long as possible. The aircraft initially touched down on the main wheels, but as the nose wheel touched down the aircraft nosed over coming to rest upside down. The pilot made the aircraft safe and exited the aircraft through the shattered canopy. He phoned his CFI using his mobile phone, and explained what had happened. Shortly afterwards a Tornado aircraft flew overhead, followed by a civilian helicopter, which landed and offered assistance. As this helicopter departed a Sea King from Wattisham arrived and took the pilot to hospital at Kings Lynn where he was examined by a doctor and then discharged.

Landing site

One of the reasons the pilot chose the landing site was that he could see a tractor operating in the field and therefore, if necessary, the driver would be able to assist him in vacating the aircraft. The field was large and flat, with trees along one edge and was being harrowed by the tractor driver. Ground marks indicated that the aircraft landed across the small furrows, touching down firstly on the mainwheels, followed shortly afterwards by the nose wheel. The marks indicated that the nose wheel then dug into the soft ground, the nose leg broke and the aircraft nosed over coming to rest inverted.

Meteorological information

The local weather observation at Marham at 1313 hrs on the day of the accident reported the surface wind as 030º/16 kt and the surface temperature as 5ºC with a dew point of 2ºC. The prevailing visibility was recorded as 25 km with 7 km visibility to the north, where the accident occurred. There were also reports of sleet and rain showers. The cloud base was reported as scattered at 1,800 ft and broken at 4,000 ft. The CAA carburettor icing prediction chart indicates that with these conditions there would have been a serious risk of carburettor icing at any power setting.

Data from a radiosonde ascent for Nottingham, which the Met Office assessed was in the same airmass and therefore represented the conditions at the time of the accident, gave the temperature, dew point and relative humidity at 1,100 ft as 4.6ºC, -0.7ºC and 68%. These conditions would indicate that there was a moderate risk of icing at cruise power and a serious risk of icing at descent power.

Aircraft examination

An external examination of the engine and fuel system was carried out by the AAIB. Apart from mud, which had probably entered the fuel tank as a result of the accident, there was no evidence of any contaminants in the fuel system. Both the electrical and mechanical fuel pumps were found to be serviceable and all the carburettor fuel and heat controls were connected. The induction and ignition systems were intact and the spark plugs indicated that the engine had been running slightly rich. The engine turned over freely, the pistons appeared to be intact and the engine contained an acceptable amount of clean oil. Marks on the propeller indicated that it was producing relatively little power when it made contact with the ground.

A review of the maintenance records revealed that the engine had operated for just under 500 hours since the last factory overhaul with no recent faults that could account for the loss of power.

Analysis

The damage to the aircraft occurred as a result of the nose wheel sinking into the soft ground causing the nose leg to break and the aircraft to nose over.

There were no reports of any engine problems on the flights leading up to the accident flight, nor were there any obvious indications after the accident to suggest that there was a fault in the engine or fuel system. Not only were the weather conditions at the time conducive to carburettor icing, but the gradual reduction in engine power described by the pilot is symptomatic of carburettor icing. A flying instructor from the club stated that he had experienced carburettor icing on this aircraft twice during the previous six months and on both occasions full power had been restored within 30 seconds of carburettor heat having been applied. It is possible that given the pilot's cruising height that he had insufficient time available after selecting carburettor heat for the ice to clear before he was committed to undertaking a forced landing.

ACCIDENT

Aircraft Type and Registration:	Agusta Bell 206B, G-GLSS
No & Type of Engines:	1 Allison 250-C20 turboshaft engine
Year of Manufacture:	1968
Date & Time (UTC):	5 April 2006 at 1423 hrs
Location:	Southend Airport, Essex
Type of Flight:	Training
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Minor) Passengers - N/A
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Student Pilot
Commander's Age:	55 years
Commander's Flying Experience:	36 hours (all on type) Last 90 days - 18 hours Last 28 days - 3 hours
Information Source:	Aircraft Accident Report Form submitted by the instructor pilot and a statement from the student pilot

Synopsis

The student pilot was flying a solo circuit exercise under the close supervision of his instructor. After a satisfactory circuit the helicopter pilot attempted a normal landing. In the subsequent descent the helicopter started to yaw and struck the ground, causing both skids to break off; it continued to yaw whilst remaining substantially upright. As the yaw ceased, the main rotor blades hit the ground, destroying themselves and causing extensive damage to the helicopter. The student pilot received a head wound but was able to secure and vacate the helicopter.

