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SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-73V, G-EZJK	
No & Type of Engines:	2 CFM56-7B20 turbofan engines	
Year of Manufacture:	2002	
Date & Time (UTC):	12 January 2009 at 1545 hrs	
Location:	West of Norwich, Norfolk	
Type of Flight:	Private	
Persons on Board:	Crew - 2	Passengers - 2
Injuries:	Crew - None	Passengers - None
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	43 years	
Commander's Flying Experience:	10,716 hours (of which 7,719 were on type) Last 90 days - 56 hours Last 28 days - 9 hours	
Information Source:	AAIB Field Investigation	

The investigation

The Air Accidents Investigation Branch (AAIB) was informed of the serious incident involving this aircraft at 1630 hrs on 12 January 2009 and an investigation was commenced immediately under the provisions of the *Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996*. In accordance with established international arrangements, the National Transportation Safety Board (NTSB) of the USA,

representing the State of Design and Manufacture of the aircraft, appointed an Accredited Representative to participate in the investigation. The investigation is also being fully supported by all parties involved.

This is a preliminary report detailing the facts of the incident; no analysis has been attempted.

This bulletin contains facts which have been determined up to the time of issue. This information is published to inform the aviation industry and the public of the general circumstances of accidents and must necessarily be regarded as tentative and subject to alteration or correction if additional evidence becomes available.

The investigations in this bulletin have been carried out in accordance with The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996, Annex 13 to the ICAO Convention on International Civil Aviation and EU Directive 94/56/EC.

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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History of the flight

The operator was intending to complete a combined maintenance check and customer demonstration flight on the aircraft, which was at the end of its lease and had just undergone maintenance, prior to it being handed over to another operator. The customer demonstration flight, designed to confirm the aircraft's serviceability, was loosely based on the Boeing new aircraft delivery test schedule and comprised a series of checks agreed between the existing operator and the aircraft owner.

The commander of the incident flight had, the previous month, flown the aircraft to Southend for maintenance. During that flight he carried out the 'demonstration flight schedule' in order to identify any defects. He returned to Southend on 12 January 2009 to collect the aircraft for a further check flight and discussed with the crew chief from the maintenance provider, who had been responsible for the aircraft during the check, the work that had been carried out; he recalled being told that an adjustment to the elevator balance tab setting had been made. For the forthcoming test flight, the commander was given extracts from the Aircraft Maintenance Manual (AMM) to assist him in conducting an in-flight elevator power-off test and to identify any asymmetrical flight control forces; both were required as part of the maintenance procedures. Prior to departure he checked the aircraft's technical log and confirmed that arrangements had been made with ATC for the flight to be conducted in the East Anglia Military Training Area (MTA). The commander and co-pilot, a first officer from the operator, were to be accompanied on the flight by a representative of the aircraft owner and a representative of the airline due to take delivery of the aircraft. No problems were identified during the pre-flight preparation and the aircraft departed at 1400 hrs with the commander as the handling pilot.

After take off, the aircraft climbed to FL410. Various checks were conducted during the climb and with the aircraft level at FL410. After about 45 minutes the aircraft descended to FL150, during which more checks were conducted. On reaching FL150 an APU bleed check was performed and the aircraft then configured to perform a flight control manual reversion check. This required the aircraft to be flown at FL150, at 250 kt IAS with the fuel balanced, the AUTOPILOT and AUTOTHRUST selected OFF, the STAB TRIM MAIN ELEC and AUTOPILOT switches set to CUTOUT and the aircraft in trim. The 'customer demonstration flight schedule' also required SPOILER A and B switches to be selected OFF. All these checks were conducted using the operator's 'customer demonstration flight schedule' and not the maintenance manual extracts as the guiding reference.

Before the manual reversion check commenced, the individual hydraulic systems were isolated by placing the FLT CONTROL switches A and B to the OFF position individually and reinstating in turn enabling the flight controls to be checked for normal operation on a single hydraulic system. Operation was confirmed as satisfactory on both systems. Then, with the commander having released the controls, the co-pilot selected FLT CONTROL switches A and B to the OFF position, removing all hydraulic assistance from the primary flying controls. As he did so the aircraft suddenly pitched nose down. The commander pulled back on the control column with considerable force but was unable to prevent the aircraft from maintaining a nose down pitch attitude of -2.81° and descending at up to 3,100 fpm. The commander, therefore, decided to abandon the check but did not wish to re-engage the hydraulics whilst applying significant backpressure to the controls.

The commander stated that, should the aircraft pitch up or down uncontrollably during a manual reversion check, he had been trained to roll the aircraft to unload the pressure on the elevator and release the controls before reinstating the hydraulics. The commander therefore, rolled the aircraft left 91.2° and believes he released the controls before calling for the co-pilot to re-engage the FLT CONTROL switches. The recording from the Cockpit Voice Recording (CVR) indicated that at this point there was confusion between the two pilots. This resulted in the commander thinking that hydraulic power had been restored to the flight controls although there is no evidence that the FLT CONTROL switches had been moved from the OFF position.

The commander rolled the wings level and attempted to arrest the rate of descent which had increased considerably, peaking at 21,000 fpm; the aircraft had pitched 30° nose down after the aircraft had been rolled to the left. The control forces remained high but the commander considered this to be due to the aircraft's speed, which both pilots observed to be indicating above 440 kt. He retarded the thrust levers and selected the speed brakes, however, the spoilers had been switched OFF as part of the test procedure.

