AIRCRAFT ACCIDENT REPORT 2/2010

Air Accidents Investigation Branch

Department for Transport

Report on the accident to Beech 200C Super King Air, VQ-TIU at 1 nm south-east of North Caicos Airport Turks and Caicos Islands, British West Indies on 6 February 2007

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996

The sole objective of the investigation of an accident or incident under these Regulations shall be the prevention of accidents and incidents. It shall not be the purpose of such an investigation to apportion blame or liability.

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This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidents.

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Department for Transport
Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
Aldershot
Hampshire GU11 2HH

April 2010

Mr Gordon Wetherell
Governor of Turks and Caicos Islands

Dear Sir

I have the honour to submit the report by Mr P E B Taylor, an Inspector of Air Accidents, on the circumstances of the accident to Beech 200C Super King Air, registration VQ-TIU at North Caicos Airport, Turks and Caicos Islands on 6 February 2007.

Yours sincerely

David King
Chief Inspector of Air Accidents

Department for Transport
Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
Aldershot
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April 2010

The Right Honourable Lord Adonis
Secretary of State for Transport

Dear Secretary of State

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Yours sincerely

David King
Chief Inspector of Air Accidents

Contents

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
AC	alternating current
AFM	Airplane Flight Manual
agl	above ground level
AN(OT)O	Air Navigation (Overseas Territories) Order
AOA	angle of attack
AOB	angle of bank
ASSI	Air Safety Support International
ATC	Air Traffic Control
CAD	Civil Aviation Department
CFR	Code of Federal Requirements
°C,M,T	degrees celsius, magnetic, true
CVR	cockpit voice recorder
DC	direct current
EDX	energy dispersive X-ray
FAA	Federal Aviation Administration (USA)
FCU	fuel control units
FDR	flight deck recorder
FOD	foreign object damage
ft	feet
g	normal acceleration
GPS	Global Positioning System
hrs	hours (clock time as in 1200 hrs)
HSI	horizontal situation indicator
IAS	indicated airspeed
ICAO	International Civil Aviation Organisation
in	inch(es)
kt	knot(s)
lb	pound(s)
lb/hr	pounds per hour
m	metres
mg	milligram
ml	millilitre
N_g	gas-generator rpm
nm	nautical mile(s)
P_X	modified compressor discharge air
P_Y	compressor discharge pressure derivative
rpm	revolutions per minute
SAR	Search and Rescue
SEM	scanning electron microscope
TCI	Turks and Caicos Islands
UK	United Kingdom
USA	United States of America
USCG	United States Coastguard
UTC	Co-ordinated Universal Time (GMT)
VOR	vestibulo-ocular reflex

Air Accidents Investigation Branch

Aircraft Accident Report No: 2/2010 EW/C2007/02/08

Registered Owner and Operator:	Air Turks and Caicos (2003) Limited
Aircraft Type:	Beech 200C Super King Air
Serial number:	BL-131
Nationality:	Turks and Caicos Islands
Registration:	VQ-TIU
Location of Accident:	1 nm south-east of North Caicos Airport, Turks and Caicos Islands, British West Indies (N21º 54.7′ W071º 55.0′)
Date and Time:	6 February 2007 at 1842 hours All times in this report are local (UTC-5)

Synopsis

The accident was reported to the Turks and Caicos Islands (TCI) Civil Aviation Department (CAD) on the evening of 6 February 2007. The same evening, a request for assistance was made to the United Kingdom Air Accidents Investigation Branch (AAIB), under the terms of a pre-existing Memorandum of Understanding; AAIB Inspectors arrived in the TCI on 8 February 2007. The TCI CAD appointed a TCI national as Investigator-in-Charge, tasked with conducting an investigation in accordance with the provisions of Annex 13 to the International Civil Aviation Organisation (ICAO) Convention. The investigation was conducted by: Mr P Forbes (Investigator-in-Charge), Mr K Fairbank (AAIB Operations), Mr P Thomas (Operations), Mr A Robinson (AAIB Engineering) and Mr K Malcolm (Engineering). The manufacturers of the aircraft, the engines and the propellers assisted during the later stages of the investigation.

VQ-TIU crashed soon after takeoff from North Caicos Airport, at the start of a flight bound for Grand Turk, TCI. On board were one pilot and five passengers. The pilot received fatal injuries in the accident; the passengers mostly suffered serious injuries, but all survived the accident. Weather conditions at the time were good, but it was after nightfall; the moon had not risen and there was little cultural lighting in the area.

The aircraft crashed into a shallow lagoon approximately one nautical mile south-east of North Caicos Airport. Wreckage was spread along a trail that extended in excess of 370 m along a track of 220°(M). The aircraft's fuselage had come to rest comparatively intact, although lying in an inverted attitude. Evidence from the accident site indicated that the aircraft had struck the water in a nominally upright attitude, with only a moderate rate of descent but at relatively high forward speed.

From a detailed examination of the wreckage and the circumstances of the accident, it was concluded that the aircraft was structurally intact and probably under control when it struck the surface. The evidence indicated that each engine was producing power throughout the short flight and at the time of impact. Although anomalies were found which suggested that a possible power asymmetry may have existed, this should not have been sufficient to cause the pilot serious control difficulties.

None of the passengers described an obvious problem with the aircraft during the flight, and most remained unaware of the impending crash. The circumstances of the accident suggested that the pilot became spatially disorientated, to the extent that the aircraft diverged from its intended flight path and reached an irrecoverable situation. The environmental conditions were conducive to a disorientation event, and a postmortem toxicological examination showed that the pilot had a level of blood alcohol which, although below the prescribed limit, was significant in terms of piloting an aircraft and would have made him more prone to disorientation.

The evidence indicated that the pilot had probably started a recovery to normal flight, but too late to prevent the accident. However, his actions had the effect of reducing the descent rate and placing the aircraft in a nearly level attitude at impact. This lessened the impact damage and helped preserve the fuselage structure relatively intact, increasing the passengers' chance of survival.

The investigation identified the following causal factors:

1. The aircraft adopted an excessive degree of right bank soon after takeoff. This led to a descending, turning flight path which persisted until the aircraft was too low to make a safe recovery.

2. The pilot probably became spatially disorientated and was unable to recognise or correct the situation in time to prevent the accident.

The investigation identified the following contributory factors:

1. The environmental conditions were conducive to a spatial disorientation event.

2. The pilot had probably consumed alcohol prior to the flight, which made him more prone to becoming disorientated.

3. The flight was operated single-pilot when two pilots were required under applicable regulations. The presence of a second pilot would have provided a significant measure of protection against the effects of the flying pilot becoming disorientated.

No Safety Recommendations are made.

1. Factual information

1.1 History of the flight

1.1.1 Background to the flight

The pilot flew part-time for the aircraft operating company, whose main operating base was at Providenciales Airport, the main international airport of the TCI. The pilot resided on North Caicos, and it was a common arrangement for him to fly a company aircraft there at the end of a working day, once it had completed its scheduled flights. On these occasions, the aircraft (not necessarily VQ-TIU) would normally remain at North Caicos overnight before recommencing scheduled operations the next morning. However, the intention on the evening of the accident was for the pilot to take a private party of five passengers from North Caicos to Grand Turk for a political function, returning early the next morning. It was reported that the passengers were being carried gratuitously, hence the pilot and aircraft operator considered that it was a private flight.

1.1.2 The flight from Providenciales to North Caicos

On the day of the accident, VQ-TIU flew on seven commercial sectors, finishing operations at 1515 hrs in Providenciales. It was refuelled at about 1700 hrs; fuelling documentation indicated that the aircraft's main tanks were filled to full, which would have provided in excess of 3 hours flight time. During the afternoon the pilot, who had not been scheduled to fly commercially that day, travelled as a passenger from North Caicos to Providenciales in order to collect VQ-TIU and fly it back to North Caicos.

VQ-TIU took off from Providenciales at 1735 hrs; on board were the pilot and a female passenger who also lived on North Caicos. The aircraft arrived at North Caicos just seven minutes later, two minutes after official sunset. The passenger recalled nothing abnormal about the flight, the aircraft or the pilot.

1.1.3 The accident flight

The aircraft was parked on the small apron at North Caicos Airport while the pilot went home to collect some personal items. One of the intended passengers saw the aircraft arrive. He remained in the vicinity until the pilot returned, and reported that the aircraft was unattended in the intervening time.

When the pilot returned, four of the five passengers were gathered near the aircraft, and the last passenger arrived soon afterwards. The pilot, a local man well-known to the passengers, appeared to be his normal self and in good spirits. As most inter-island travel in the TCI is by air, the passengers were also familiar with the operator's aircraft and used to travelling by air. Some had flown frequently on VQ-TIU.

The pilot supervised embarkation and gave an emergency briefing. One passenger reported that the pilot made a mobile telephone call, which he presumed to be to Air Traffic Control (ATC) at Providenciales to notify them of the proposed flight. Prior to seating himself at the controls, the pilot told the passengers that they may expect some turbulence.

The aircraft taxied onto the runway at its eastern end and along its length for a departure from Runway 08. It was about one hour after sunset and outside the airport's normal operating hours, so there were no ATC personnel on duty. The runway lights were operated by the operator's station manager.

The aircraft took off at 1840 hrs. Soon after takeoff the aircraft was seen to start a turn to the right, which was consistent with its routing to Grand Turk, some 54 nm to the south-east. However, the aircraft reached a relatively large angle of bank and started to descend. The descent continued until it crashed with significant forward speed into an area of very shallow water. The aircraft broke up on impact, with the fuselage section coming to rest nearly inverted but comparatively intact. All those on board survived the impact sequence with varying degrees of injury. However, the pilot died before he could receive specialist medical treatment.

1.1.4 Eyewitness accounts

Seven local witnesses who saw the aircraft during or after takeoff gave their accounts. They generally described a very dark, moonless night, which prevented them seeing much of the aircraft apart from its navigation lights. The majority of witnesses were towards the coastline (about 1,300 m from the departure end of Runway 08) and did not see the takeoff or early climb out. Detailed witness accounts are at Section 1.18 of this report.

The witnesses collectively described the aircraft climbing ahead until just after crossing the coast, after which it started a right turn. The initial track they described may have been up to 20º to the right of the runway heading. The approximate flight path as described by witnesses is shown at Figure 1, together with the accident site location.

Witnesses were divided about the sound the aircraft made during the flight. Whilst some thought it remained normal, others described a change in note as the aircraft turned, or described an unusual engine sound, as if one engine was labouring. Similarly, some witnesses thought the aircraft did not gain very much height before turning right, whilst others reported a normal takeoff flight path.

Those witnesses who saw the aircraft turn right described it rolling to a larger than normal bank angle (variously described as being banked between 45° and 70° to the right). As the aircraft banked it began to descend, and the witnesses realised that the aircraft was no longer following a normal profile. It descended at a relatively high speed, remaining in a banked, right wing low attitude.

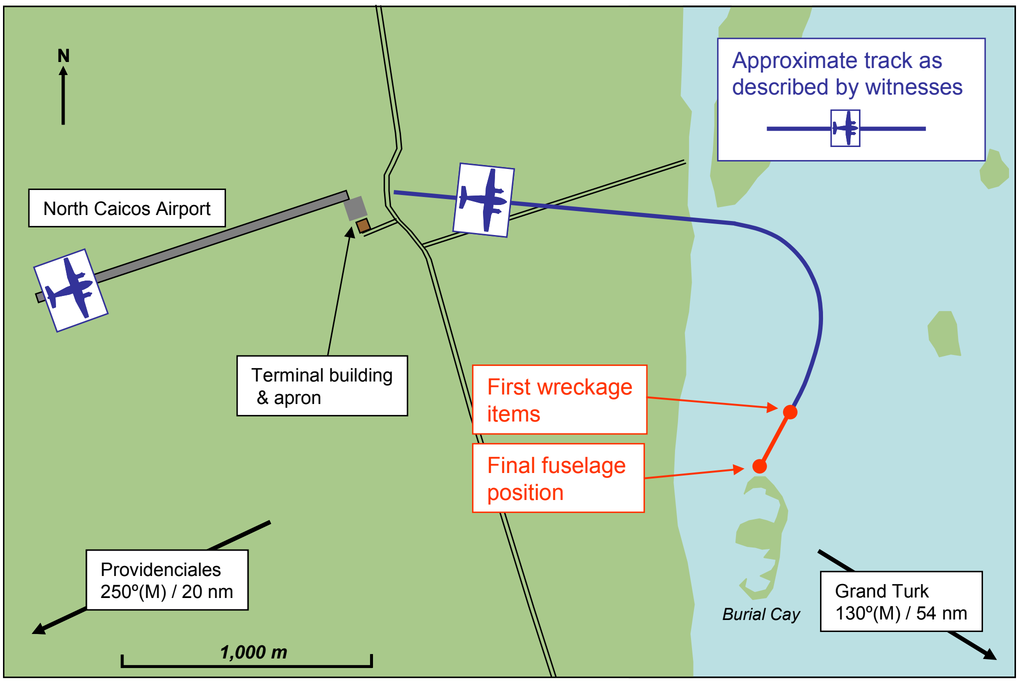

Figure 1

Aircraft flight path as described by witnesses, with location of impact and wreckage trail

1.1.5 Passenger accounts

1.1.5.1 General

The passengers reported a normal sequence of pre-flight checks and engine starts. There was a pause before takeoff, while cockpit checks were carried out. All the passengers reported that the takeoff and initial climb seemed normal, with no unusual noises or sensations. The passengers' accounts are summarised individually below, starting with Passenger A next to the pilot and progressing to Passenger E who was at the rear of the cabin. General cabin layout and seating positions are shown at Figure 2.