History of the flight

The helicopter had flown from its base at Earls Colne in Essex to Southend Airport, crewed by an instructor pilot and his student. The student pilot had flown less than two hours solo; this had included solo circuit exercises on the previous two days and his instructor remarked that the student had handled the exercises well. Runway 06 was in use at Southend, with CAVOK conditions and a surface wind from 010º (M) at 6 kt. The weather conditions were similar to those the student had experienced during the previous solo exercises. Helicopter circuits at Southend were flown parallel to, and to the north of, the main runway.

After arriving at Southend a dual circuit was flown from a grass area adjacent to the runway. This was handled satisfactorily by the student, so the instructor then briefed him for solo circuits, reminding the student of the expected handling differences when flying solo. The instructor also re-positioned a ballast weight, which would help counter the effects of flying without the instructor's weight in the helicopter. The instructor observed the student's first circuit, which appeared good but with the comment that the transition to the hover was a little fast and the landing itself was not at the specified point. The second circuit was very similar to the first initially, with a similar slight overshoot of the desired landing area. As the helicopter descended to a low hover it began to yaw to the left and right by up to 10º in each direction. The student was not happy with the hover so he increased the hover height to 6 to 8 ft whilst stabilising the helicopter.

The helicopter then descended and again began to yaw to the left. The rear part of the left skid touched the ground and caused the rate of rotation to increase as the helicopter pivoted about the contact point. The helicopter struck the ground, and the skids broke away while it continued to yaw while the fuselage body remained upright. It stopped rotating after about 400º of yaw and started to settle to one side. At this point the main rotor blades struck the ground and were destroyed, while the rotor head and main gearbox assembly were ripped from the fuselage and the tail boom detached. The student shut down the engine and secured the helicopter whilst his instructor rushed to the scene to assist. There was no fire, but the student sustained a head injury which required stitches.

Crash rescue

Once the instructor had helped the student to a safe place away from the helicopter wreckage, he tried to attract the attention of staff in the control tower, situated across the runway near the terminal buildings. Initially all he could do was to wave a high visibility jacket but, when no help was forthcoming, he ventured back into the helicopter to retrieve a mobile phone which he used to call the tower directly.

Having cleared the student pilot to *'land at your discretion north of runway'*, the ATC aerodrome controller saw the helicopter come to a low hover in the expected place. He then turned his attention to an aircraft on final approach to Runway 06 and was not aware that the helicopter had crashed. He was only alerted to the fact when the Airport Fire Service contacted him by radio to request clearance to attend the accident on the 'north grass'.

ACCIDENT

Aircraft Type and Registration:	Hughes 369HS (Hughes 500), G-LINC
No & Type of Engines:	1 Allison 250-C18A turboshaft engine
Year of Manufacture:	1973
Date & Time (UTC):	2 January 2006 at 1530 hrs
Location:	Sywell Aerodrome, Northants
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Tail boom separated and landing skids splayed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	263 hours (of which 60 were on type) Last 90 days - 5 hours Last 28 days - 5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

The helicopter's engine flamed out whilst it was on final approach to land at Sywell Aerodrome. The pilot established autorotation but upon landing, the helicopter's tail boom was struck by the main rotor and the skids were splayed by a heavy landing. The helicopter had run out of fuel.

History of the flight

The pilot reports that he did not physically check that the fuel tank was full, but it was indicating FULL at start up. The refueller of the helicopter reports that he filled it up "to the brim" after its preceding flight a few days before.

Initially, the pilot flew 16 nm from Sywell to Catthorpe, near Rugby in Warwickshire, in order to pick up his passenger. After landing, the pilot kept the engine running while his passenger boarded. They then flew to Folkestone Race Course (113 nm point-to-point) where they spent the day. The helicopter was not refuelled at Folkestone because no fuel was available.