The commander continued to maintain backpressure on the controls and made a PAN call to ATC. The aircraft eventually recovered from the dive at about 5,600 ft, having entered a layer of cloud. The pilots reviewed the situation and selected the FLT CONTROL switches, which had remained OFF throughout the flight excursion, to the ON position. The control forces returned to normal.

As a result of the incident the check flight was abandoned and the aircraft returned to Southend. Suspecting possible structural damage, the commander kept the speed below 250 kt and configured the aircraft for landing early during the approach. The aircraft appeared to operate normally and landed without further incident at 1606 hrs.

Weight and Centre of Gravity

The aircraft's take off weight was 47,633 kg and MACTOW 20.6%. The centre of gravity remained within limits throughout the flight.

Guidance Material

The Boeing 737-700 AMM extract given to the crew referred to recovery techniques to be used in the event of a pitch upset being encountered during the manual reversion test. These are also published in the Boeing 737-700 Quick Reference Handbook (QRH) and call for the possible use of bank to recover from a 'pitch-up upset' event. In the 'pitch-down upset' case the QRH advises rolling the wings level.

In April 2006 the CAA published a Check Flight Handbook containing guidance to pilots and flight test engineers approved to conduct CAA flight check schedules on UK registered aircraft. This guidance is only intended to be used as a supplement to briefings given by the CAA when conducting their published schedules. Section 3, Tech 2, Part 10 covers flying control checks and states:

'It might be possible to put some bank on the aircraft to turn a large pitch up or pitch down into a turn manoeuvre before re-powering the system. This might prevent an unusually high or low pitch manoeuvre developing.'

Engineering investigation

The aircraft was reaching the end of its lease contract with the operator and had been removed from the operating fleet for a maintenance input to comply with hand-back contractual requirements. The maintenance arrangement was specific to the operator's aircraft 'hand-back' activities and was sub-contracted to a third

party maintenance provider by the operator's established line and base maintenance provider. It also included a complex structure of 'sub-contracted' management and oversight responsibilities involving a number of additional third party companies.

During the ferry flight to deliver the aircraft to the maintenance provider, the operator had flown a 'shakedown' test using the same customer 'demonstration flight test schedule' to identify any existing defects, allowing rectification work to be completed during the maintenance input. This 'shakedown' flight included the manual reversion test to assess the trim of the aircraft. This involved switching off both hydraulic systems powering the aircraft flight controls and assessing the amount of manual stabiliser trim wheel adjustment required to balance the aircraft in level flight. The results of this test identified that the aircraft was within, but very close to, the approved maintenance manual limits. Following the flight, the commander verbally requested that this be addressed during the subsequent maintenance input, but elected not to enter it in the tech log, as the level of stabiliser trim required during the test had been within limits. The absence of a formal post-flight debrief and formal written record resulted in the balance tabs, attached to the elevators of the aircraft,

being adjusted in the opposite sense to that identified as necessary by the flight test. The aircraft was therefore significantly out of trim during the post-maintenance test flight, and it was that which initiated the pitch-down incident during the manual reversion test.

The investigation is continuing and a final report will be published by the AAIB.

Safety Actions

- The operator suspended further check flights until it had carried out a review of maintenance procedures, check pilot procedures and flight check schedules
- The CAA are reviewing Section 3, Tech 2, Part 10 of its Check Flight Handbook to ensure the specific guidance related to flying control checks is not open to misinterpretation.
- The CAA intend to publish an Airworthiness Communication (AIRCOM) addressing the issues relating to the co-ordination between operators and maintenance organisations surrounding the conduct of maintenance check flights.

ACCIDENT

Aircraft Type and Registration:	Boeing 777-236ER, G-YMMM	
No & Type of Engines:	2 Rolls-Royce RB211 Trent 895-17 turbofan engines	
Year of Manufacture:	2001	
Date & Time (UTC):	17 January 2008 at 1242 hrs	
Location:	Runway 27L, London Heathrow Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 16	Passengers - 136
Injuries:	Crew - 4 (Minor)	Passengers - 1 (Serious) 8 (Minor)
Nature of Damage:	Aircraft damaged beyond economic repair	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	43 years	
Commander's Flying Experience:	12,700 hours (of which 8,500 hours were on type) Last 90 days - 85 hours Last 28 days - 52 hours	
Information Source:	Inspector's Investigation	

The investigation

This report is an update on the progress of the investigation into the accident to G-YMMM on 17 January 2008, and should be read in conjunction with the initial Interim Report issued on 4 September 2008. That report includes a detailed history of the accident flight, a technical description of the fuel system in the

Boeing 777, details of the investigation up to that point and three Safety Recommendations.

The Air Accidents Investigation Branch (AAIB) was informed of the accident at 1251 hrs on 17 January 2008 and the investigation commenced immediately. In

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accordance with established international arrangements, the National Transportation Safety Board (NTSB) of the USA, representing the State of Design and Manufacture of the aircraft, has appointed an Accredited Representative to participate fully in the investigation. The NTSB Accredited Representative is supported by a team which includes additional investigators from the NTSB, the Federal Aviation Administration and Boeing; Rolls-Royce, the engine manufacturer, is also participating fully in the investigation. British Airways, the operator, is co-operating with the investigation and providing expertise as required. The Civil Aviation Authority (CAA) and the European Aviation Safety Agency (EASA) are being kept informed of developments.