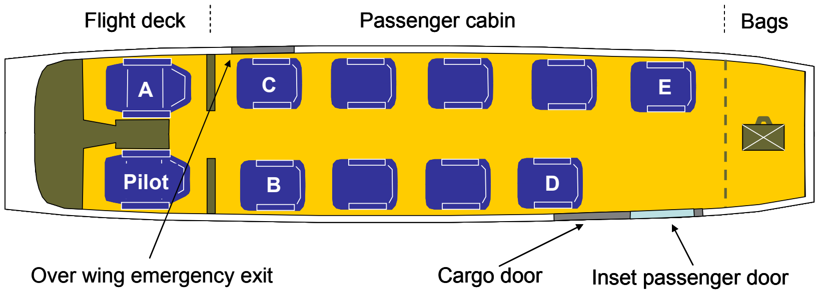

Figure 2

General aircraft layout and seating positions

1.1.5.2 Passenger A

This passenger, who was a friend of the pilot and had flown in the aircraft with him before, was seated to his right in what was normally the co-pilot's seat. However, she was not a pilot nor had she ever received any pilot training, and was unfamiliar with the instrument displays and indications. She stated that she did not touch the control wheel or rudder pedals during the flight. During the taxi to the runway she talked with the pilot, and later described his manner as completely normal. She also stated that the takeoff and initial climb were normal, and she remembered seeing lights on the ground to the aircraft's right. Then the aircraft seemed to level off, and she described an up and down motion, which she felt as a sensation in her stomach.

Initially, she thought the pilot may have been deliberately inducing the sensation in a mischievous manner, as he had done something similar when flying with her before. She tapped his arm as a light-hearted reproof, a gesture which was seen by another passenger who interpreted it as such. Passenger A was not concerned at this stage, as the pilot was obviously flying the aircraft. She did not recall hearing any unusual or changing engine sounds, or seeing any warning lights.

She then became aware that the aircraft was descending, but did not sense any turn. Again, she was not concerned initially, until she next looked at the pilot shortly before the accident. He looked at her also, but did not say anything. He looked neither frightened nor confused, but she knew at this point that something was wrong. The pilot had both hands on the control wheel: when asked if she remembered what the pilot may have been doing with it, she described a large, probably full, deflection to the left, probably with some aft deflection (ie a large left roll demand and moderate nose up demand). At this point Passenger A covered her face with her hands, just before the aircraft crashed.

1.1.5.3 Passenger B

This passenger was seated in the forward left cabin seat, behind the pilot. He also reported that the takeoff and initial climb appeared normal. The aircraft then started to bounce as it encountered turbulence. He recalled that the pilot was controlling the aircraft and that Passenger A knocked the pilot's arm and told him to stop it; he inferred that she thought he was generating the 'turbulence' deliberately. He remembered the pilot looking at Passenger A in the co-pilot seat next to him. The turbulence was Passenger B's last recollection before impact.

1.1.5.4 Passenger C

This passenger was seated in the forward right cabin seat, behind the co-pilot's seat. He said that the aircraft became airborne at the end of the runway, but that the climb appeared good. Then, the aircraft's right wing suddenly dropped. He recalled shouting "hold it, hold it" to the pilot, which was said out of concern, after which the aircraft rolled level. There were no unusual noises during or after takeoff. He thought that the aircraft rolled to the left before impact.

1.1.5.5 Passenger D

This passenger was seated in the rear left seat. He reported that the takeoff and climb were smooth and appeared normal. The aircraft started to roll to the right and appeared to encounter turbulence; he described it "shooting up" as if it had hit an air pocket. He was aware of a passenger at the front shouting a comment to the pilot about controlling the aircraft, and thought it was intended to be light-hearted. He did not hear a reply from the pilot. Passenger D's next recollection was after the crash.

1.1.5.6 Passenger E

This passenger, seated in the rear right seat, recalled a smooth takeoff and climb, with no unusual noise or change in engine sounds. It was dark and he could see only distant lights. He did not recall any turning or other motions and his next recollection was the impact.

1.2 Injuries to persons

	Crew	Passengers	Others
Fatal	1	-	-
Serious	-	4	-
Minor	-	1	-
None	-	-	-

1.3 Damage to the aircraft

The aircraft was destroyed.

1.4 Other damage

Nil.

1.5 Personnel information

1.5.1 Pilot

Male, aged 46 years

Licence:	FAA Commercial Pilot's Licence	
Ratings:	Single engine aeroplane Multi engine aeroplane Instrument, aeroplane	
Medical certificate:	FAA First class, valid. Bearing limitation: *'Holder shall wear corrective lenses'*	
Flying hours:	Total all types:	Estimated 8,500 hours
	Total on type:	394 hours
	Total last 90 days:	64 hours
	Total last 28 days:	29 hours
	Total last 24 hours:	0.25 hours

1.5.1.1 Pilot's flying hours

The pilot's personal flying logbook was not found. Records held by the aircraft operator showed that the pilot declared 2,800 flying hours when he started flying as a company pilot in 1998. The same records showed that the pilot flew a total of 1,312 hours on company public transport or training flights between April 2002 and the date of the accident. It was reported that the pilot regularly flew various light aircraft in a private capacity, but no records of this flying were found.

To arrive at the estimate of total flying hours in paragraph 1.5.1 above, the following assumptions were made:

(1) Company flying during the period June 1998 to March 2002 was at the maximum yearly rate shown in subsequent records (approximately 500 hours per year),

(2) A total of 30 hours private flying was added for each and every month between June 1998 and February 2007.

When the pilot applied to have his FAA licence validated by the TCI CAD in April 2006, he declared a total of 10,680 flying hours: this figure could not be verified from available records.

1.5.1.2 Pilot's flying history

The pilot had flown various light single-engine and twin-engine aircraft as a private pilot before gaining a commercial licence in 1998. In the same year he started flying commercially with the aircraft operator (in an earlier corporate identity), having been working there in an administrative capacity for about four years. Since 1998 the pilot had flown the majority of the company's types.

In 2004/2005, the pilot held an Authorised Examiner appointment, issued by the TCI CAD, to conduct Instrument Rating Renewal tests and Proficiency and Instrument Approach to Land tests in the operator's BN2A Islander and Cessna 401 aircraft.

The pilot started conversion training for the Be200C in August 2004 and passed the final qualifying check flight in June 2005. At the time of the accident he had nearly 400 hours flying experience on type, as well as being in current flying practice on the BN2A and DHC-6 Twin Otter aircraft. At the time of the accident, the pilot was flying for the operator on a part-time basis.

1.5.1.3 Pilot's training records

The aircraft operator maintained records of the pilot's flying training and testing. All required training and test items had been completed and were valid. The pilot's training records since 2002 (the earliest date for which full records were available) generally described his performance under test as 'satisfactory', with most test items being passed at the first attempt. The only remarks which could be of relevance to the accident and which appeared more than once, referred to a possible weaknesses in the pilot's instrument scan[1] technique. The most recent of these remarks was made at the time of a recurrent check flight in the Be200C, 7 months before the accident.

At interview, senior management pilots described the pilot as having good aircraft handling skills but that he was not always well-organised in the cockpit, which could lead to him getting distracted. His practice engine failure handling was reportedly satisfactory.

1.5.1.4 Pilot's management status

The pilot was the brother of the aircraft operating company's Chairman and President, and was reportedly a company director. According to the operator's General Operations Manual in force at the time of the accident, the pilot held the post of Traffic Dispatch Manager but he did not, in practice, appear to be fulfilling this function. His precise role in the management structure was thus not clearly defined.

1.5.2 Passengers

The five passengers were being flown to a political rally taking place that evening in Grand Turk, ahead of a forthcoming general election. They had not paid for their seats, but were being flown by private arrangement. The intention was for them to travel back to North Caicos on VQ-TIU the following morning.

1.6 Aircraft Information

1.6.1 Leading particulars

Manufacturer:	Raytheon Beechcraft
Model:	Be200C Super King Air
Constructor's No:	BL-131
Year of manufacture:	1989
Total airframe hours/cycles:	24,578 hours/31,684 cycles

1 A term used to describe how a pilot visually scans his flight instruments when flying by sole reference to them, in order to quickly assimilate necessary information about the aircraft's flight path and performance.

Engines:	Pratt & Whitney Canada PT6A-42 turboprop engines
Engine serial numbers:	Left: PCE-93915; Right: PCE-93918
Engine hours/cycles:	Left: 4796 hours/7,540 cycles Right: 5127 hours/6,761 cycles
Most recent engine inspection:	100 hour inspection on 1 February 2007
Most recent airframe inspection:	Phase 3 Inspection on 21 December 2006 at 24,470 hours
Certificate of Airworthiness:	Renewed on 21 December 2006, valid for 12 months

VQ-TIU had previously been on the Australian Register and was imported into the Turks and Caicos Islands in 2005, where it received its Certificate of Airworthiness on 13 April of that year.

1.6.2 Aircraft description

The Beech 200C Super King Air is a twin turboprop, pressurised light transport aircraft, the 'C' designation indicating that it is equipped with a 1.32 m x 1.32 m cargo door at the rear left side.

The aircraft is fitted with two pilot seats and dual flight controls. In its standard fit, the aircraft is equipped with six seats in the passenger cabin, with alternative layouts of up to 13 seats. The cabin and flight deck are separated by a fixed partition and curtain or sliding door.

Access to the aircraft is by a passenger door on the rear left side, set into the larger cargo door. The passenger door has an integral airstair. There is an inward opening emergency exit on the right side in the over wing area.

VQ-TIU was equipped with nine passenger seats in the cabin, each equipped with lap straps. The seats were secured to longitudinal seat rails on the cabin floor. At the rear of the cabin was a baggage area with a retaining net.

The minimum flight crew for the aircraft is one pilot, except where otherwise prescribed by the appropriate operating regulations. For public transport operations at night within the TCI, the minimum flight crew was two pilots (see Section 1.18.2, page 39).

1.6.3 Mass and balance

A post-accident mass and balance calculation was performed. The calculated takeoff mass was 11,940 lbs, 560 lbs below the maximum allowed. The centre of gravity was at 189.9 inches, which was approximately in the centre of the allowable range.

1.6.4 Aircraft performance

Post-accident aircraft performance calculations were made using the data supplied in the Pilot's Operating Handbook and FAA Approved Airplane Flight Manual (AFM). The calculated takeoff mass and reported or estimated environmental conditions were used, assuming a takeoff run starting at the beginning of Runway 08, with a headwind component of 5 kt. Predictions based on the calculations assume that the aircraft was piloted according to normal procedures.

The aircraft would have lifted off in about half of the available runway length. Climbing with landing gear retracted and both engines operating, the aircraft should have achieved a climb gradient of 18.5% with the wing flaps at their takeoff setting of 40º, and 20.0% with wing flaps retracted. These gradients equate to 61 ft / 100 m and 67 ft / 100 m respectively. The aircraft would have crossed the shoreline at about 1,200 ft above aerodrome level, about 55 seconds after the start of the takeoff run. Based upon this and witness accounts, the likely time between starting the takeoff run and impact would have been about 75 seconds, with the maximum gain in height about 1,200 to 1,400 ft.

1.6.4.1 Stalling characteristics

A stall occurs at the point when the Angle of Attack (AOA) of the wing exceeds that at which the airflow over the wing upper surface can remain attached to the surface. Separation of the airflow's boundary layer from the upper surface causes a large reduction in lift. Recovery from a stall includes briskly reducing the AOA by moving the control wheel forward.

At the estimated takeoff mass, with wing flaps and landing gear retracted, the power-off stall speed would have been 97 kt Indicated Air Speed (IAS). In a level 25º banked turn, the stall speed would have been 102 kt IAS. Power-on stall speeds would be lower because the aircraft's weight would be partially offset by the vertical component of engine thrust and because of the beneficial effects of the propellers' slipstreams.

The aircraft was equipped with a stall warning system which would activate a stall warning horn when a stall was imminent. The stall warning system was based on sensed AOA and was independent of the cockpit flight instruments.

1.6.4.2 Turn performance

The turn towards Grand Turk should have involved a track change of about 30°, allowing for the initial track being somewhat to the right of the Runway 08 centreline. Figure 3 shows the approximate turn point and a turning diameter for an aircraft flying in nil wind at 125 kt with a steady 25° angle of bank (AOB). This would be about the maximum AOB for normal operations. For comparison purposes, a turn diameter is shown for 45° AOB. For an aircraft maintaining level flight, this would require a constant load factor of 1.4g.

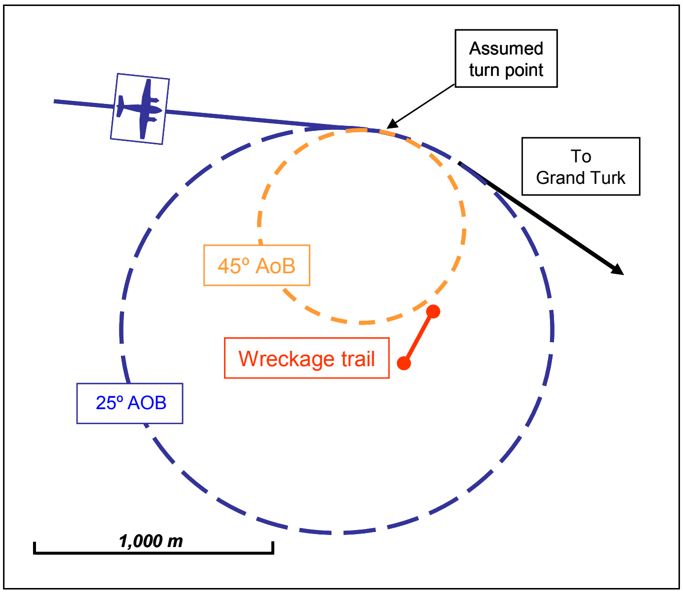

Figure 3

Aircraft turn performance

1.6.5 Multi pilot operations

When two pilots are carried, one typically operates as the 'pilot flying', controlling the aircraft manually or through the autopilot. The second pilot (their roles normally being reversed each flight) would typically be responsible for operating the radios, keeping navigation logs, moving control levers or switches (eg landing gear and flaps) under the direction of the pilot flying, completing checklists items, and assisting with emergency drills. A critical safety function of the second pilot is to monitor the flying pilot's actions and the aircraft's flight path, and to alert him to deviations outside defined limits.