The flight back to Sywell was uneventful until just north of Luton Airport. At this point the FUEL LOW caution light flickered once or twice. The pilot was not concerned as this had occurred to him before with a low fuel state. He attributed the flickering caption to the fuel moving around in the tank as a result of air turbulence. Prior to this, the pilot had not made a fuel burn check while en route.

At approximately 10 nm from Sywell the FUEL LOW caution light came on permanently. He was not too worried by this because his GPS indicated he was 6 mins from Sywell. He believed that when the FUEL LOW caution light came on, he still had 15 mins flying time available.

Due to a number of microlight aircraft in the circuit at Sywell, the pilot elected to join the circuit at the end of the downwind leg rather than fly a straight-in approach. Whilst on final approach, at 400 ft agl, the engine flamed out. The pilot commenced an autorotation and landed firmly short of the threshold of Runway 23. He did not recall what his cyclic control inputs were during the touchdown. The pilot and his passenger vacated the helicopter uninjured.

Sywell Aerodrome is normally a licensed airfield. On the day of the accident, a Bank Holiday, the aerodrome was closed and so it was unlicensed; consequently, the fire tender was not available. However, a member of the fire crew was on the airfield at the time of the accident. Upon seeing the accident he ran over to the helicopter with a fire extinguisher and checked that the helicopter was made safe as the occupants vacated the helicopter.

Weather

The weather in the Sywell area was generally fine but cool with light and variable surface winds; there was no cloud below 2,000 ft altitude. The wind at cruising altitude was variable over Kent but north-westerly at 10 kt in the West Midlands area. This gave an average headwind component of about 5 kt for the return journey.

Pilot's fuel planning

The pilot reported that he used a fuel burn estimation of 150 lb/hr in the cruise and has found this to work on previous flights in this helicopter. He did not add an allowance for start up, taxi and takeoff.

The helicopter left Sywell with a full tank of 435 lb of AVTUR fuel. Prior to the accident flight the pilot flew for 6 mins from Sywell to Catthorpe, before flying a further 1 hr 10 mins to Folkestone.

Before departing Folkestone for Sywell, the pilot made the following calculations.

Indicated fuel on board	200 lb
Distance from Folkestone to Sywell	99 nm
Pilot's own fuel burn figure	150 lb/hr
Flight time at 110 kt cruise	54 mins
Flight time factored for headwind component of 5 kt	57 mins
Fuel burn	143 lb
Fuel in reserve	57 lb

The total planned flight time for the day would have been 2 hours 13 minutes. The owner of the helicopter added that he always plans to fly for a maximum of 2 hours without refuelling.

Fuel planning advice

An extract from Safety Sense leaflet 17, *Helicopter Airmanship* is shown below.

> *3.9 Fuel Planning*
>
> *a. Always plan to land by the time the tank(s) are down to the greater of 1/4 tank or 45 minutes, but don't rely solely on the gauge(s) or low fuel warning. Remember, a headwind may be stronger than forecast, which particularly affects slower flying helicopters. Frequent use of carb heat/ hot air will also increase fuel consumption.*

b. Know the hourly fuel consumption of your helicopter. In flight, check that the gauge(s) agree with your calculations.

c. Understand the operation and limitations of the fuel system, gauges, pumps, mixture control (do not lean mixture unless it is permitted), unusable fuel etc.

Helicopter manufacturer's information

Fuel gauge accuracy

The volumetric capacity of the fuel tank is 242 ltr of which 2 ltr is unusable. Depending on the fuel type, the weight of fuel in a full tank varies between 435 lb and 416 lb. Loading Jet A fuel results in a total fuel weight of 435 lb.

The fuel gauge uses a float resistance measuring system. The gauge is marked in increments of 100 lb and the full capacity marked on it is 420 lb. The accuracy of the fuel gauge markings and the low-level light are tested by putting fuel in the tank and measuring or adjusting as necessary to meet the Handbook of Maintenance Instructions specifications.

Fuel planning figures

There is no quoted fuel burn figure to be used for planning purposes or to account for the fuel used during start up, taxi and takeoff. The aircraft manufacturer advised that for planning purposes, 435 lb of fuel is sufficient for 1 hr 48 mins of flight time. A figure of 30 to 40 lb of fuel would be a reasonable allowance for start up, taxi and takeoff. Fuel consumption on a standard day (sea level/15ºC) can vary from 150 to 220 lb/hr depending on conditions, flight profile, engine performance, etc.