Brief history of the flight

The flight from Beijing, China, to London (Heathrow) was uneventful and engine operation was normal until the final approach. During the approach the autothrottles commanded an increase in thrust from both engines and the engines initially responded. However, at a height of about 720 ft agl the thrust of the right engine reduced to approximately 1.03 EPR (Engine Pressure Ratio); some seven seconds later the thrust on the left engine reduced to approximately 1.02 EPR. The reduction in thrust on both engines (rollback) was the result of a reduced fuel flow and all engine parameters after the thrust reduction were consistent with this.

Related event

On 26 November 2008 an American operator of a Boeing 777-200ER (N862DA), also powered by Rolls-Royce Trent 895 engines, experienced an uncommanded rollback of the right engine whilst in the cruise at FL390. The aircraft was on a flight from Shanghai, China, to Atlanta, USA, when the incident

occurred in the vicinity of Great Falls, Montana. The crew executed the applicable Flight Manual procedures, introduced after the G-YMMM accident, following which normal engine control was recovered and the aircraft proceeded to an uneventful landing at Atlanta.

Whilst the phase of flight, environmental conditions and fuel temperature profiles were not common to the G-YMMM accident, many of the characteristics of the engine rollback were similar, including the fuel temperature at the time of the event. Analysis of the data from both events, and the testing undertaken by the aircraft and engine manufacturers, have further enabled the investigation to understand how ice generated within the aircraft fuel feed system might lead to an engine rollback.

Fuel Oil Heat Exchanger restriction tests

It was reported in the AAIB initial interim report that testing has shown that, under certain conditions, it is possible for ice to restrict the fuel flow at the face of the Fuel Oil Heat Exchanger (FOHE). However, during all the testing the fuel flow never fell below that required by an engine at flight idle. Moreover, the restriction could always be cleared by reducing the fuel flow to idle, which resulted in a change in the equilibrium between the cold fuel and hot oil in the heat exchanger, such that the ice melted on the inlet face of the FOHE, sufficient to restore the demanded fuel flow.

Further testing has established that 25 ml of water, when introduced into the fuel flow at the boost pump inlet at an extremely high concentration, can form sufficient ice to restrict the fuel flow through the FOHE. During these tests it was concluded that it was not possible to restrict the fuel flow through the FOHE when the temperature of the fuel in the main tank was above -15°C (5°F) at

a fuel flow of 6,000 pounds per hour (pph) and -10°C (14°F) at a fuel flow of 12,000 pph.

It should be emphasised that the FOHE, which is part of the engine fuel system, was shown to comply with all the requirements placed on the engine manufacturer at the time of certification; the tests conducted in the course of the investigation have not, to the knowledge of the AAIB, been proposed or conducted before.

Further testing

Since the publication of the AAIB initial interim report the aircraft manufacturer has undertaken further testing on a fuel rig to establish how ice might accumulate in the aircraft fuel feed system.

Blockage in the aircraft fuel feed system

During the testing, blockage of the fuel boost pump inlet screen was achieved on six occasions sufficient to restrict the flow. The restrictions occurred during the testing and were believed to have occurred as a result of the method by which water was introduced into the fuel to maintain the required concentration; consequently these restrictions were believed to be an artefact of the test set-up. The restrictions were all characterised by a drop in the fuel pressure, sufficient to generate the boost pump low fuel pressure warning, and a reduction in the electrical current draw of the boost pump. The data from the accident flight showed that the boost pump low pressure switches did not trigger throughout the flight, therefore, icing of the inlet screens is unlikely to have caused the particular fuel flow restrictions experienced on G-YMMM.

Observations from the earlier tests showed that, apart from the inlet screens and the FOHE, restrictions did not occur in any of the other fuel system components, or in any of the aircraft fuel feed pipes. During some

of the long-duration tests it was observed that, at a low fuel flow, ice could accumulate on the inside of the pipe walls. It was suspected that this ice would clear when the fuel flow was increased. However, on these early tests the geometry, material and lengths of the pipes on the fuel rig were not identical to the aircraft installation, nor were they exposed to the same environment as experienced on the accident flight.

Ice accumulation tests

To establish how ice might have accumulated within the fuel feed system on the accident flight, the fuel rig was reconfigured to include the majority of the right fuel system feed pipes from G-YMMM. The pipes were arranged so that their gradients were representative of the attitude of the aircraft in the cruise. An environmental tank, filled with cold fuel, was used to simulate the environment surrounding the fuel feed pipes in the main fuel tank. An insulated box was built around those fuel pipes which pass through the centre 'cheek' tanks and dry ice was used to control the temperature in this area. The pipes located along the top of the strut (engine pylon) were exposed to the ambient conditions of the building in which the fuel rig was located; thermal modelling by the aircraft manufacturer indicated that this would approximate to the temperature in this area during the cruise.