1.6.6 Normal takeoff procedures

The aircraft operator's Operations Manual detailed the takeoff procedures and techniques to be used by company pilots. The Manual stipulated that the minimum crew for the Be200C aircraft would be two pilots, and procedures were defined accordingly.

When above 400 ft agl after takeoff, and with at least the final takeoff speed (119 kt in this case), the wing flaps would be retracted, engine power and propeller rpm reduced to the climb power settings, and the yaw damper selected on. Once these actions were complete, and above 1,000 ft agl, the flying pilot would direct the non-flying pilot to complete the 'After Takeoff Check' items. The final climb speed until passing 2,500 ft was 125 kt.

The 'After Takeoff Check' items, in addition to landing gear, flaps and climb power were:

Bleeds and Mode Selector	ON and AUTO
Pressurization …………………......	CHECKED
Yaw Damp ………………..............	ON
Prop Sync ……………………………	ON
Landing/Taxi Light …………................	OFF
Off and On Times ………………	RECORDED

As found, the cockpit control and switch positions were consistent with the 'After Takeoff Check' having been completed.

1.7 Meteorological information

The 1800 hrs meteorological observation for Providenciales Airport (20 nm from North Caicos Airport) showed a surface wind from 060º(M) at 5 kt, scattered cloud at 2,000 ft and a temperature of 24ºC. Witness accounts indicated that similar conditions existed at North Caicos.

The time of sunset was 1740 hrs, and moonrise (82% visible disc) was at 2132 hrs; it was therefore dark, and the moon had not risen at the time of the accident. The pilot informed his passengers of possible turbulence after takeoff, presumably because he had experienced it during his flight an hour earlier. However, the conditions were not conducive to severe turbulence.

1.8 Aids to navigation

Not applicable.

1.9 Communications

The accident flight took place after North Caicos Airport had closed for the day, so there were no communications between VQ-TIU and ATC at the airport. The pilot would have been required to file a flight plan for the flight to Grand Turk, and it is likely that he intended to do this when airborne, on first contact with ATC at Providenciales (a recognised procedure). There were no known transmissions made by the pilot during the short accident flight, and ATC at Providenciales had not been notified of the flight.

1.10 Aerodrome information

1.10.1 General

The airport at North Caicos is owned and operated by the TCI CAD. Although equipped for night operations, it is notified as being open only during daylight hours. The airport has an asphalt runway, designated 08/26, which is 4,248 ft (1,294 m) long and 75 ft (23 m) wide. An Aerodrome Flight Information Service is normally provided during the notified hours of operation.

1.10.2 Aerodrome and cultural lighting

The runway is equipped with low intensity lighting; there is no approach lighting. Aircraft departing from Runway 08 cross the shore line soon after takeoff and fly over an area of shallow water. This area forms a lagoon between the main island of North Caicos and a much smaller off-shore island. Beyond this lies a barrier reef and the open sea. There is no cultural lighting in this direction.

Local pilots gave a description of the lighting conditions that would have faced the pilot on the night of the accident. There would have been no visual references immediately after takeoff. As the aircraft turned right on course for Grand Turk, the lights of Bottle Creek, about 4 km south of the airport, would have become visible on the aircraft's right side. There would have been some lights on Middle Caicos to the south-east but these would have been dim and widely spread. For an aircraft flying at relatively low height to the east of the airport, the only lighting visible in the eastern sector would come from Grand Turk some 54 nm away, also to the south-east.

1.10.3 'Out of hours' operations

A local procedure was in place for company aircraft departing outside normal operating hours. In such situations, the airfield lighting would be switched on by the aircraft operator's station manager, as happened on the night of the accident. He would then switch the lights off a suitable period after the aircraft had departed.

1.11 Flight Recorders

1.11.1 General

Under existing regulations, the aircraft was not required to have a Flight Data Recorder (FDR) or a Cockpit Voice Recorder (CVR) fitted. However, a Honeywell AV-557C CVR, with a 30 minute recording capacity, had been fitted by a previous operator and was recovered from the wreckage. This was transported to the AAIB's headquarters at Farnborough, England, for replay.

1.11.2 Examination and replay

The unit had been submersed in sea water and visual inspection of the inside of the unit revealed deposits of sand and signs of corrosion due to the exposure to sea water. This type of CVR uses magnetic tape as the storage medium. This was removed from the unit and cleaned. Inspection of the cleaned tape revealed areas of wear, indicating that the driving mechanism had, for periods of time, been rubbing instead of driving the tape. The recording contained periods of very high-speed audio, normal audio and indeterminate noise. The very high-speed audio would be created if the tape was moving much slower than the designed tape speed and replayed at the normal speed. Normal speed recording was found between periods of high-speed audio, indicating that the problem with speed control was intermittent.

There appeared to be recorded data from a number of previous, unidentified flights. The recorded periods did not start or end predictably as would be expected during normal operations, indicating the recorder was operating intermittently. None of the recordings included a takeoff sequence and there were indications that much of the data was recorded some considerable time before the accident. In summary, the CVR had an intermittent fault and did not provide any information pertinent to the accident investigation.

CVRs, especially tape based units, are reliant on good maintenance and ongoing quality checks. However, given that the aircraft was not required to have a recorder installed, there was no requirement for it to be maintained.

1.12 Wreckage and impact information

1.12.1 On site examination

The aircraft had crashed into a shallow lagoon approximately one nautical mile southeast of North Caicos Airport. Wreckage was spread along a trail that extended in excess of 370 m along a track of 220°(M). A hand-held GPS instrument revealed that the first wreckage items were located 1,980 m on a bearing of 125°(M) from the upwind end of Runway 08. The final pieces in the wreckage trail were found on the beach of Burial Cay. Figure 4 shows a plot of the major pieces of identified wreckage.

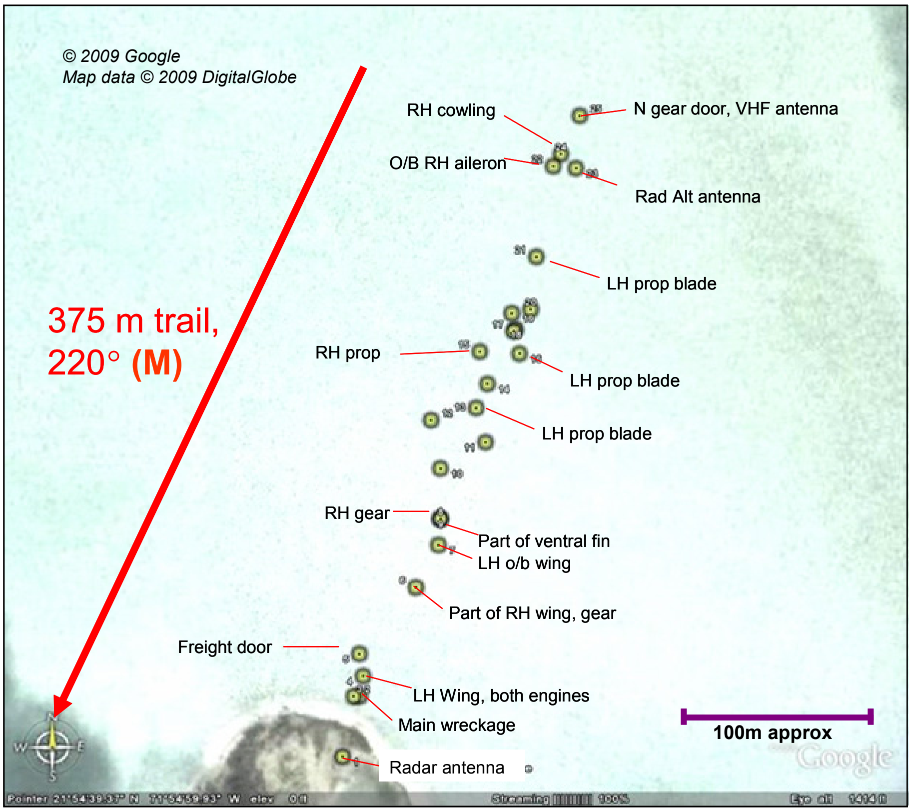

Figure 4

Wreckage plot, prepared from hand-held GPS

The depth of water in the lagoon, which was subject to little observable tidal influence, was of the order 0.3 to 0.5 m, with some areas of greater depth. The lagoon bed was sandy, of varying degrees of softness, with sparse vegetation cover. Access to the site was via helicopter or flat-bottomed boat, while the shallow water enabled the length of the wreckage trail to be accessed on foot.

From the air, the extent of the wreckage trail could be clearly seen, together with what appeared to be a shallow trench in the sand. However, whilst wading around the site, no discernible impact marks could be observed on the lagoon bed, such as could have been made by the wing tips or propellers. Since such contacts would have been inevitable as the groundspeed decayed, it is considered that the sand probably flowed back into any indentations during the hours following the accident and before a detailed assessment of the site was undertaken. It was also apparent that the sand, raised by water disturbance, had settled back on top of the vegetation and partially obscured it, this contributing to the appearance, especially from the air, of a scar or shallow trench across the lagoon bed.

In the section of the wreckage trail close to the estimated point of impact, items recovered included part of the right engine cowling, the radio altimeter antenna (located on the underside of the fuselage, towards the rear) and a nose-landing gear door. There was also part of the right aileron, which, together with the rather more extensive disintegration of the right wing compared with the left, suggested that the aircraft had struck the water with a small bank angle to the right. The right wing leading edge had been considerably flattened by the impact, with the wing itself breaking into two major portions: the inboard section, which included the landing gear structure, and the outboard section, minus the tip. The left wing had remained comparatively complete, apart from the tip, with much of the leading edge substantially intact. The flap surfaces on both wings had been torn off, with the exception of the inboard right section, which was in the retracted position.

The fuselage had come to rest comparatively intact, although lying in an inverted attitude. The empennage was the least damaged part of the airframe, and had remained attached to the fuselage by flying control cables and light structure. The right engine had detached from the right wing and come to rest immediately adjacent to the left engine, which had become separated from its wing structure, although it remained attached by its control cables.

The underside of the fuselage had been extensively damaged in the impact, but significantly, no sand had been scooped into the nose landing gear bay or the floor area. Also, the skin had been distorted inwards in the unsupported areas between the fuselage frames, which was considered to be the result of hydraulic forces generated by the water impact. The radar antenna, relatively undamaged, was found on the beach of Burial Cay, with its associated radome, intact, being found floating nearby on the water. Consideration of these facts, together with those wreckage items, such as the radio altimeter antenna, found early in the trail, indicated that the fuselage had struck the water in a slightly right wing low, level attitude, with no contact being made, at least initially, with the lagoon floor. The extent of the damage to the underside suggested a moderate descent rate.

The disposition of the wreckage suggested that, following the initial impact, the aircraft ‘skimmed’ over the surface of the lagoon, with the wing tips and propellers most probably contacting the lagoon bed, with progressive disintegration of the right wing. The slight right wing low impact attitude would have tended to induce a yaw to the right. Towards the end of the ground/water slide, it is probable that the left wing tip dug into the sand, which attempted to flip the fuselage inverted. However, the comparative lack of damage to the fuselage crown suggested that, although the left wing had become inverted, the wing/fuselage attachment structure had failed in a way that allowed the fuselage to roll inverted and slide in this attitude for a short distance, without being flipped into the air.

Although it was not possible to quantify the impact speed accurately, the near 400 m length of the wreckage trail, together with the extent of the break-up of the wing structure, suggested that it was likely to be high, i.e. well in excess of stall speed.

The wreckage was recovered with the aid of a helicopter, which conducted a series of airlifts to a nearby landing stage at Major Hill. This necessitated the fuselage being cut into several sections in order to remain within the lifting capability of the helicopter. Once ashore, the wreckage was loaded onto a number of vehicles and taken to a hangar at North Caicos Airfield, where it was stored for three nights. It was then transported by barge to Providenciales, where it was off-loaded into a hangar at the airport and subsequently examined in detail by the accident investigation team.

Whilst it is estimated that the vast majority of the aircraft wreckage was recovered, the nature of the site meant that some items would have sunk in the soft lagoon bed or had become covered as a result of agitation of the sand during the recovery. For example, no propeller counterweights were recovered, and only one propeller hub cylinder was recovered and identified. It is also possible that some items were flung or floated to areas beyond those searched.

1.12.2 Detailed examination of the wreckage

1.12.2.1 Airframe

The initial examination of the wreckage indicated that the aircraft had been intact at the time of the accident. Although the freight door had become detached during the impact, it was found that the latching mechanism had remained intact, with failures in the surrounding structure, including the door frame, causing the door to be released.

The flaps and landing gear were retracted and there was no evidence of either an airborne or post-impact fire. The rudder and elevator trim controls on the pedestal were found in their mid positions. The aileron trim control was found in its full left position; however, the screw jack type actuator was found at its full right limit. This was considered to be the result of one part of the operating cable loop failing during the impact sequence, so that the tension in the intact section back-drove the cockpit control and the actuator to their as-found positions.

The primary control cables were checked for continuity, with all the failures attributed to overload or to deliberate cutting during the wreckage recovery.

The aircraft was equipped with a rudder boost system, which used bleed air from both engines acting on a differential pressure switch. In the case of a power loss on one engine, the resulting pressure differential operated a solenoid valve, which ported pressure from the de-ice manifold to actuate one of two pneumatic servos that were attached to the rudder cables in the rear of the aircraft. This provided assistance to the pilot in maintaining directional control in the event of what is described in the Pilot Training Manual as a 'large variation of power between the engines.'

It was found that, although disrupted, the servos and associated control linkages had remained connected.