The amount of unusable fuel quoted in the Flight Manual is 4.9 lb. After the accident, the fuel tank of helicopter G-LINC was drained of residual fuel and 4.5 lb were recovered.

Information obtained from a commercial operator

A commercial operator of the Hughes 369 reports that the company use an allowance of 30 lb for start up, taxi and takeoff. Thereafter the company uses a 'trip fuel'[1] consumption rate of 200 lb/hr for flight planning purposes (their helicopters have a different engine type to G-LINC and a slightly higher consumption rate). The company also makes appropriate allowances for reserve fuel, contingency fuel and unusable fuel when calculating the fuel required for a revenue flight.

The pilot expected to have 57 lb of fuel in reserve on arrival at Sywell. If 30 lb is subtracted to allow for start up, taxi and takeoff, this leaves 27 lb in reserve, of which 5 lb is unusable, leaving 22 lb of usable fuel before engine flame-out. Optimistically, this equates to 8 mins 48 sec of flying time at 150 lb/hr before fuel exhaustion.

Helicopter Flight Manual

An extract from the helicopter's Flight Manual is shown below stating the action to be taken when a FUEL LOW caption illuminates.

FUEL LOW

Indications: *Yellow FUEL LOW indicator ON when approximately 35 pounds of fuel remains in fuel tank.*

Procedures:

- *Avoid large steady side slip angles and uncoordinated manoeuvres.*

CAUTION- Never use the FUEL LOW light as a working indication of fuel quantity.

- *Land as soon as possible.*

Footnote

[1] Trip fuel consumption is a coarse estimate of fuel consumption per hour that takes account of fuel used during all airborne flight phases (takeoff, climb, cruise, descent, approach and landing).

WARNING Fuel consumption rates vary with power demand. Pilots should land prior to fuel exhaustion. Fuel exhaustion will result in engine flameout.

The Flight Manual's definition of '*Land as soon as possible*' was:

Execute a power-on approach and landing to the nearest safe landing area that does not further jeopardize the aircraft or occupants.

Conclusion

The helicopter's skids splayed as a result of a heavy landing. The tail boom was 'chopped off' by the main rotor; this was probably a result of moving the cyclic rearwards in a bid to cushion the heavy, autorotative landing, causing the rotor disc to tilt as it slowed down, thereby inducing the blades to'flap'.

At a 'trip fuel' consumption rate of 150 lb/hr, the pilot should have expected the helicopter to have consumed 190 lb of fuel on landing at Folkestone, leaving him with 245 lb fuel remaining. He recalls having an indicated 200 lb at Folkestone but he did not question the discrepancy or make any allowance for the apparent 'trip' consumption rate of 185 lb/hr. Consequently, the pilot's initial fuel calculations were simplistic and did not make any allowance for start up and taxiing. Not performing a fuel burn check, either at Folkestone or en route, left the pilot with no way of monitoring his in-flight fuel usage, denying him the chance of accurate fuel monitoring to improve his situational awareness and to aid his decision making.

Subsequently the pilot failed to carry out the appropriate actions when the FUEL LOW caption illuminated, misbelieving that he had 15 mins of flight time remaining before fuel exhaustion. By continuing the flight to the intended destination in conditions that required an immediate precautionary landing, the engine fuel supply was exhausted. The helicopter was then seriously damaged during the heavy forced landing.

Safety action pending

In 2005 the AAIB completed an investigation into an accident involving an Enstrom F-28A-UK, which was provoked by fuel exhaustion (see Bulletin 10/2005 registration G-BAAU). The Branch identified one causal factor as the complete absence of any fuel consumption data in the helicopter's flight manual. Consequently, in September 2005, the following safety recommendation was made to the FAA and copied to the helicopter manufacturer:

Safety Recommendation 2005-059

The Federal Aviation Administration of the USA should instruct the Enstrom Helicopter Corporation to include useful information on fuel consumption rates in all their Rotorcraft Flight Manuals.