Tests were carried out with fuel flowing for 3, 6 and 7 hours at 6,000 pph, containing a water concentration of approximately 90 parts per million (ppm)¹ and fuel temperatures of 5°C (41°F), -12°C (10°F), -20°C (-4°F) and -34°C (-29°F) respectively. These test conditions were intended to replicate the conditions during the accident flight and to simulate the environment around

Footnote

¹ 90 ppm is an industry standard as defined in SAE ARP 1401 and SAE AIR 790.

the fuel feed pipes. The following observations were made:

- When warm fuel (at a temperature of 5°C (41°F)) was fed from the centre tank, ice formed around the inside of the fuel feed pipes that pass through the main fuel tank (fuel at a temperature of -20°C (-4°F)).
- Ice formed around the inside of all the fuel feed pipes from the boost pump discharge port to the front of the strut when fuel flowed for 3 hours at temperatures of -12°C (10°F) and -20°C (-4°F). The thickness of the ice was similar (1 to 2 mm) at both temperatures; however at -12°C (-10°F) the build-up of ice was more consistent and visually there appeared to be more ice throughout the system.
- Very little ice formed on the inside of the fuel feed pipes when the fuel temperature was at -34°C (-29°F).
- There was less repeatability in the amount of ice found in the fuel pipes at the end of the accumulation runs when the duration was increased from 3 to 6 hours. Several tests were carried out, using the same batch of fuel, at a fuel temperature of -20°C (-4°F) with quite different results. The amount of ice within the system ranged from very little ice to a build up of approximately 6 mm along the bottom of the pipe and 1 to 2 mm around the circumference of the pipe (Figure 1). However, it is possible that on some of the runs, ice might have been released before the end of the test.



Figure 1

Ice in the flexible hose located at the rear of the strut

- When the fuel temperature was cooled from -12°C (10°F) to -33°C (-27°F), over a 7 hour period, at a similar rate to the accident flight, the amount of ice found in the fuel pipes was consistent with the findings after the 3 hour run at a fuel temperature of -12°C (10°F).
- The ice was soft and easy to move and there appeared to be no difference in the properties of the ice that accumulated at any of the cold test temperatures. However, in the test when the fuel temperature was cooled from -12°C (10°F) to -33°C (-27°F), the surface of the ice took on a 'pebbly' appearance.
- Examination of the melted ice showed that it consisted of a mixture of water and fuel. The quantity of water in the ice deposited along the inside of the fuel pipes in the strut area was greater than the amount found necessary, in previous tests, to restrict the FOHE.

- On two occasions approximately 90 ml of water was recovered from the ice that had accumulated in pipes in the strut area. On another occasion approximately 170 ml of water was recovered from this area; however, the possibility that this sample had been contaminated after the test could not be excluded.

Ice release tests – cold FOHE²

Tests were carried out using the environmental test rig to establish whether increasing the flow rate would release sufficient ice, that had accumulated on the inside of the fuel pipes, to cause a restriction at the face of a FOHE. However, because of the limitations of the test rig, and the apparent ‘random’ process by which ice forms, it was not possible to fully replicate the conditions just prior to the engine rollback on G-YMMM.

The first phase of each test was to accumulate ice within the fuel system using a boost pump to maintain the fuel flow at 6,000 pph, with the fuel conditioned with approximately 90 ppm of water and maintained at a temperature of -20°C (-4°F). This was the approximate fuel temperature at which the rollbacks occurred on G-YMMM and N862DA. It should be noted that it was not possible to establish visually how much ice had accumulated at the end of this phase, without compromising the release test. After the accumulation phase, the fuel flow returning from the end of the strut was diverted through a cold FOHE and the fuel flow was increased.

In the first test, ice was allowed to accumulate for 3 hours before the fuel flow was increased to 10,000 pph for

3 minutes; during this test no pressure drop was detected across the FOHE. On examining the fuel system no ice was found on the face of the cold FOHE and the amount of ice found on the inside of the fuel pipes was similar to the amount found during the previous accumulation tests undertaken at similar conditions.

In order to increase the flow rate above 10,000 pph it was necessary to fit an engine LP pump into the flow path. Under normal operation the LP pump increases the fuel pressure from around 30 to 200 psig, which is sufficient to provide a flow rate of approximately 30,000 pph with the control valve fully open.

During the next two tests, ice was allowed to accumulate for 6 hours before the fuel flow was diverted to the LP pump and cold FOHE. The fuel flow was increased by progressively opening the control valve during which, on both tests, the pressure drop across the FOHE increased and the LP pump outlet pressure reduced. In the first of these tests, as the control valve was gradually moved fully open, the pressure drop across the FOHE began to increase³ when the fuel flow was between 6,000 and 10,000 pph, indicating that ice had released and started to form a restriction at the FOHE. The fuel flow became restricted to 14,500 pph before decreasing to 11,000 pph, with a corresponding pressure drop of 165 psid across the FOHE. During the next test the pressure drop across the FOHE also began to increase when the flow rate was between 6,000 and 10,000 pph. The fuel flow became restricted to 10,000 pph before decreasing to 6,000 pph, with a pressure drop of 195 psid across the FOHE. Whilst the pressure drop across the FOHE, in both cases, was evidence of the cold FOHE being restricted by ice, the reduction in

Footnote

² A cold FOHE does not have any hot oil flowing through it and was used in the tests as a strainer to ‘catch’ any released ice.

Footnote

³ In normal operation the differential pressure across the FOHE increases slightly with increasing fuel flow. In these tests the pressure differential was higher than would be expected in normal operation.

the boost pump and LP pump outlet pressures, and a reduction in the current drawn by the boost pump, were indications that the fuel flow through the system was also restricted by ice collecting on the boost pump inlet screen.

Following these tests, 35 ml and 55 ml of water was collected from the ice that melted from the face of the FOHE. From a visual inspection of the inside of the fuel pipes, it appeared that in the penultimate test the ice was released from the strut area, whereas in the final test it released from all the fuel pipes.