1.12.2.2 Cockpit instruments

The cockpit flight instruments were examined, including the pilot's attitude indicator, the co-pilot's attitude indicator and the standby attitude indicator. The latter two contained integral, pneumatically driven gyroscopes. The pilot's unit, was a King (now Honeywell) KCI 310, which was electrically driven via a remote vertical gyro, a King KVG 350. The instrument's moving sky/ground representation was fabricated from thin sheet metal, and had been 'frozen' as a result of being struck by an object during the impact sequence. The displayed attitude, as can be seen in Figure 5, was a right bank of around 9°, together with a slight nose-down pitch angle. This was close to the impact attitude as assessed from the on-site examination.

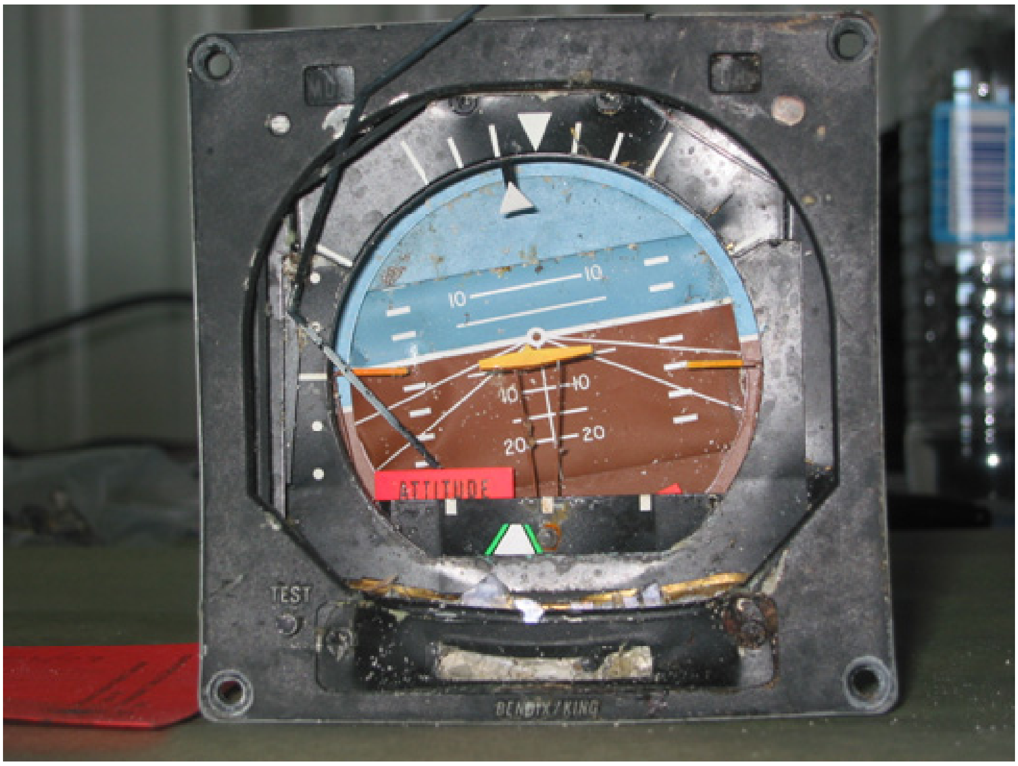

Figure 5

Pilot's main attitude indicator, showing as-found indication

The attitude display drive mechanism used both AC and DC electrical power, with the pitch and roll components of the display being driven by small electric motors. When the aircraft struck the lagoon's surface, the structure under the floor was substantially disrupted together with the electrical looms contained in it. This, coupled with the seawater inundation, would have resulted in the virtually immediate disabling of the electrical system. Only two circuit breakers were found to be tripped (for the left and right generator control units located in the wing centre section), which may be an indication that electrical power had ceased before the multiple short circuit conditions, that undoubtedly occurred, had time to trip the majority of the circuit breakers.

The attitude indication system manufacturers were asked to conduct a simple test in which an attitude indicator was mounted on a test station so that it could display representative indications, according to various input signals. When AC power was removed, the attitude scrolled to 90° pitch-up and the computer and attitude flags were displayed. AC power was restored; then, using the test panel controls, a descending right bank presentation was displayed on the instrument. When DC power was removed, the computer and attitude flags came into view, but the presentation remained unchanged, even when the instrument was slapped or moved sharply.

It is considered that this test provided a degree of confidence that the attitude system was operating normally at the time of the impact, with the sudden loss of electrical power resulting in the displayed indication freezing at the impact attitude.

After its removal from the pilot's instrument panel, the standby attitude indicator was tested by spinning up the gyroscope by means of a compressed air supply; it was found to function normally. On the bench, its at-rest indication was similar to that of the pilot's main attitude indicator, ie the estimated impact attitude, but slightly more nose down. Photographs taken on the accident site showed that its display reflected the inverted attitude of the cabin. Information from the instrument manufacturer indicated that this gyro design has an air erection system that uses air blowing on vanes. These also sense gravity, so that when the gyro is at rest, they hang generally downwards, but tend to rest against the vane stops on the rotor housing, which causes the display to show pitch and roll displaced from the straight and level. Thus the at-rest display was entirely normal for a functional instrument, but with a coincidental resemblance to the impact attitude as derived from the wreckage disposition and supported by the pilot's indicator.

The co-pilot's instrument was similarly tested but found to be inoperable in that it gave random, unstable attitude displays. An internal examination revealed that it had been contaminated with seawater. Whilst most instruments had avoided total immersion, it was evident that many had been splashed with seawater, which in some cases had penetrated to the internal components.

The pilot's horizontal situation indicator (HSI) displayed a heading of 215º(M), while the co-pilot's instrument displayed 205º(M). These readings were both broadly consistent with the measured wreckage trail of 220º(M). The pilot's HSI heading bug was set to 084° and its course bar set to 118°. The heading bug was consistent with having been set at takeoff from Runway 08 and not changed. The course bar corresponded within 2° of a published instrument approach inbound course at Grand Turk airport. The HSI settings could have changed during the impact sequence, although the course bar is reasonably secure as it rotates in concert with a sizeable mass within the instrument.

The aircraft was equipped with an automatic flight control system. This included an autopilot and yaw damper, with engagement levers for each on the mode select panel. As found, the status of the control levers was: autopilot disengaged, yaw damper engaged.

The master caution panel, located ahead of the throttle pedestal, and the master warning panel on the glare shield were removed from the aircraft. Each of the warning segments contained two light bulbs which would illuminate in the event of a fault occurring in the associated system. 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. Accordingly, all the available bulbs were extracted and examined under a microscope. (A few of the segments had been broken during the impact, with their bulbs consequently unavailable for inspection.) This failed to reveal any stretched filaments, leading to the tentative conclusion that no captions were illuminated at the time of the accident. However, it was not possible to be certain that the impact was severe enough to stretch any filaments that might have been illuminated.

1.12.2.3 Engines

Whilst an external examination of the engines revealed nothing untoward, it was decided to subject them to strip-examinations at the manufacturer's facility in Montreal, Canada. This occurred between 1 and 3 May 2007 and was witnessed by members of the accident investigation team.

The rotating assemblies of both engines could not be turned by hand. This was found to be due to the presence of sand and the extensive corrosion that had occurred on the magnesium alloy accessory and reduction gearboxes. Other observations included noting that control linkages, pneumatic lines and associated wire locking were intact, other than those failures attributed to the impact.

Upon disassembly, the compressor and turbine stages of both engines exhibited evidence of rubbing contact between the blade tips and shrouds and this indicated rotation at impact. The combustion chambers were both in good condition, with normal flame patterns being observed.

The right engine compressor stages all showed evidence of foreign object damage (FOD) on the blade leading edges. The notches and raised burrs so caused were accompanied by stream-wise streaking on the blade surfaces, which indicated that this damage was not associated with the impact but had occurred at some time prior to the accident. Figure 6 shows a photograph of some of the damaged blades.

Figure 6

View of typical damage to compressor blade leading edges of No 2 engine. Note streaking, indicating that damage pre-dated the accident

The bearings of both engines were all corroded as a result of immersion in seawater, but there was no evidence of running distress. The reduction gears had sustained post-accident corrosion but were intact. The planetary gears were free to rotate, although they were covered in magnesium oxide residues from the disintegrated casings. The magnetic chip detectors were clear of debris.

It was concluded that there was no evidence of a pre-impact mechanical failure that would have prevented the engines from producing power.

1.12.2.4 Engine accessories

The extensive corrosion that had occurred on all the accessories meant that few were capable of being tested with the prospect of meaningful results. Disassembly and detailed examination was therefore conducted on all components, which included the fuel control units (FCUs), fuel pumps, compressor bleed valves, propeller and overspeed governors, torque limiters, flow divider valves, fuel/oil heat exchanger and the fuel nozzles. This revealed no indications of pre-impact failures, with two exceptions, both concerning components from the right-hand engine.

The first failure concerned the torque limiter, the essential component of which is an oil-filled bellows assembly that senses torque-meter pressure. When the oil pressure reaches a specified threshold, the bellows expand, which causes a flapper valve to open. This in turn allows modified compressor discharge pressure from the FCU to bleed to atmosphere, which reduces the fuel flow, thus preventing an over-torque condition. It was found that the bellows had been crushed, which would have rendered the over-torque protection inoperative. Since the bellows was contained within the undamaged body of the unit, it was not clear how the damage had occurred, although it must have occurred prior to the accident. The engine manufacturer noted that although this defect would have rendered the over-torque protection inoperative, it had no relevance to the accident, although conceivably it could have led to an oil loss. However, the technical log for the aircraft revealed that after the 78.6 flying hours that were flown during the period between 22 December 2006 and 31 January 2007, one quart of oil was added to each engine. This was not considered abnormal.

The second failure concerned the bellows assembly within the right engine FCU, a schematic illustration of which is presented at Figure 7. It can be seen that the assembly comprises the governor bellows and the acceleration bellows, the latter being evacuated. The tandem arrangement of the combined bellows assembly acts on a torque tube that in turn alters the position of the fuel metering valve and hence the fuel flow. The governor bellows initiates acceleration, deceleration and controls the gas generator rpm (N_g) steady state, with bellows movement being achieved by modified compressor discharge air, P_Y. The evacuated acceleration bellows expands or contracts in response to changes in another compressor discharge pressure derivative, P_X. An increase or decrease in P_Y will respectively increase or decrease the N_g, as it acts solely on the governor bellows. The evacuated acceleration bellows are attached to the FCU housing, whilst the rest of the bellows assembly is allowed to move up and down depending on P_X and P_Y. The acceleration bellows thus control the acceleration and deceleration rates in response to P_X variations following changes in N_g.

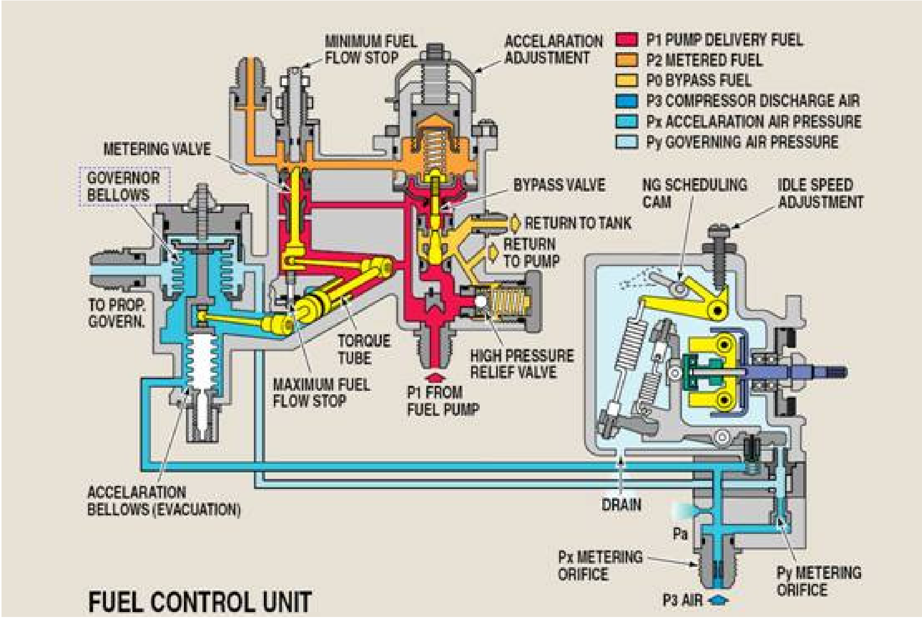

Figure 7

Schematic diagram of Fuel Control Unit

A photograph of the actual components is shown at Figure 8.

Figure 8

Bellows assembly from right engine FCU

(refer to schematic diagram shown at Figure 7)

It was found that the bellows assembly was 0.017 in longer than its manufactured length of 1.025 in, which was stamped on the component. The maximum permissible extension was 0.007 in. This indicated that the evacuated bellows had developed a leak, which had allowed ambient air inside, thereby causing the bellows assembly to expand. Furthermore, an area of green-coloured deposits was visible on the copper surface of the bellows, at a position opposite the point where the P_X tapping entered the chamber in the FCU within which the bellows had been located.

An increased power demand on the engine will result in an increase in P_X pressure: this will cause the evacuated bellows to contract, thus moving the metering valve to increase the fuel flow. In the event of a leak, the pressure inside the bellows will gradually rise, causing the bellows to expand, with a consequent fuel flow reduction.

On 3 May 2007 (ie approximately 12 weeks after the accident) the bellows assembly was installed in a serviceable FCU, which was placed on a test rig. Following a calibration in which it was confirmed that idle fuel flow could be achieved, the compressor discharge pressure, and hence the P_X value, was increased to simulate a demand for increased power. The test point on the schedule required a fuel flow of 635 lb/hr; however only 447 lb/hr was achieved. After leaving the inputs unchanged for a period of 5 minutes, it was found that the fuel flow had reduced to 250 lb/hr. This confirmed that the evacuated portion of the bellows was leaking.