The helicopter manufacturer decided not to act independently upon the safety recommendation because (quote):

'in accordance with the applicable regulations under which the aircraft was certified, ie CAR 6.743, Performance Information, fuel consumption rates are not "required" to be included as part of the performance information in the Flight Manual'.

Therefore, it seems unlikely that US manufacturers of light helicopters will include fuel consumption data in their flight manuals unless regulatory action is taken by the FAA. A formal response from the FAA to this Safety Recommendation was due after 90 days but it has not yet been received by the AAIB.

ACCIDENT

Aircraft Type and Registration:	Schweizer 269C-1, G-CCJE
No & Type of Engines:	1 Lycoming HIO-360-G1A piston engine
Year of Manufacture:	2003
Date & Time (UTC):	18 February 2006 at 1800 hrs
Location:	Sheffield City Airport
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Commercial Pilot's Licence with Flying Instructor Rating
Commander's Age:	50 years
Commander's Flying Experience:	3,987 hours (of which 248 were on type) Last 90 days - 101 hours Last 28 days - 34 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot, additional AAIB inquiries and testing of engine

Synopsis

Following an uneventful flight, the commander was demonstrating an autorotation to a student PPL who had recently purchased a similar type of helicopter. He entered the flare with a relatively high rate of descent, which he was unable to arrest by raising the collective lever. As the helicopter landed, the skids dug in to the relatively soft ground, causing it to roll on to its right side.

Examination of the helicopter, its engine in particular, failed to find any pre-accident defects. The helicopter had been flying close to its maximum permitted weight and, after leaving the helicopter, the commander noted from the wind sock that the approach had been made with a tailwind component.

History of the flight

The purpose of the flight was to demonstrate the Schweizer 269 to a passenger who had five hours experience as a PPL student on Robinson R22 helicopters, and who had recently purchased the similar Schweizer 269 CBi model.

The takeoff from Sheffield Airport and upper air work in the local area was uneventful and, on their return, the passenger asked the commander for an autorotation demonstration. It was decided that a practice engine-off landing would be performed back at the airport and, as the wind had been light and variable all day, the commander decided that a power recovery would be the most sensible option. The appropriate checks, which included the engine parameters, were conducted on the approach to Sheffield at around 1,000 ft agl, and a reference point was chosen on the active Runway 28. The entry into autorotation was normal and the aircraft was stabilised, initially at 60 kt. This was subsequently reduced to 50-55 kts in order to reduce the ground speed and to fly closer to the published best speed for autorotation. At 500 ft agl, the engine temperatures and pressures were checked and the descent rate appeared normal. The flare was commenced at about 150 ft with an accompanying opening of the throttle; however, no increase in engine noise was apparent. The flare was progressively 'tightened' but this had little effect and it still appeared to the commander that the engine was not responding. At this point, it became clear that the aircraft was going to strike the ground with a high rate of descent; the commander attempted to cushion this as much as possible by raising the collective lever. The aircraft struck the ground, which had been softened by earlier rain, and the front of the skids dug in, causing the helicopter to tip forward and to the right; it came to rest on its right side. The engine was not running but the commander pulled the fuel shut-off lever and turned off the battery. Both occupants left the aircraft via the shattered canopy and found they had suffered no more than minor cuts and bruises. There was no fire and the emergency services were on the scene almost immediately. After leaving the aircraft the commander observed that the wind sock was indicating the approach had been flown with a tailwind component.

Photographs of the accident site supplied by the airfield operator showed that the main rotor blades were lying in a 'coned' position, indicating low rotor speed at the time of the ground impact.

Examination of the engine

Although the aircraft was damaged beyond repair, the engine and its accessories had remained intact and hence were assessed as capable of being run. Accordingly, the engine was removed from the airframe, which involved severing the throttle and mixture controls and disconnecting the oil cooler. At this time, the fuel gascolator was found to be clean and the electric fuel boost pump to be functional.