Ice release tests – hot FOHE⁴

Two further ice release tests were carried out with hot oil at 85°C (167°F) flowing through the FOHE. A clear cap was fitted to the FOHE in order to monitor its face visually.

In the first test there was only a small rise in the pressure drop across the FOHE as the fuel flow was increased above 6,000 pph. However, with the control valve fully open the fuel flow peaked at 14,900 pph before falling back to around 11,000 pph. The drop in the current drawn by the boost pump, and a reduction in the boost pump outlet pressure, indicated that the fuel flow was probably restricted as a result of ice forming on the boost pump inlet screen.

After removing the bypass loop it was possible to observe the ice entering the FOHE for approximately 15 seconds before the fuel became too cloudy to make visual observations. The size of the ice varied from small flakes up to a piece approximately 21 mm x 15 mm. The appearance and thickness of the ice was

consistent with it having been shed from the inside walls of the fuel pipes. On making contact with the face of the FOHE the smaller pieces of ice would ‘instantly’ melt, whereas it took several seconds for the larger pieces of ice to disappear. Some of the ice was still intact after three seconds but, as the fuel turned cloudy, it was not possible to establish if this ice would melt or grow.

The second test was run at the same conditions as the first test and used the same batch of fuel. In this test the pressure drop across the FOHE began to increase when the fuel flow was at 10,000 pph. The fuel flow peaked at 19,000 pph, with the control valve fully open, and a corresponding pressure drop across the FOHE of 105 psid. Over the following two minutes the fuel flow decreased to 17,000 pph with an increase in the pressure drop across the FOHE to 125 psid. There were no indications that the fuel flow was restricted by icing of the inlet screen and very little ice was found in any of the fuel pipes at the end of the test.

This last test demonstrated the principle that ice can accumulate and release from the inside of the fuel feed pipes in a sufficient quantity to restrict the fuel flow through a hot FOHE. However, the level of restriction during this test was less than that experienced on the accident flight.

Ice release test – effect of temperature in the strut

A test was carried out to establish if the increase in total air temperature (TAT) during the descent might have caused ice to be released from the fuel pipes in the strut.

Ice was allowed to accumulate for 6 hours at a fuel flow of 6,000 pph and a temperature of -20°C (-4°F). At the end of this period, hot air was blown into a box surrounding the strut pipes to increase the temperature

Footnote

⁴ A hot FOHE has oil flowing through it at a temperature representative of an operating engine.

from approximately 15°C (59°F) to 38°C (100°F). Whilst the frost on the outside of the strut pipes remained intact, the pressure drop across a cold FOHE slowly increased from 20 to 75 psid. After a further hour the fuel flow was increased, but despite the control valve being moved to the fully open position the fuel flow peaked briefly at 10,000 pph before dropping back to 8,000 pph with a corresponding increase in the pressure drop across the FOHE of 170 psid. This was indicative of a restriction at the FOHE.

An inspection of the fuel pipes revealed that, whilst there was no ice in the rigid pipes in the strut, there was some ice in the flexible pipe in the strut and a large amount of ice throughout the rest of the fuel system. Approximately 35 ml of water was collected from the ice on the face of the FOHE.

Water concentration

It was estimated that the fuel uplifted in Beijing at the start of the accident flight might have contained up to 70 ppm⁵ of dissolved and entrained (suspended) water; this concentration occurs naturally in aviation jet fuel and would have reduced during the flight as some of the water settled and froze on the bottom of the fuel tank. Fuel samples taken from G-YMMM after the accident indicated that the water concentration in the fuel taken from the left main tank sump, APU line and Variable Stator Vane actuator was approximately 40 ppm. This was comparable with the water concentration in fuel samples taken from the engine fuel filter housings on another Boeing 777 that flew a similar route.

For the accumulation and release tests it was decided to use the industry standard⁶ for continuous system

Footnote

⁵ Refer to the initial interim report for details on water concentration in aviation turbine fuels.

⁶ SAE ARP 1401 and SAE AIR 790.

operation tests, aiming to condition the fuel with 90 ppm of water.

The water concentration in the fuel used in the accumulation and release tests was established by running at least two Karl Fischer tests on each fuel sample in accordance with the industry standard ASTM D6304. Despite closely metering the amount of water added to the fuel, the results of the testing of fuel samples taken every 30 minutes indicated that the amount of water in the fuel flowing through the pipes varied from approximately 45 to 150 ppm. The discrepancy between the metered and measured water content might be explained by ice collecting, and being released, from the supply tank, pump inlet screen and the feed pipes between the supply tank and the pipes being tested. However, it was also observed, from the results of several Karl Fischer tests carried out on the same sample of fuel, that the measured water concentration could vary by up to 60 ppm.

The variation in the measured water content of the fuel, and the accuracy of the Karl Fischer tests, could not be improved and were, therefore, accepted as test limitations.

Analysis - testing

Fuel system tests

The aircraft manufacturer's tests show that, with normal concentrations of dissolved and entrained (suspended) water present in aviation turbine fuel, ice can form around the inside of the fuel feed pipes. The accumulation of ice appears to be dependent on the velocity of the fuel and the fuel and environmental temperatures. The testing established that ice can accumulate in the fuel system when the fuel is at a temperature of +5°C⁷ (41°F),

Footnote

⁷ Ice will form when fuel at a temperature of +5°C is flowing through cold fuel pipes.