It was the intention to test the bellows assembly on a serviceable engine in order to attempt to quantify the effect of the leak on power output. After identifying a suitable engine a second rig test of the bellows was conducted on 26 June 2007. However, on this occasion, the initial fuel flow was down to 110 lb/hr, which, had it been installed in a serviceable engine, may have resulted in a hung start. It was therefore concluded that a substantial deterioration had occurred in the bellows assembly and that there was an associated risk of damaging a serviceable engine. Moreover, any results would have been meaningless. The cause of the deterioration may have been due to additional corrosion occurring during the period between the two tests, although it is also possible that damage occurred when the bellows expanded as a result of the P_X air pressure applied during the first test.

The bellows assembly was then subjected to a destructive examination, which included a chemical analysis of the corrosion deposits found on the evacuated bellows. A tube was attached, which allowed helium, under pressure, to be applied whilst the assembly was immersed in water. This revealed the presence of three leaks; their positions are indicated at Figure 9. One of the leaks was associated with a significant pinhole, which was surrounded by pitting corrosion, as can be seen in the scanning electron microscope (SEM) images at Figure 10. The engine manufacturer noted that copper (the primary constituent of the bellows material) does not normally corrode by pitting. An energy dispersive X-ray (EDX) analysis revealed the presence of a strong chlorine signal in the contaminant material adhering to the bellows' surface. Whilst some of this would have originated from the chlorides of sodium and other metals, the level was considered to represent a concentration considerably in excess of that found due to seawater exposure and therefore was not likely to have come from the environment.

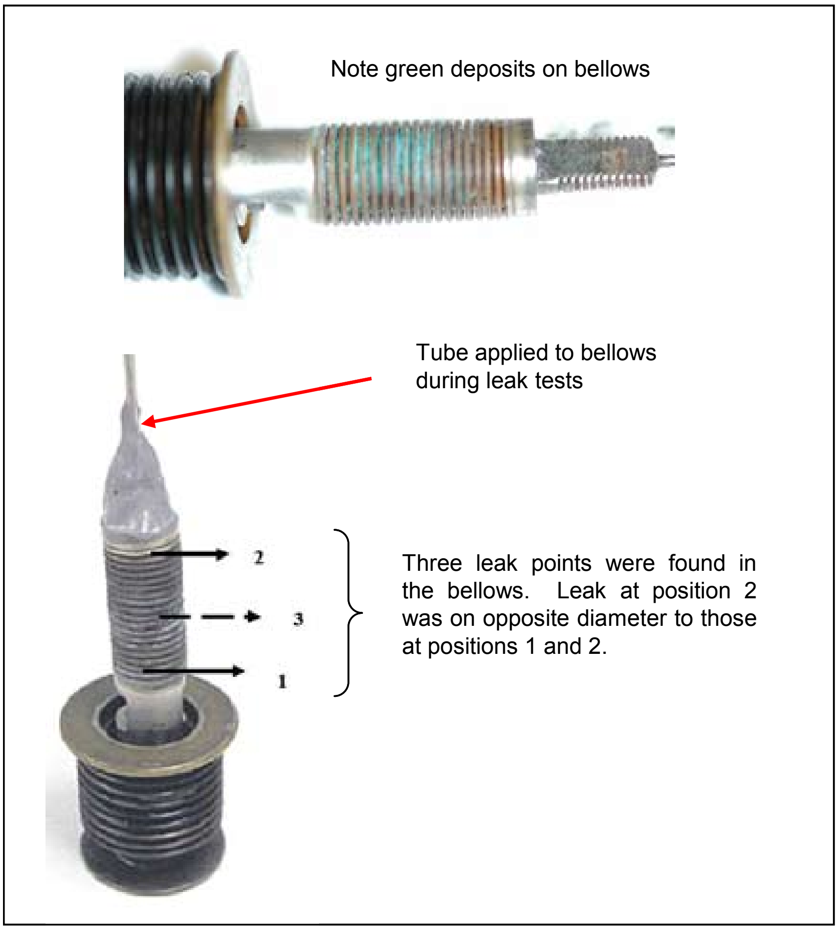

Figure 9

Details of bellows assembly, showing leak points

Photos: Pratt & Whitney (Canada)

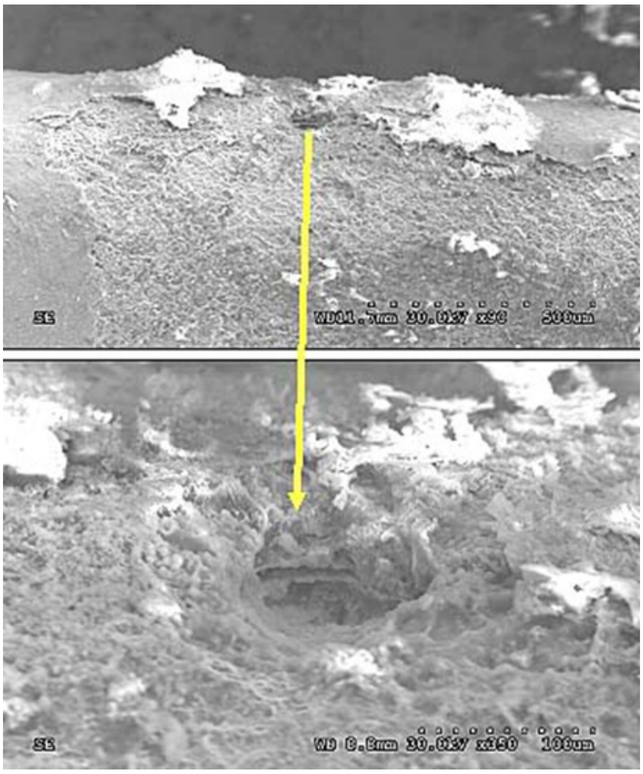

Figure 10

SEM photographs showing corrosion pit in bellows

Photos: Pratt & Whitney (Canada)

The FCU and bellows manufacturers were consulted during the investigation and they stated that chlorine was not used in the manufacturing processes. The FCU bellows from the left engine bore no similar evidence of corrosion, suggesting that the operator was not routinely introducing a chorine-containing chemical into the engines. Thus the origin of the chlorine and hence the reason for the corrosion was not determined.

The engine manufacturer noted that the bellows are constructed from two layers of copper alloy and that they had seen previous cases where a gradual puncture occurred over a period of time. First, a hole develops in one layer, followed by a similar puncture in the other. The result is a gradual reduction in the fuel flow, for which the pilot would compensate by advancing the power lever on the affected engine. Over time, this would result in a ‘throttle stagger’ condition that eventually would lead to the pilot making a Technical Log entry and the defect being investigated. The time taken to reach this situation clearly depends on the size of the hole, but, in discussions between the engine manufacturer and the investigators, typical periods of several hours were mentioned. However, the manufacturer noted that there had been rare occurrences of sudden bellows fracture, leading to immediate reductions in fuel flow. Whilst there clearly had not been a sudden fracture in this case, there was no way of inferring, from the rig tests, what the likely effect on an engine would have been. This is because the tests were conducted at constant P_X and N_g values, during which time the fuel flow was observed to reduce. In reality, P_X and N_g would decrease with reducing fuel flow, in turn causing further reductions in fuel flow.

There was no record in the aircraft Technical Log, or verbal statements from anyone associated with the operation of the aircraft, that indicated a potential problem with the engines, or indeed, any other system.

1.12.2.5 Propellers

The propeller blades had sustained bending and twisting damage due to contact with the water and, possibly, the lagoon bed. Whilst this indicated that both engines had been developing power at impact (as opposed to being in their feathered positions), it was not possible to quantify this, although the relative symmetry of the damage suggested approximately equal power settings. Photographs of the propeller components were sent to the manufacturer, who, in addition to concurring with the power assessment, offered additional advice and comment.

A schematic diagram of the propeller hub is shown in Figure 11. Propeller pitch angle is a function of the position of the piston in the cylinder, which in turn is determined by propeller governor oil pressure behind the piston, operating in opposition to the force generated by the counterweights and feathering springs. Thus, in the diagram, the piston, which is shown in a representative position in the middle of the governed range, moves to the right for feather, to the left for flight idle and further left for reverse pitch. The beta feedback collar does not move significantly to the right of the position shown on the diagram, but moves progressively to the left with decreasing pitch angles below flight idle, such that the lock-nuts on the beta rods, close to their attachments to the collar, enter the countersunk holes in the hub that contain the beta rod bushings.

Both feedback collars were recovered, with all three beta rods present on one of them and two on the other as shown in Figure 12. The fracture positions of the beta rods indicated that the collars were towards their aft positions, meaning that the propellers were operating within their governed range, as opposed to flight idle or reverse.

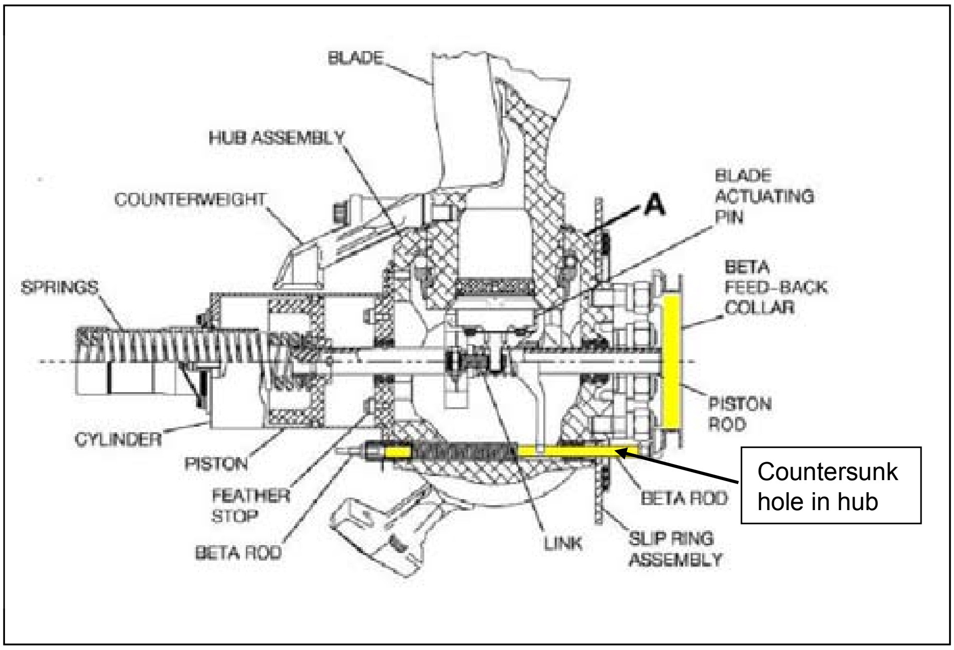

Figure 11

Section through propeller hub, showing beta rods and feed back collar (highlighted)

Figure 12

Feedback collars, showing broken beta rods; fractures probably occurred within countersunk holes in hub

1.13 Medical and pathological information

1.13.1 The pilot

The pilot held a current FAA first class medical certificate and had no known recent illnesses. He was known to have suffered some eyesight difficulties at night (though not untypical for his age), and was required to wear spectacles as a limitation of his medical certificate. Passenger A confirmed that the pilot had been wearing his spectacles.

A postmortem examination showed that the pilot had suffered a severe head injury as well as lacerations and fractures of the extremities. The cause of death was given as blunt force head injury.

Toxicological tests were conducted in the USA. No drugs were detected but blood and ocular (eye) fluid samples produced ethanol (alcohol) concentrations of 0.03% and 0.04% respectively (these concentrations equate to 30 mg/100 ml and 40 mg/100 ml respectively, in units more commonly used in the UK).

1.13.1.1 Postmortem analysis

At the request of the AAIB, the postmortem examination report and toxicology results were subject to assessment by an aviation pathologist in the UK. He observed that the postmortem did not reveal any significant pre-existing natural pathology which could have played a causative or contributory role in the accident.

From the report, it seemed likely that there was a mild degree of enlargement of the left ventricle of the heart. It was noted that this condition can be associated with abnormalities in heart rhythm, which could potentially be distracting or incapacitating. However, Passenger A's account that the pilot had his hands on the control wheel throughout the short flight, and appeared to be attempting to control the aircraft, was not suggestive to the pathologist of any significant degree of incapacitation.

The possibility that the alcohol levels were the result of natural postmortem alcohol production was considered. However, there was no mention in the autopsy or toxicology reports of factors which may have contributed to this and there was good agreement between the measured ethanol levels in the blood and ocular fluid specimens. Ocular fluid is more resistant to natural postmortem alcohol than blood; the presence of significant quantities of alcohol in the ocular fluid was strongly suggestive that at least some of the alcohol in the blood was antemortem in origin.

The pathologist opined that, whilst the possibility of postmortem alcohol production could not be entirely ruled out, it was reasonable to regard the measured alcohol levels as likely to be approximating those which would have been present at the time of death. The measured levels could have been attained by the consumption of a relatively modest amount of alcohol shortly before the flight, or by the metabolism of a larger amount of alcohol consumed at an earlier time – there was no way of distinguishing between these possibilities on the basis of the toxicology results.

Significant effects on pilot performance have been documented even at low blood alcohol concentrations. A blood alcohol level of 30 mg/100 ml is below the applicable FAA prescribed maximum of 40 mg/100 ml, although it is noteworthy that it is in excess of the current legal limit in the UK for piloting an aircraft (20 mg/100 ml). Of potential significance to this accident, impairment of task performance has been demonstrated during aircraft descent and during angular acceleration at blood alcohol levels of between 10 and 30 mg/100ml[2].

The contributory effect of alcohol to spatial disorientation is discussed in this report at Section 1.18 (page 38).

1.13.2 The passengers

All five passengers were injured in the accident, with the most serious injuries occurring to those in the forward cabin, as shown at Figure 13. The two occupants at the rear of the cabin sustained the least injuries and were treated locally in the TCI. The remaining three passengers were flown to Miami, USA, for treatment.