The engine was taken to a Lycoming engine overhaul agent and installed in a test cell, where, apart from removing such accessories that were necessary for mounting it on the test stand, it was run in the 'as found' condition. On starting, some smoke emitted from the exhausts as a result of oil that had accumulated in the cylinder heads as the aircraft lay on its side after the accident. Subsequently, it ran normally throughout the test schedule, which included checking the operation of each magneto. 'Slam' accelerations and decelerations were also conducted, without problems; in particular it was noted that the engine picked-up cleanly during each acceleration. The oil pressure was noted to be slightly low: however, this could have been rectified by adjusting the oil pressure relief valve and was not considered a significant problem. The tests also confirmed that the engine-driven fuel pump was delivering a satisfactory fuel pressure.

The engine had achieved almost 1,100 hours of service and had been installed in the aircraft since new. The overhaul agent commented that the performance parameters were typical for an engine at such a stage in its overhaul life.

Analysis

The pilot reported that the combined weight of himself and passenger, together with an estimated 68 kg of fuel on board, put the all-up-weight (AUW) of the helicopter to within approximately 20 kg of its maximum. Higher AUWs, and hence the increased inertia of any helicopter, result in higher descent rates during autorotation and additional height loss during the flare while recovering to a hover. Some instructors on this type of helicopter have commented that they tend to maintain an airspeed of 60 kt, or more, during autorotation, which represents additional energy that can be used to maintain rotor speed during the flare. Any significant reduction in rotor speed may result in the blades 'over-pitching' as the collective lever is raised at the end of the flare, leading to further rotor speed reduction. In this condition, the available engine power cannot overcome the excessive drag on the blades in order to regain normal rotor speed, leading to the blades coning upwards.

It seems possible that, in this case, the weight of the aircraft and the higher than usual descent rate was compounded by a tailwind component that made judging the manoeuvre more difficult. In addition, the commander had not appreciated the boggy nature of the ground, and this precluded what might otherwise have been a successful run-on landing, albeit with a high rate of descent.

The available evidence does not entirely discount an engine problem during the descent; however, the test cell results did not suggest any such problem. The helicopter's fuel system is simple in design with the fuel tanks being mounted high on the airframe. Thus, even had the electric boost pump failed, the combination of gravity feed and engine-driven pump would have been sufficient to maintain the fuel supply to the engine. Also, as this was a fuel injected engine, the possibility of induction icing was considered remote.

ACCIDENT

Aircraft Type and Registration:	Ikarus C42 FB80 microlight, G-SGEN
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	2004
Date & Time (UTC):	27 April 2006 at 1550 hrs
Location:	Private Airstrip, West Tisted, near Alton, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Nosewheel and propeller damaged
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	135 hours (of which 77 were on type) Last 90 days - 12 hours Last 28 days - 9 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Whilst making an approach to land with a gusting tail wind component, the aircraft stalled during the flare, resulting in a heavy landing which damaged the nosewheel and propeller.

History of the flight

The pilot and his passenger, also a pilot, departed from Wickham, Hampshire, to fly to a private strip at West Tisted, approximately 13 miles to the north-east, in order to conduct practice forced landings. West Tisted has a 700 m grass strip which is oriented approximately 06/24. Having arrived there, the pilot proceeded to make several successful practice forced landings on 06, which was into wind. He then chose to perform a normal approach and landing from the opposite direction, on 24, to gain further experience. He was aware that there would be a slight tailwind component, but considered his airspeed on the approach to be sufficient. As he flared at a height of about 8 to 10 ft, the aircraft stalled and came down on its nosewheel, which buckled on impact; the propeller was also damaged from contact with the ground. The aircraft then slid along the ground for about 30 m, before coming to a halt.

According to the aviation weather brief obtained by the pilot at 11:00 hrs, the forecast wind speed/direction was 030°/5 kt; the actual wind at the time of the accident was 030°/5 kt, gusting to 10 kt.

The pilot felt that he had been caught out by the tailwind, which he had not expected to be gusting, and that his airspeed in the latter part of the approach may not have been high enough for the given conditions.