-12°C (10°F) and -20°C (-4°F), with ice appearing to accumulate at a lower rate at -20°C (-4°F). Whilst very little ice accumulates at -35°C (-31°F), ice which has accumulated at warmer temperatures will stay attached to the pipe walls as the temperature is reduced to -35°C (-31°F) with no apparent change in its properties. These results are consistent with the earlier 'beaker tests' undertaken by the aircraft manufacturer as well as previous research on the formation of ice in aircraft fuel systems. This work identified that there is a 'sticky range' between approximately -5°C (23°F) and -20°C (-4°F), where ice will adhere to its surroundings with ice being at its most 'sticky' at around -12°C (10°F).

The tests carried out in the environmental fuel test rig demonstrated that increasing the fuel flow can result in the release of a quantity of ice sufficient to restrict the fuel flow through the FOHE. An increase in the TAT, which occurs when the aircraft descends, results in an increase in the temperature in the strut, which the tests proved could also cause ice to be released from the fuel pipes in the strut area.

It was also evident, from all the fuel rig testing, that ice can move through the fuel feed system and under very low flow conditions might collect in areas such as the strut pipes, which form a low point when the aircraft is in its normal cruise attitude, and the LP pump inlet. However, it should be emphasised that the investigation did not identify any features in the aircraft fuel system which would cause a large enough concentration of ice to accumulate and cause a restriction.

Generation of ice

To overcome the difficulties in maintaining the water concentration in cold fuel, the aircraft manufacturer fitted a Perspex box around the boost pump inlet and introduced a mixture of warm fuel and water into the

cold fuel, through an atomising nozzle. Nitrogen was then blown across the nozzle to prevent the water freezing and blocking the holes. This produced ice crystals which had formed from a high concentration of entrained (suspended) water, which would then adhere to the inside of the pipes. On the accident flight, the ice crystals would have formed from a lower concentration of entrained water. Some of this entrained water would already be present in the fuel and some would have formed as dissolved water was released as the fuel cooled. These processes may produce varying sizes of water droplet which, with the different concentrations and agitation of the fuel, might influence the properties of the ice crystals and the ice which subsequently formed on the inside of the fuel feed pipes.

In the testing of the FOHE, on the fuel rig, the ice crystals were formed by injecting a mixture of water, at very high concentrations, and fuel directly into the boost pump inlet. These ice crystals would then travel at the same velocity as the fuel through the fuel system and collect on the face of the FOHE, causing a restriction of the fuel flow. However, it is not known if the properties of the ice generated in this manner are the same as the properties of the ice which might release from the inside of the fuel feed pipes. It is also not known if ice released from the inside of the fuel pipes travels through the system at the same velocity as the fuel.

Engine testing

The AAIB initial interim report of 4 September 2008 included an extensive description of the flight data recorded on the accident flight and the analysis. It also described the initial fuel system testing performed at the engine manufacturer.

Tests carried out by the engine manufacturer demonstrated that fluctuations in the P30 burner pressure, fuel flow and spool speeds, recorded on the FDR and QAR during the engine rollback on G-YMMM, were generally more closely matched when a restriction was placed in the fuel feed pipe approximately 25 feet or more from the aircraft to strut interface. These tests were carried out using warm, un-weathered⁸ fuel and with fixed 'restrictor' plates and the analysis could not, therefore, consider the dynamics of ice moving through the system, or possible changes in the porosity of the ice as it becomes compressed onto the face of the FOHE. Further, within the extensive testing to date it has not been possible to generate a restriction anywhere within the fuel system, other than at the boost pump inlet screens⁹ and on the face of the FOHE.

Engine oil temperature recorded data

If the fuel path in an FOHE becomes substantially blocked for any reason, then its heat transfer efficiency will become degraded. This is because the fuel has to flow down a greatly reduced number of tubes at a higher velocity to maintain the overall flow rate. This loss of efficiency would imply that the engine oil temperature should rise accordingly, such as was seen during the N862DA event. The oil temperature, which is sensed at the scavenge outlet, takes some time to register variations but experience has shown that the oil pressure sensor, which is sensitive to changes in viscosity due to temperature changes, is quicker to react.

During early analysis of the G-YMMM recorded data, attempts were made to interpret the oil temperature

parameters but this was hampered by the fact that the FDR records oil temperature and pressure at intervals of 64 seconds. The QAR samples at a faster rate - every two seconds - but, because of data buffering issues (outlined in the initial Interim Bulletin), QAR data was lost immediately after the left engine rolled back. It was concluded that no meaningful trend of oil temperature could be discerned at that time.

The data has been re-examined with respect to oil pressure. This showed that both left and right engines' oil pressure generally follow each other until the start of the final acceleration, which resulted in first the right and then the left engines rolling back. The left engine oil pressure rose, as expected, as the engine accelerated: the right engine oil pressure, however, started to decrease, even though the engine was also accelerating prior to its rollback. Whilst, this observation was based only on a few data points, it can be inferred that this was due to an oil temperature increase caused by a restricted FOHE and that the blockage occurred at, or close to, the start of the final acceleration. Unfortunately, the loss of QAR data so close to the left engine rollback meant that it was not possible to draw a similar conclusion for this engine.