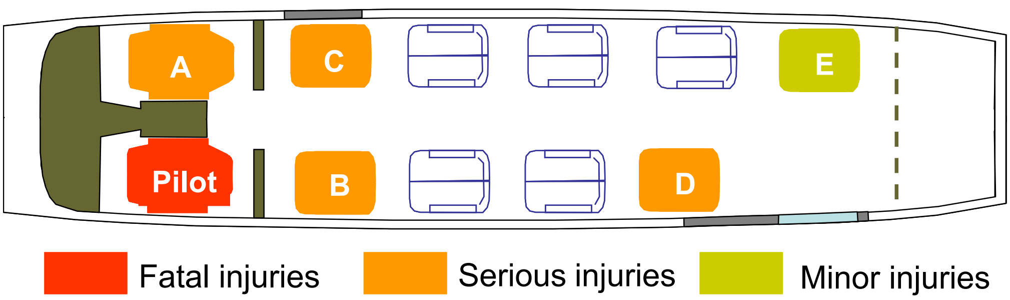

Figure 13

Occupant injuries by seat position

2 Cook CCH. *Alcohol and Aviation. Addiction*; May 1997; 92(5):539-555.

1.14 Fire

There was no evidence of either a pre-crash or post-crash fire.

1.15 Survival aspects

1.15.1 Emergency egress and immediate rescue

From passengers' accounts, all the aircraft's occupants were conscious immediately, or very soon after, the fuselage came to rest. The fuselage was in a nearly inverted attitude, but relatively intact, as can be seen from Figure 14. However, there was considerable damage within the structure; the cabin floor was heavily disrupted as described earlier, and some seats had detached from their mounting points. Numerous lightweight fixtures and panels had become detached within the cabin.

Figure 14

Aircraft fuselage as found on initial inspection by the investigation team, 8 February 2007

The emergency exit was situated on the right side but the attitude of the fuselage after the accident prevented its use. However, the cargo door detached during the impact sequence, allowing an egress path for Passenger E in the rearmost seat. He recalled unbuckling his seatbelt and exiting through the door aperture, although his footwear became trapped and had to be freed by Passenger C, who was still trapped within the cabin. Passenger E then helped Passenger C from the wreckage.

When the first local rescuers arrived, only Passengers E and C were outside the fuselage, although Passenger C was lying in the shallow water and unable to assist further. Access to the remaining occupants was only possible through the disrupted fuselage floor, which rescuers opened up further by hand in order to gain entry. Passenger D was the first they freed, followed by Passenger B, who at this point appeared to have the most severe injuries. Seats were removed from the wreckage and placed in the shallow water for the passengers to sit on.

The pilot and Passenger A were found in their seats, suspended upside down in their seat harnesses. With considerable difficulty, the rescuers were able to free them from the wreckage. From the accounts of the first local rescuers on scene, the pilot was alive when they first reached the aircraft. He reportedly spoke some words, but was not able to hold a coherent conversation or answer questions. Before the pilot was freed from the wreckage he ceased talking and the rescuers suspected that he may have died at that point.

1.15.2 Crew and passenger seats

Whilst the two cockpit seats remained attached to their mountings on the floor, most of those in the cabin had broken loose in the impact. It is probable that the occupants of these seats suffered additional injuries as a result. The disruption to the fuselage underside had left lengths of floor panels, which contained the seat mounting rails, relatively intact, although there would have been considerable flexing that may have contributed to individual failures of the seat mounts.

The part numbers of the seats were the same as those that were on the aircraft at initial build, meaning that either they were the original equipment or they had been replaced with identical items. According to the aircraft manufacturer, the seats were certificated to FAA Code of Federal Requirements (CFR) Part 23, which corresponded to 9g forward, 1.5g lateral, 3g up and 7.8g down. The manufacturer additionally stated that they had tested the seats to these values, but with the lateral and down figures increased to 3g and 8.25g respectively. There was an additional reserve factor of 1.33 applied to these values.

Figure 15 shows one of the seats on which the supports had remained intact, although it had become detached from its mountings. The distortion indicates that the design loads had been exceeded, although not to the point of fracture.

Figure 15

Typical passenger seat, showing frame distortion

1.15.3 Search and Rescue (SAR) operations

The emergency services were alerted by witnesses on North Caicos. Local residents located the wreckage with some difficulty in the dark, with access by boat hindered by the very shallow water.

The pilot, who was most seriously injured, was taken immediately by small boat to the shore and then to North Caicos Airport. Medical teams from Providenciales had not yet arrived, and the decision was taken to fly the pilot by light aircraft the short distance to Providenciales where medical help would be available, rather than wait an unknown length of time before medical aid arrived on scene. However, the pilot was pronounced dead on arrival at Providenciales Airport by the medical team that met the aircraft.

In accordance with local procedures on North Caicos, a local medical doctor was alerted soon after the accident and travelled to the scene with a police escort. There was some confusion about the precise locations of the accident and shore access point, so the doctor went to the airport, where she met with a local nurse and community helper. The aircraft carrying the pilot had just departed for Providenciales. The doctor boarded a helicopter, which had arrived from Providenciales in response to the accident, and was flown the short distance to the accident site.

When the doctor arrived (the helicopter landed on Burial Cay, adjacent to the accident site), the passengers were still in the shallow water next to the fuselage. Conditions and risk of infection prevented the use of advanced first aid, such as insertion of drips, but external supports were applied, as necessary, to stabilise injuries and the passengers were treated for shock.

The doctor left the scene in the helicopter with Passenger B. The remaining passengers were then ferried by helicopter to the airport and on to Providenciales by a number of private aircraft which had flown to North Caicos to assist.

The helicopter used by the medical team was based at Providenciales. It had recently arrived in the TCI as part of a planned expansion of SAR capability in the Islands. It was assisted by a United States Coastguard helicopter (USCG), based at Great Inagua in The Bahamas.

1.16 Tests and research

Not applicable.

1.17 Organisational and management information

1.17.1 Operator information

The aircraft was operated by Air Turks and Caicos (2003) Limited, which had its operations and engineering base at Providenciales Airport. The airline operated a number of light to medium utility and passenger aircraft on scheduled and chartered flights within the TCI and to nearby international destinations.

1.17.2 Regulation of Civil Aviation in the TCI

The Air Navigation (Overseas Territories) Order (AN(OT)O) details the legislation passed by the British Government concerning the operation of Civil Aviation in the United Kingdom's Overseas Territories, which include the Turks and Caicos Islands.

Air Safety Support International (ASSI), a subsidiary company of the UK Civil Aviation Authority, was established under directions from the UK Department for Transport to be responsible for supporting the Overseas Territories' existing authorities in the safety regulation of all aspects of civil aviation.

In Territories where the civil aviation regulator does not have the resources to undertake the task themselves, ASSI can be designated by the Governor to perform the civil aviation regulatory tasks on behalf of the Governor. However, the regulatory task in the TCI is delegated to the TCI CAD.

1.17.3 Emergency response arrangements

The TCI authorities had emergency response plans in place for an aircraft crash in the Territory. Under the plans, ATC at Providenciales would co-ordinate the initial response, alerting the police and fire services. A 'cascade' system would then alert the medical services who would arrange for the necessary ambulance and hospital reaction, and ensure suitable medical personnel were available.

With limited resources available away from the main areas of population, rescue plans for less accessible areas relied on assistance from Providenciales and Grand Turk in the TCI, and from the USCG at Great Inagua. With many locations inaccessible by boat due to shallow water, rescue teams would almost invariably need to access an accident area by air.

This accident occurred at night and involved a flight not in contact with ATC. Although the crash site was close to habitation it was not easily accessible. Thus, the formal rescue effort faced a considerable challenge and was helped greatly by the actions of local residents and private pilots who flew their aircraft to the scene to assist.

1.18 Additional information

1.18.1 Accident flight status

The AN(OT)O 2001 (being in force at the time of the accident and hereinafter referred to as the Order), stated at Article 131(2):

> *'Subject to the provisions of this article, an aircraft in flight shall for the purposes of this Order be deemed to fly for the purposes of public transport:*
>
> *... if any passengers or cargo are carried gratuitously in the aircraft on that flight by an air transport undertaking, not being persons in the employment of the undertaking (including, in the case of a body corporate, its directors) and persons with the authority of the Governor either making any inspection or witnessing any training, practice or test for the purposes of this Order, or cargo intended to be used by any such passengers as aforesaid, or by the undertaking.'*

An air transport undertaking was defined in the Order at article 130(5) as '*an organisation whose business includes the carriage by air of passengers or cargo*'. Thus, the holder of an Air Operator's Certificate (AOC) was by definition an air transport undertaking. At the time of the accident flight, VQ-TIU held a Certificate of Airworthiness (C of A) in the Transport Category and therefore was required to comply with all the relevant provisions of the Order. The aircraft was under the operational control of the operator under the terms of its AOC. An operator, for the purposes of the Order, was defined as '*the person who at the relevant time has the management of that aircraft*'.

ASSI provided assistance to the investigation with interpretation of the relevant legislation. In summing up, it was stated that:

> *'...where an aircraft is under the management of an AOC holder and has a Transport Category C of A then any flights operated with it that carry passengers or cargo are public transport flights...'*

Thus, although the accident flight was considered by the operator to be a private flight, it was in fact deemed to be a public transport flight under the terms of the relevant legislation. As such, the flight was subject to the requirements of the Order with respect to public transport flights.

Following this accident, ASSI issued in its Operations Weekly Briefing a reminder of the relevant legislation and the potential for confusion over the status of flights in certain specific circumstances.

1.18.2 Regulatory requirements for public transport flights

Article 20 of the Order stipulated that the minimum flight crew for aircraft in VQ-TIU's weight and configuration category flying for public transport was one pilot. However, this was increased to two pilots when flying in accordance with the Instrument Flight Rules which, as the accident flight occurred at night, was applicable to VQ-TIU. Article 101 of the Order stipulated that an aircraft in VQ-TIU's weight and configuration category, flying for public transport, was required to take off and land only at aerodromes licensed under the Order.

The accident flight was operated by a single pilot and takeoff was made outside of the airports hours of operation. Thus the flight did not meet the requirements of the Order in respect of either of these requirements.

1.18.3 Spatial disorientation

Information in the following paragraphs is drawn from a number of source documents, of which the main are:

> Newman, DG (2007) '*An overview of spatial disorientation as a factor in aviation accidents and incidents*', Australian Transport Safety Bureau; Melcher, JA '*Spatial Disorientation' and 'Spatial Disorientation – Visual illusions*', Federal Aviation Administration safety brochures; '*Spatial Disorientation – confusion that kills*', AOPA Air Safety Foundation; and '*Pilot's Spatial Disorientation*', FAA Advisory Circular 60-4A (1983).

1.18.3.1 Description

Spatial disorientation is a common problem in aviation and a well recognised cause of accidents, many of which are fatal. A pilot normally determines an aircraft's attitude by reference to external cues, the most important of which is the natural horizon. However, if such cues are limited or non-existent (due to darkness or poor weather for example), artificial cues provided by the flight instruments must be used. Sight is the most important sense to a pilot in maintaining orientation. Other senses may produce different or conflicting information which, in conditions of poor visibility, can lead to sensory mismatches that can result in a pilot becoming disorientated.

The three sensory systems involved in spatial orientation are: the visual system; the vestibular system (the balance organs of the inner ear); and the proprioceptive system, consisting of pressure sensors throughout the body and which provides what is sometimes called 'seat of the pants' information.

The visual system normally provides some 80% of the sensory information for orientation. Without it, the other two systems (which are each prone to illusion and misinterpretation in flight), must provide all the information. For this reason, the majority of spatial disorientation accidents occur at night or in poor weather.

1.18.3.2 Common illusions in poor visual conditions

Vestibular illusions arise when the balance organs of the inner ear produce erroneous information in flight, leading to false sensations of rotation. A common illusion is known as 'the leans'. This results from a pilot's failure to detect a rolling motion when the aircraft rolls at a rate below the sensing capability of the balance organs (about 2º per second), or when a stable turn has been maintained for an extended period and the balance organs have ceased to register it. If any subsequent rolling motion in the opposite direction is made above the sensory threshold, it will be detected and can produce a strong sensation that the aircraft is banking in the opposite direction.

In the case where a rolling motion is not detected by the balance organs, the aircraft may start to descend, due to the increasing bank angle, and to accelerate. The natural tendency would be to pull back on the control wheel to arrest the descent, but this would only tighten the turn and may increase the descent rate.

The Coriolis illusion can produce a strong sensation of tumbling, and can have a rapid onset. It is caused by moving the head out of the plane of rotation, such as may occur if a pilot moves his head whilst turning. In this case, the semi-circular canals of the ear which were sensing the turn will cease to do so, whilst another set of semi-circular canals which was previously not sensing the turn will start to do so. The resulting contradictory signals of acceleration and deceleration can lead to a pilot suddenly experiencing a complex series of tumbling motions which can be extremely disorientating.

1.18.3.3 Effects of alcohol

Alcohol is known to have significant effects on both vestibular and visual systems. It changes the specific gravity of the fluid within the vestibular system, causing it to produce exaggerated signals. Similarly, the vestibulo-ocular reflex (see below) that results from Coriolis stimulation can also be exaggerated and prolonged.

The aviation pathologist who assisted the investigation with an independent assessment of the postmortem and toxicology results included the following text in his report.

> '*During motion of the head, vestibular inputs help to stabilise eye movements with reference to static objects, by a mechanism known as the vestibulo-ocular reflex (VOR). This reflex is inappropriate for objects which move along with the individual, such as aircraft instruments, but it can usually be overridden by the pilot visually fixating on the instrument. A study has shown that this ability to override the VOR can be degraded by alcohol levels as low as 27mg/100ml, and that the effect is particularly pronounced during conditions of dim display illumination*[3]*. The authors of the study conclude their paper by stating:*

3 Gilson RD, Schroeder DJ and Collins W. *Effects of different alcohol dosages and display illumination on tracking performance during vestibular stimulation*. Aerospace Medicine. 1975; 43:656-660.