ACCIDENT

Aircraft Type and Registration:	Pelican PL microlight, G-MPAC
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	2001
Date & Time (UTC):	12 May 2006 at 1600 hrs
Location:	Clipgate Farm, Kent
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Front wheel collapsed, exhaust system, shock loading to engine
Commander's Licence:	Private Pilot's Licence
Commander's Age:	64 years
Commander's Flying Experience:	412 hours (of which 15 were on type) Last 90 days - 12 hours Last 28 days - 10 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot reports that, on commencing his final approach to Clipgate during the return leg of a flight to Headcorn, he saw another aircraft on the runway. After returning to the circuit and making a second approach to land, at 60 mph with full flap selected, he flared the aircraft a little high causing it to bounce on touchdown. Instead of maintaining the aircraft's attitude during the bounce, he believes that he must have relaxed the control column, allowing the aircraft to adopt a slightly nose down attitude; the nose wheel collapsed during the subsequent touchdown. After skidding to a halt, the pilot turned off the fuel and master switch and vacated the aircraft unhurt.

ACCIDENT

Aircraft Type and Registration:	Skyranger 912S(1), G-PSKY
No & Type of Engines:	1 Rotax 912ULS piston engine
Year of Manufacture:	2005
Date & Time (UTC):	23 April 2006 at 1450 hrs
Location:	Diggle, Oldham
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Landing gear and propeller damaged
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	187 hours (of which 59 were on type) Last 90 days - 14 hours Last 28 days - 10 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Following a circling manoeuvre, the commander applied climb power. The engine failed to respond, resulting in a forced landing and collision with a dry stone wall. Subsequent examination of the aircraft revealed water in both fuel tanks and the carburettor float bowls.

History of the flight

Prior to the flight the aircraft was fuelled with MOGAS obtained from a local garage. Fuel drawn from the drain of the two fuel tanks was clean and did not show any signs of water contamination. The taxi, takeoff and climb, from Crosland Moor, were all without problems and, about 15 minutes into the flight, the commander circled over a farmhouse owned by a family member of the passenger. On completion of this manoeuvre the commander applied climb power; however, the engine did not respond, 'spluttered' and failed to provide enough power to remain airborne. The commander immediately found a field in which to conduct an emergency landing, but during the approach the engine started to produce some power. The commander assessed that the intended field was too short and so he elected to use this available engine power to attempt a climb away. The aircraft failed to climb and touched down heavily, bounced, and then landed heavily again some 20 to 30 yards further on, resulting in a bounce just before a dry stone wall. The nose wheel contacted the top of the stone wall, causing the aircraft to pitch nose down, with contact by the main wheels bringing it to a halt on top of the wall. Both commander and passenger were wearing lap strap and diagonal harnesses and were not injured. There was no fire and they exited the aircraft normally.

A subsequent inspection of the aircraft revealed water and sediment in the bottom of both fuel tanks, as well as water in the float bowls of both carburettors. Discussions with the commander revealed that the aircraft was normally stored with the tanks partially full, which could have promoted condensate to build up in the fuel tanks over a period of time.

FORMAL AIRCRAFT ACCIDENT REPORTS ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

2004

1/2004 BAe 146, G-JEAK during descent into Birmingham Airport on 5 November 2000.

Published February 2004.

2/2004 Sikorsky S-61, G-BBHM at Poole, Dorset on 15 July 2002.

Published April 2004.

3/2004 AS332L Super Puma, G-BKZE on-board the West Navion Drilling Ship, 80 nm to the west of the Shetland Isles on 12 November 2001.

Published June 2004.

4/2004 Fokker F27 Mk 500 Friendship, G-CEXF at Jersey Airport, Channel Islands on 5 June 2001.

Published July 2004.

5/2004 Bombardier CL600-2B16 Series 604, N90AG at Birmingham International Airport on 4 January 2002.

Published August 2004.

2005

1/2005 Sikorsky S-76A+, G-BJVX near the Leman 49/26 Foxtrot Platform in the North Sea on 16 July 2002.

Published February 2005.

2/2005 Pegasus Quik, G-STYX at Eastchurch, Isle of Sheppey, Kent on 21 August 2004.

Published November 2005.

3/2005 Boeing 757-236, G-CPER on 7 September 2003.

Published December 2005.

2006

1/2006 Fairey Britten Norman BN2A Mk III-2 Trislander, G-BEVT at Guernsey Airport, Channel Islands on 23 July 2004.

Published January 2006.

AAIB Reports are available on the Internet
http://www.aaib.gov.uk