Most likely scenario

Based on the available data, testing, and the analysis contained in the AAIB initial interim report, the investigation has established, that with a relatively low fuel flow, ice would start to form on the inside of the fuel feed pipes that pass through the main fuel tank whilst the centre tank was supplying fuel to the engines. When the main fuel tanks started to supply fuel to the engines, the temperature of the fuel in the main tanks was approximately -21°C (-6°F) and reduced over the following 5 hours to a temperature of -34°C (-29°F). During this period the rate that the ice accumulated in the

Footnote

⁸ Aviation fuel contains dissolved air some of which dissipates out of the fuel as the fuel temperature and fuel tank pressure decreases. This condition is called weathering, which is the condition of the fuel on G-YMMM at the time of the accident.

⁹ The icing of inlet screens is unlikely to have occurred on the accident flight.

pipes located in the main fuel tanks would have reduced as the fuel temperature moved out of the 'sticky range'; however it is likely, due to the warmer environment in the strut (engine pylon), that ice would have accumulated in the fuel feed pipes located in this area. Towards the end of the flight the rate that ice accumulated in the fuel feed pipes would change as the TAT and the fuel temperature increased.

It is considered that, in the later stages of the approach, the engine accelerations, and perhaps a combination of other factors such as turbulence, aircraft pitch changes and an increase in the strut temperature, could have contributed to a sudden release of soft ice in the fuel feed system for both engines. This ice would have travelled through the fuel feed pipes, where it could have formed a restriction on the face of the FOHE sufficient to cause the subsequent engine rollbacks.

Whilst this is considered to be the most likely cause of the engine roll backs on G-YMMM, and is consistent with data from the incident to N862DA, it has not been possible, due to limitations in the available recorded data, to totally eliminate the possibility that a fuel restriction, from ice, formed elsewhere in the fuel system which, in addition to an FOHE restriction, contributed to the engine roll backs on G-YMMM. It should be noted that extensive testing and data analysis has not identified any features elsewhere in the aircraft fuel system which would have caused a large enough concentration of ice to accumulate and cause a restriction.

In summary, the investigation has established that it is possible for sufficient ice to build up within the fuel feed system, such that its sudden release would cause a restriction at the FOHE sufficient to cause an engine rollback. Therefore:

Safety Recommendation 2009-028

It is recommended that Boeing and Rolls-Royce jointly review the aircraft and engine fuel system design for the Boeing 777, powered by Rolls-Royce Trent 800 engines, to develop changes which prevent ice from causing a restriction to the fuel flow at the fuel oil heat exchanger.

In response to Safety Recommendation 2009-028 Boeing and Rolls-Royce have stated that:

'Boeing and Rolls-Royce have accepted the above recommendation. To mitigate the potential for a future fuel system ice accumulation and release event, to cause a blockage at the inlet to the FOHE, Rolls-Royce have developed a modification to the FOHE. The modification will improve the FOHE's capability in the event of a fuel system ice release event.'

To ensure that changes as a result of Safety Recommendation 2009-028 are introduced onto in-service aircraft in a timely manner:

Safety Recommendation 2009-029

It is recommended that the Federal Aviation Administration and the European Aviation Safety Agency consider mandating design changes that are introduced as a result of recommendation 2009-028, developed to prevent ice from causing a restriction to the fuel flow at the fuel oil heat exchanger on Boeing 777 aircraft powered by Rolls-Royce Trent 800 engines.

The tests that have been carried out were all related to the Boeing 777 and Trent 800 fuel system. It is unknown if other airframe-engine combinations are susceptible to this phenomenon; therefore

Recommendation 2008-048 was made to EASA and the FAA in the initial interim report to address this concern.

Anti-ice additives in aviation fuel

Ice in aviation turbine fuel is an industry-wide problem and currently the mechanism by which it accumulates and is released within an aircraft and engine fuel system is not fully understood.

The military, and some business jet operators, have used anti-icing additives in aviation turbine fuel as a means of preventing ice from forming within the aircraft and engine fuel systems. The widespread use of such additives would reduce the risk from ice in fuel. However, its introduction worldwide would not only require changes to the infrastructure and ground fuel handling systems, but it could also lead to increased aircraft maintenance. Moreover, unlike the Boeing 777, not all aircraft are currently cleared to use existing anti-icing additives.

Despite the difficulties, the use of an anti-icing additive could significantly reduce, or even eliminate, ice formation in aviation turbine fuel. Therefore, to clarify the current issues:

Safety Recommendation 2009-030

It is recommended that the Federal Aviation Administration and the European Aviation Safety Agency conduct a study into the feasibility of expanding the use of anti-ice additives in aviation turbine fuel on civil aircraft.

Future industry activity

The formation of ice in aircraft fuel systems from dissolved and entrained water in aviation turbine fuel is well documented and is largely based on

observations and conclusions made during research projects undertaken in the 1950s. This research formed the basis of the SAE Aerospace Information Report (AIR) 790 and SAE Aerospace Recommended Practice (ARP) 1401, which advises the aerospace industry on suggested procedures to test aircraft fuel systems and components for icing.

This early research established that it is possible for ice to form from dissolved water, alone, in aviation turbine fuel which can then block filters and small orifices. A number of different types of ice were observed which was described as being 'slush ice' and 'soft white ice', which when melted contained between 10% and 30% water. During this period the United States Air Force (USAF) undertook research into the formation of ice in fuel and observed that not all the water droplets form ice crystals, but some of the water remains as supercooled droplets. The research concluded that the type of ice is dependent on a number of factors including the rate of cooling, water droplet size and the agitation of the fuel. It was also noted that the variation in fuel composition between batches of fuel affects the concentration and size of the water droplets and the amount of subsequent icing.