> *"A pilot who drinks lightly may be able to convince himself on the ground that his abilities are unimpaired and thus may feel safe to enter the cockpit. Results of this study suggest, however, that he is entering a potentially dangerous situation. If, while flying, particularly at night with dim display illumination, the pilot encounters vestibular stimulation as a result of maneuvers, turbulence, or some inner-ear dysfunction he may experience some blurring of vision. The visual control of his eye movements has been reduced by the alcohol, and vestibular control is free to take over driving the eyes relative to the instruments. This increases the likelihood that he will misread the instruments and react incorrectly, causing more severe maneuvering and what may be the beginning of an irreversible, vicious circle".*
>
> *It is uncertain as to how far the results of this study may be read over to this particular accident, but it would appear to provide a potential mechanism for impaired pilot performance under these conditions.'*

1.18.4 Eyewitness accounts

There were seven known eyewitnesses who saw the aircraft in flight. Of these, five saw it turn and descend and one reported seeing the impact. Two further witnesses saw the initial part of the climb only. Those who saw the majority of the final descent described it as occurring over a period of just seconds. The witness locations are shown at Figure 16.

Witness 1 described the aircraft flying overhead, just to the south of his location, and starting a right turn. The aircraft's navigation lights were on and he could discern the shape of the aircraft. The engine noise did not appear to change in note or type, but reduced in volume as the aircraft turned. The aircraft continued to roll to the right, reaching a bank angle described as 70º to 80º. The witness described seeing the aircraft strike the surface in a right wing low attitude and possibly nose down, followed by tumbling. There was nothing unusual about the aircraft, apart from its flight path.

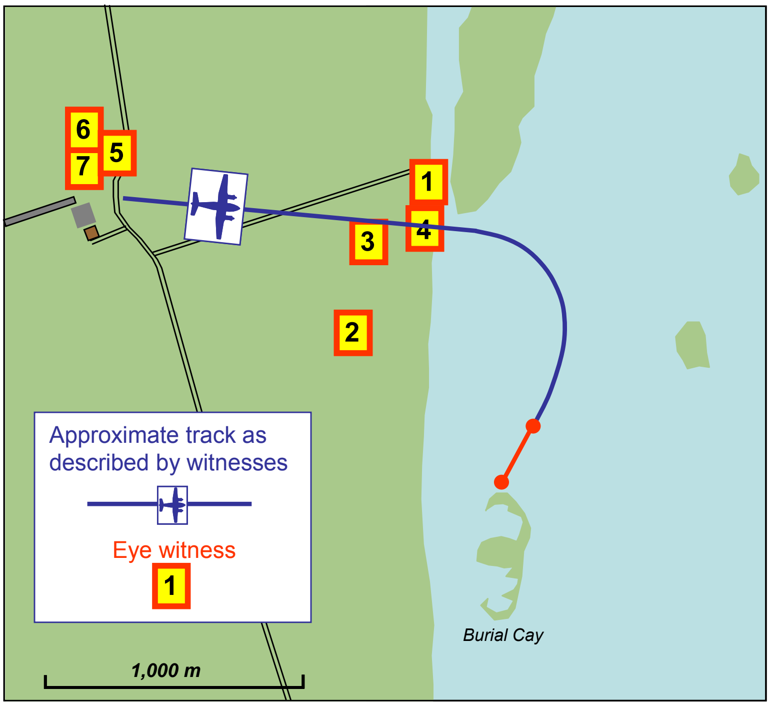

Figure 16

Witness locations

Witness 2 first saw the aircraft in a steep right bank, his attention being drawn to it by the engine noise, which he described as abnormal and "straining". Only the aircraft's navigation lights were visible. The aircraft descended at a moderate forward speed with an approximately constant angle of descent. Apart from the engine noise and flight path, there was nothing further unusual about the aircraft in flight.

Witness 3 saw the aircraft fly directly overhead and at first there was nothing unusual about it or the noise it made. The aircraft rolled to the right, to an angle of bank described as about 45º, after which the engine note seemed "harder than regular". The aircraft started descending from the point of turn, and the aircraft maintained a right wing low attitude until it descended out of sight.

Witness 4 saw the aircraft turn right after it had crossed the shore line. Up to that point it seemed like a normal takeoff. It appeared to the witness that the aircraft was turning further than expected, as if it may be returning to the airport.

Witness 5 saw the aircraft takeoff and climb normally, then turn right and descend out of view. The aircraft had appeared normal and there were no unusual engine noises.

Witnesses 6 and 7 were by buildings just to the north of the departure end of Runway 08. One described hearing one of the engines making an unusual sound soon after takeoff, and seeing the aircraft making a right turn at about 300 to 400 ft, after which it descended. The second witness saw the aircraft's navigation lights as it took off. He thought the takeoff seemed normal and paid no further attention to it. His attention was only drawn back to the flight by Witness 5 who was concerned that the aircraft may have crashed.

1.18.5 Unlawful interference

The operator reported an instance of suspected unlawful interference with one of its aircraft, which occurred in October 2006. In that incident, the aircraft had had its tyres damaged whilst parked overnight, without security, at an outstation. The incident was reported to the TCI CAD, by Mandatory Occurrence reporting action, and also to the TCI Police.

The pilot and members of his family were related to the Premier of the TCI and were active politically. A general election was days away and the purpose of the accident flight was to convey supporters to a political function. With this background, the possibility that the aircraft (or indeed its pilot) could have been unlawfully interfered with was considered.

Although the aircraft was unattended on the small apron at North Caicos Airport prior to the flight, this was for less than an hour and at least one intended passenger was in the immediate vicinity during this time. The area beside the apron was an informal gathering area for members of the small local community, so it is likely that any inappropriate activity around the aircraft would have attracted attention, or would have been remembered after the accident. However, no-one came forward after the accident to describe any suspicious activities.

It is likely that any malicious activity directed at the aircraft in the time available would have been opportunistic and relatively unsophisticated, and, therefore, relatively easily detected. The circumstances of the accident are such that it would have required a knowledgeable and skilled individual some time to create a condition which would initiate the accident sequence at a critical stage of flight, in a manner such that the pilot and passengers remained unaware of it and of which there was no subsequent evidence.

It was therefore considered that unlawful interference was not a factor in the accident.

2. Analysis

2.1 Impact parameters

In an accident where an aircraft impacts water, as opposed to solid ground, it will always be more difficult to assess the impact parameters, due to the absence of ground marks. In this case, it was fortunate that the shallow water conditions helped to preserve the wreckage distribution, on which the impact attitude was largely estimated. In addition, the degree of break-up of the wreckage items, together with features such as the hydraulic deformation in the skin on the forward fuselage underside, led to the determination of an approximately level pitch attitude, with a small amount of right bank, at impact. This assessment was supported by the as-found indication on the pilot's attitude indicator.

An accurate assessment of the impact speed was not possible, although the length of the wreckage trail and the fragmented condition of the wing structure, suggested that the impact occurred at a moderate speed, ie well above stall speed.

2.2 Aircraft's flight path

2.2.1 General

The weight of available evidence indicates that the aircraft was flying normally until the point at which it started to roll to the right after crossing the North Caicos coastline, but that it may have encountered some turbulence. The point at which the aircraft started to roll and turn to the right would have been consistent with a turn for Grand Turk. Whether the roll, when it happened, was deliberate or not, it is at this point that the actual flight path began to deviate significantly from the expected flight path.

As Figure 3 (page 13) shows, only a moderate angle of bank was required to take up a track towards its destination, Grand Turk, yet a much greater angle of bank must have been reached for the aircraft to achieve the turn that it did, and this is confirmed by witness accounts.

Without pilot intervention, an increasing bank angle directs wing lift away from the vertical, so reducing climb rate. Eventually, the vertical component of lift becomes insufficient to support the aircraft's weight, and it descends. The aircraft also turns in the direction that it is banked – in this case, to the right. Any attempt to arrest the descent by applying aft control wheel only serves to increase the turn rate.

The descending sensations reported by some of the passengers are later in the accident flight and not associated with any obvious adverse event, which suggests that the descent was indeed the result of an excessive bank angle, rather than of another factor such as a sudden power loss. The roll to an excessive bank angle, although inadvertent, was therefore probably the single most critical step in the accident sequence, and possible reasons for it can be considered.

2.2.2 Possible reasons for the excessive bank angle

Considered in isolation, the possible reasons for an uncommanded or inadvertent roll are:

(i) Power loss on one engine or thrust asymmetry, leading to yaw which in turn leads to roll;

(ii) Flight control failure, jam or restriction;

(iii) Autopilot failure;

(iv) Change in the aerodynamic characteristics of the aircraft, for example due to structural failure, damage or ice accretion;

(v) Failure of critical flight instrumentation;

(vi) Inadvertent speed loss and stall encounter;

(vii) Weather factors such as turbulence or wind shear;

(viii) Human Factors, such as distraction, incapacitation or disorientation.

It should be stressed that an inadvertent or uncommanded roll will not necessarily lead to an excessive bank angle. In the following paragraphs, the technical, environmental and handling aspects are discussed with regard to their possible contribution to this accident. Human Factors are discussed in more detail at Section 2.3 (page 51).

2.2.2.1 Power loss or thrust asymmetry

The physical damage that had occurred to the propellers indicated that they were operating within their governed range, with the power being developed at impact being broadly symmetrical. However, it is possible that such a basic method of assessment could have masked differences in power between the two engines, which although they may have been small, could have contributed to an inadvertent yaw and roll to the right.

The engine strip examination revealed a number of anomalies, such as the foreign object damage to the compressor blades and the inoperative torque limiter on the right-hand engine. These were not thought to have any relevance to the accident. However, a defect within the right engine FCU, in the form of a punctured bellows assembly, is worthy of detailed consideration. The evidence was inconclusive in that it was not possible to quantify the effect on the engine, or even confirm the existence of the leak at the time of the accident. Additional analysis of corrosion deposits on the bellows indicated the presence of chlorine at a concentration that was in excess of what could be expected in a seawater environment. The origin of this contamination was not determined but, as none was found in the left engine, it seemed unlikely to have been introduced during the aircraft's normal operating or maintenance procedures.

The effect of a bellows leak is to gradually reduce engine power to the extent that, in maintaining symmetrical power on the aircraft, a throttle stagger becomes apparent. This process would typically take several hours, although the engine manufacturer was aware of rare cases of sudden bellows failure. The evidence in this case did not point to a sudden failure; in fact two rig tests on the FCU, conducted some seven weeks apart, indicated that significant deterioration in the bellows' condition had occurred during this period. Thus, it is probable that a similar degree of deterioration had occurred during the earlier period before the first rig test, with the bellows being immersed in seawater for much of this time. If this is accepted, it follows that the bulk of the bellows' deterioration occurred after the accident, so that the leak, if it existed at all at the time of the accident, was likely to have been small, with any effect on engine power occurring over a relatively long period. Some reinforcement of this view was provided by the lack of any verbal or written evidence of any engine-related defect.

An equally logical reason for concluding that any leak was small is that the pilot would likely have rejected the aircraft in the event of a significant degree of throttle stagger. A leak into the evacuated bellows would start to have an effect after the engine was started, with any throttle stagger being most apparent when the power levers were advanced prior to takeoff, whilst the pilot was matching the engine torque values. Any loss of power from the right engine during the takeoff roll would have caused the aircraft to veer to the right. The fact that this apparently did not occur suggests that either there was no power loss, or the pilot corrected for it, in which case he would have been made aware of the problem. Once airborne, any power loss in the right engine that occurred as a result of the bellows leak would have been insufficient to activate the rudder boost system, although it may have contributed to the right turn that in any event would have been necessary to bring the aircraft onto the intended track.

A compelling factor in this analysis is the short time period, probably little more than a minute, between the start of the takeoff roll and the point at which the aircraft adopted an over-banked attitude. This represents a very small window, either for the FCU bellows to develop a leak, or for an existing leak to affect the engine power significantly. Furthermore, any deviation from the aircraft attitude being flown by the pilot would have been presented on the attitude indicator. It is therefore concluded that any leak which existed in the FCU bellows is likely to have been small and had no significant effect on the circumstances of this accident.

2.2.2.2 Flight control failure, jam or restriction

The evidence from Passenger A in the seat alongside the pilot did not suggest that the pilot's words and actions, or lack of them, were consistent with a flying control malfunction such as a disconnect, jam or restriction. On the contrary, the estimated attitude at impact was changed markedly from the most extreme attitude the aircraft is believed to have reached, which implies a recognition and reaction, however belated, on the part of the pilot to the flight path of the aircraft. This in turn implies that the flight controls were operating normally and that the aircraft responded correctly to the pilot's roll left / pitch up control input described by Passenger A.

It would be possible for certain failures to impart a yawing/rolling motion to the aircraft, which may cause an attitude excursion before the pilot could correct the situation. A malfunction of the rudder boost system could potentially have had this effect, but the system was examined during the investigation and judged to have been serviceable prior to the accident.

2.2.2.3 Autopilot malfunction

Although a malfunctioning autopilot could lead to a bank angle excursion, it is unlikely that the pilot would have engaged the autopilot so early in the flight and just before a turn was to be made. In any case, the period immediately after engaging an autopilot is one in which its performance would be monitored closely by the pilot.

Erroneous control inputs by the autopilot would be felt through the control wheel (the pilot's hands reportedly remained on the controls), and seen on the flight instruments as undesirable attitude changes. Had the pilot manually disconnected a malfunctioning autopilot, the yaw damper would also have disengaged. However, the autopilot control unit switches were in the expected positions: the yaw damper was engaged and the autopilot was disengaged.

2.2.2.4 Change in the aerodynamic characteristics of the aircraft

There was no evidence of any failure or damage to the aircraft's structure prior to impact, nor were environmental conditions conducive to airframe icing. As previously stated, the aircraft appears to have responded normally to pilot inputs in the moments before impact.

2.2.2.5 Failure of critical flight instrumentation

The attitude displayed on the pilot's main attitude indicator was consistent with the impact attitude derived from the aircraft wreckage and crash site. Tests suggested that the display would have been frozen at the moment the DC element of the electrical power was disrupted, which is likely to be the initial impact with the water. This provided some confidence that the attitude reference system was functioning normally at the time of the accident. There is every reason to believe that, as the aircraft deviated from the intended flight path, attitude indications would have been correctly presented to the pilot, and that an instrument crosscheck was available to him from one or both of the other two attitude instruments. Failures affecting pressure instruments would not have affected the available attitude information.

2.2.2.6 Inadvertent speed loss and stall encounter

If the aircraft's airspeed had reduced significantly, the aircraft could have encountered the adverse (although somewhat predictable) handling characteristics associated with a stall. On its own, an inadvertent speed loss of this magnitude would amount to gross mishandling by the pilot, which was unlikely, given his experience. An erroneous high airspeed indication could possibly have led to an actual speed loss if the pilot had reacted to the indication by increasing pitch attitude. In the absence of external visual cues, the conflict between the instrument indications and physical sensations would have been confusing until the problem was diagnosed.

In any case, a very low speed situation should have been alerted to the pilot by the stall warning horn, which is independent of the flight instrument system and which none of the passengers reported hearing.

A loss of control from a stall situation would have presented an altogether different cockpit environment from that reported. A more severe initial height loss would probably have occurred, which was not reported by witnesses or passengers. The available evidence thus does not support a stall encounter.

2.2.2.7 Weather factors

The pilot warned his passengers to expect some turbulence after takeoff, and it appears from their accounts that some was encountered. However, with the pilot prepared for turbulence, it is extremely unlikely that a turbulence encounter on its own would have caused him such control difficulties as to lead to the loss of the aircraft, particularly considering that the turbulence was unlikely to have been severe in the reported conditions.

Turbulence could, however, have been a contributory factor to pilot distraction or disorientation.

2.3 Human factors

2.3.1 Inadvertent control input

Passenger A demonstrated good recall of the flight and said she was not in contact with the control wheel or rudder pedals. In any case, an inadvertent input so soon after takeoff should have been apparent to the pilot, who would have felt it through the controls and seen its effects on the flight instruments in good time to take corrective action. It may reasonably be expected that he would also have voiced a warning of some kind to his passenger.

2.3.2 Distraction

The pilot was not following a published departure procedure, or dealing with ATC instructions, so his workload should have been relatively low. Although Passenger A did make a potentially distracting gesture, this was short lived and is unlikely to have been a significant distraction for the pilot. In fact, it could even have acted to alert the pilot to an unusual situation, although the pilot apparently did not respond to it.

The cockpit switch and control positions as found in the wreckage were consistent with the 'After Takeoff Check' items having been completed. Although in one sense this confirms normal operation of the aircraft by the pilot, in another sense it offers a potential source for distraction, as the check items require some actions normally carried out by the second, non-handling pilot. The 'After Takeoff Check' actions therefore represented a potential distraction at a critical phase of flight.

2.3.3 Incapacitation

There was no pathological evidence to suggest that the pilot became incapacitated. Passenger A described the pilot being in control of the aircraft and, in the latter stages, he was apparently making corrective control inputs. She knew the pilot well and had no sense that he had become ill during the short flight. However, the circumstances of the accident are such that the possibility of the pilot suffering a transient and subtle incapacitating event could not be ruled out.

2.3.4 Spatial disorientation

Takeoff was made in the dark, with no reliable visual references, so the pilot would have been reliant upon his instruments for spatial orientation. The passengers generally did not describe significant turning manoeuvres, and some, including Passenger A seated beside the pilot, were unaware that the aircraft had turned at all. The aircraft must have rolled to an excessive angle of bank, but at least some of this appears to have been at a rate which was not sensed by the passengers. It is likely that the forces acting upon the aircraft and its occupants remained substantially in the normal axis (ie the vertical axis, when the aircraft is completely level). As the pilot was subject to the same forces, a degree of mismatch was probably present between his perception of the aircraft's attitude and its true attitude, although the latter would have been displayed on his attitude indicator.

It is known that the pilot turned his head to look at Passenger A, and from her account this would have been as the aircraft was turning, in the latter stages of the flight. This head movement could induce the Coriolis illusion, which can quickly produce a disorientating tumbling sensation. Even if this were not an originating cause of any disorientation, the effect could contribute to delayed recognition of the situation and recovery from it.

As well as aircraft attitude, the flight instruments provided the pilot with performance information, notably height and airspeed, which would have quickly begun to register a descent and increasing speed. Although some rolling was reported, passengers generally recounted sensations in the vertical sense, which they related to climbs, descents and turbulence or 'air pockets'. It is possible that some of these sensations were induced by a reaction on the part of the pilot to the descent indications.

If the pilot was unaware of the excessive bank angle, which seems probable, his natural reaction to the descent indications may at first have been to pull back on the control wheel. This would increase the normal acceleration, or g-loading, and be felt by the passengers as a sudden climb. However, with a relatively high bank angle, the main effect on the aircraft would have been to increase the turn rate with little effect on the vertical flight path. Considering the significant difference between the initial aircraft track and the wreckage trail, something of this nature must have occurred for the aircraft to achieve the necessary turn in the time and space available.

Spatial disorientation accidents are frequently fatal, either because the pilot remains unaware of the increasingly dangerous situation until too late, or his ability to recover from the situation in time is severely degraded by his disorientation. The pilot's actions (or lack of them) in this case suggest that he was initially unaware of the developing situation, as were his passengers. If this was so, even though he eventually recognised the attitude excursion and was recovering from it, the pilot was probably not aware of the critically low height. A degree of instrument fixation at this point could account for his failure to assimilate the altitude information and explain the lack of any warning or exclamation.

2.3.5 Effects of alcohol

The aviation pathologist felt it was reasonable to regard the pilot's measured alcohol level to be approximately that at the time of his death, although postmortem production within the body could not be ruled out entirely. The general effects of alcohol on human performance are widely recognised. Although the levels were not excessive, they were at values shown to make a pilot more susceptible to spatial disorientation.

2.3.6 Pilot's training records and experience

The pilot's records indicated that, during flight checks, he had demonstrated the required level of competency in handling engine failures at critical stages of flight, as well as other major system malfunctions. Although an unexpected power loss or asymmetry during the takeoff or climb would be likely to cause an undesired yaw and roll, the pilot was capable of recognising such a failure and controlling the aircraft to a safe landing.

The pilot's instrument scan technique had been mentioned in his records as a possible area of weakness, although it should be noted that the pilot would have been experienced in instrument flying techniques and was at one time an approved examiner of these skills in other pilots.

During line flying, any instrument scan weakness would most likely show itself under conditions of high workload, such as when dealing with an abnormal situation. It would be very unlikely to lead to a complete loss of control in such an experienced pilot, but an instrument scan weakness would make the pilot more prone to a disorientation event, and could hinder recognition and recovery in a time-critical situation.

2.4 Status of the flight

The flight should have been operated as a public transport flight. The fact that the passengers were carried gratuitously led the pilot and operator to believe that the flight was a private one, and therefore not subject to the provisions of the ANO(OT)O relating to public transport flights. This was not the case. The accident highlighted a potential for confusion about the regulations in this respect, which was addressed soon afterwards in a communication from ASSI to aircraft operators in the Overseas Territories.

The distinction between public transport and private flight status may not have been readily apparent to the passengers, who would be used to flying in the company's aircraft on normal scheduled services. When they boarded the aircraft on the evening of the accident, they would have had no particular reason to believe that the flight would not be operated with the same safety standards as at any other time, but this was not to be the case.

A critical safety role of the second pilot is to monitor the flying of the primary pilot, including alerting him to deviations from the norm. While the presence of a second pilot does not guarantee protection against Human Factors incidents, it does provide a significant increase in safety in this respect. The lack of a second pilot, required by regulations and the operating company's procedures, was therefore a contributory factor in this accident.

2.5 Search and rescue activities

As a public transport flight, the aircraft would also have been required to operate only from properly licensed aerodromes. As North Caicos Airport was closed at the time of departure, this requirement was not met. Although this fact was not contributory to the accident, it has a bearing on the subsequent rescue activities, since ATC at North Caicos would have been immediately aware of the situation and able to implement their crash action plan. Despite that, local residents were quickly aware that the aircraft had crashed and mounted an effective rescue operation with very limited resources and in extremely difficult conditions. Combined with the response from Providenciales, the local rescue effort was creditable.

3 Conclusions

3.1 Discussion

The available evidence, which shows that a significant change in aircraft attitude occurred late in the accident sequence, strongly suggests that the pilot was in control of the aircraft when it struck the surface, and was taking appropriate recovery action. Some conclusions may be drawn from this: the aircraft was controllable; the pilot was physically able to control it and was so doing; and he probably had sufficient information from the flight instruments, alone, to make correct control inputs.

The event which caused the actual and intended flight paths to diverge was not catastrophic. There were no unusual engine or other noises in the cabin, no particularly unusual forces were experienced by the aircraft occupants and there were probably no warning lights or sounds in the cockpit. Together with the lack of obvious concern on the part of the pilot as the flight path diverged, this indicates a subtle event or situation which developed unchecked until recognised by the pilot at a late stage, and even then possibly not fully.

It was not possible to rule out a subtle technical malfunction as a contributory factor, but the weight of evidence indicated that the pilot retained sufficient reliable information from his flight instruments to prevent or correct the attitude deviation which ultimately led to the accident. Similarly, it was not possible to rule out a subtle but transient medical condition which may have interfered with the pilot's normal functioning, although there was only circumstantial evidence to support the possibility.

The circumstances of the accident strongly suggest that the pilot became spatially disorientated. It was immediately after takeoff, it was dark with no reliable outside references and the pilot was operating as single crew. He had completed the after takeoff checks shortly before, which may have been an initiating distraction. It was probable that he had consumed alcohol at some time before the flight and his blood alcohol level, although not excessive, would have made him more prone to becoming disorientated. Although very experienced, the pilot had a potential weakness in his instrument scan technique. This and the turbulence the aircraft apparently encountered could also have contributed to any disorientation.

Spatial disorientation accidents are frequently fatal, as the pilot does not recognise the danger or is unable to effect a recovery. In this case the pilot did start a recovery and appears to have been taking appropriate recovery actions when the aircraft struck the surface. This had the effect of reducing the descent rate and placing the aircraft in an almost level attitude at impact. The pilot's actions, although initiated too late to avoid the accident, lessened the impact damage and helped preserve the fuselage structure relatively intact, which probably prevented greater loss of life.

3.2 Findings

1. The pilot was correctly licensed and qualified for the flight in accordance with existing regulations.

2. Aircraft maintenance records indicated that it was correctly equipped and maintained and that all required maintenance had been carried out.

3. The aircraft was within the applicable mass and balance limitations and carried sufficient fuel for the intended flight.

4. Weather conditions were generally favourable. Some turbulence was reported but this is unlikely to have been severe.

5. It was night, with little natural or cultural lighting. The pilot would not have had external visual references immediately after takeoff and would have been flying with reference to flight instruments.

6. Shortly after takeoff the aircraft rolled to the right, achieving an excessive bank angle. It descended in a banked attitude at an approximately constant descent angle, turning as it did so.

7. Passengers did not recall unusual noises, vibrations, accelerations or other significant events after takeoff, although some motions attributed to turbulence were reported.

8. The aircraft struck the surface with only a small amount of right bank and an approximately level pitch attitude, indicating that the pilot was probably attempting to recover from the situation.

9. The aircraft was intact at impact, with landing gear and wing flaps retracted.

10. There was no evidence of a pre-impact engine failure that would have prevented either engine from producing power.

11. A defect within the right engine FCU raised the possibility of a small power asymmetry, but would be unlikely to cause the pilot handling difficulties.

12. The propellers were operating in their governed range at impact. Damage to the propellers suggested that approximately symmetrical power was applied.

13. There was no evidence of a failure affecting the flying control systems.

14. The pilot was probably being presented with correct attitude information on his main attitude indicator.

15. The aircraft was probably under the control of the pilot at impact and was capable of controlled flight.

16. Impact was at a relatively high speed and there was no indication that the aircraft had stalled.

17. There was no pathological evidence to indicate that the pilot had become incapacitated in flight.

18. Conditions were conducive to spatial disorientation.

19. The pilot was operating as single crew, and there was some potential for distraction in the cockpit.

20. The pilot had probably consumed alcohol at some stage before the flight; the measured alcohol level in his system was below the applicable limit, but is likely to have increased his susceptibility to spatial disorientation.

21. The pilot's training records showed that he had demonstrated a satisfactory standard in handling in-flight emergencies such as engine failures, but a possible weakness in his instrument scan pattern had been identified.

22. Although the passengers had not paid for their seats, the flight should have been operated as a public transport flight.

23. The flight did not meet the regulatory requirements for public transport flights in respect of minimum flight crew and airport operating restrictions.

24. The presence of a second pilot on the flight deck would probably have lessened the chance of the accident occurring.

3.3 Causal factors

The investigation identified the following causal factors:

1. The aircraft adopted an excessive degree of right bank soon after takeoff. This led to a descending, turning flight path which persisted until the aircraft was too low to make a safe recovery.

2. The pilot probably became spatially disorientated and was unable to recognise or correct the situation in time to prevent the accident.

3.4 Contributory factors

The investigation identified the following contributory factors:

1. The environmental conditions were conducive to a spatial disorientation event.

2. The pilot had probably consumed alcohol prior to the flight, which made him more prone to becoming disorientated.

3. The flight was operated single-pilot when two pilots were required under applicable regulations. The presence of a second pilot would have provided a significant measure of protection against the effects of the flying pilot becoming disorientated.

4. Safety Recommendations

No Safety Recommendations are made as a result of this investigation.