A solution to the early icing problems was to produce a remedy for the specific problem: fuel heaters and filter bypasses were introduced and the optimum mesh size for the boost pump inlet screens was determined. The USAF, like other military organisations, introduced Fuel System Icing Inhibitor (FSII), which can help to prevent the formation of ice.

Little is known about the properties of ice formed in aviation turbine fuel and, during the extensive testing undertaken by the manufacturer in this investigation, there was 'randomness' in the formation of ice, with

poor repeatability between batches of fuel with similar compositions.

Given the physical size of the Boeing 777 it was not practical to undertake a 'one pass' test of the fuel through a full scale system. Instead, as is current industry practice, for the tests cited in this report, part of the fuel system was tested by circulating the fuel through an external heat exchanger and storage tank. However, due to the cloudiness of the fuel it was not possible to visually monitor the formation of ice, nor was it always possible, using pressure sensors and temperature-measuring equipment, to determine whether ice was present. Consequently, it was not possible to detect the release and movement of ice through the fuel system without first draining out the fuel and then dismantling the system. Circulation of the fuel also makes it difficult to maintain the water concentration at levels experienced in flight. It is known, from previous research, that agitation and the rate of cooling of the fuel can affect the type of ice formed, and therefore there is uncertainty regarding the similarity of the properties of the ice generated during rig tests to the ice generated in flight.

In the testing of fuel systems at cold temperatures there are two aspects which need to be considered: fuel waxing and fuel icing. Whilst fuel waxing is determined by the temperature of the fuel, the risk from fuel icing is more complex. This investigation has established that the phenomenon, where ice can accumulate and then release, appears to be dependent on the time that the fuel temperature is in the 'sticky region', low fuel flow, environmental factors and aircraft attitude. It is considered that a combination of these factors would lead to the quantity of ice accumulating within the fuel system reaching a critical level.

Whilst the guidelines in SAE ARP 1401 and SAE AIR 790 recommend that ice testing should be carried out at various flow rates, and with the fuel temperature in the 'sticky range', they do not address the risk from ice accumulating throughout the fuel system and subsequently releasing. Consequently, there is no published guidance on the environmental conditions, or how much of the fuel system needs to be assembled in a test rig, to accomplish these fuel icing tests.

The investigation has established that the risk from fuel system icing is complex and is dependent on a number of interactions that are not fully understood. Much of the current industry guidance is based on research undertaken over 50 years ago and since that time civil aircraft have become larger, fly for longer periods and incorporate new technology and materials. In order to improve guidelines for the design and testing of aircraft fuel systems it will be necessary for the aviation industry, led by the regulatory authorities, to undertake a number of co-ordinated research projects. The first step would be to understand how ice forms in aviation turbine fuel and the properties of this ice. Therefore:

Safety Recommendation 2009-031

It is recommended that the Federal Aviation Administration and the European Aviation Safety Agency jointly conduct research into ice formation in aviation turbine fuels.

Research is also required to establish how ice accumulates in a fuel system and to establish the factors that may cause it to be released in a sufficient concentration to restrict the fuel flow. The results of this research can then be used to further develop the industry guidance on fuel system design, materials, and the development of test procedures for aircraft fuel systems. Therefore:

Safety Recommendation 2009-032

It is recommended that the Federal Aviation Administration and the European Aviation Safety Agency jointly conduct research into ice accumulation and subsequent release mechanisms within aircraft and engine fuel systems.

Further AAIB investigation

The investigation continues, including examination of the crashworthiness aspects of the accident, and further analysis is being carried out on fuel and engine data from other Boeing 777 aircraft. A final 'Inspector's investigation' report, ordered by the Chief Inspector of Air Accidents and covering all safety aspects of the accident, will be published in due course.

INCIDENT

Aircraft Type and Registration:	Avro RJ85, D-AVRJ	
No & Type of Engines:	4 Avco Lycoming LF 507-1H turbofan engines	
Year of Manufacture:	1996	
Date & Time (UTC):	21 April 2008 at 0650 hrs	
Location:	London City Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 4	Passengers - 37
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Minor damage	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	45 years	
Commander's Flying Experience:	10,000 hours (of which 7,000 were on type) Last 90 days - 150 hours Last 28 days - 50 hours	
Information Source:	AAIB Field Investigation	

Synopsis

An Avro RJ85 aircraft was parked on Stand 10 at London City Airport, with an Avro RJ100 parked to its left, on the adjacent Stand 11. Prior to taxiing, the RJ85 had been repositioned by a tug to gain sufficient wingtip clearance from the RJ100. This had the effect of reducing the tail clearance between the two aircraft, which was not identified. As the RJ85 taxied forward and to the right, its tail contacted the tail of the RJ100, causing minor damage to the RJ100's right elevator. The airport operator has taken safety actions to prevent such collisions in the future.

History of the flight

The two aircraft involved, an Avro RJ85, D-AVRJ, and an Avro RJ100, G-BZAT, were similar types and

derivatives of the BAe 146 series of aircraft. Both had a wingspan of 26 m. D-AVRJ had arrived from Munich and parked on Stand 10 at London City Airport under the guidance of a marshaller. Following a normal turnaround, the passengers were boarded and the engines started. The commander commented to his co-pilot that the RJ100 aircraft parked to the left, on Stand 11, appeared to be closer than normal. He therefore asked the marshaller to monitor his taxi off stand, paying particular attention to the left wingtip clearance. The aircraft's heading whilst parked was 338°(M).

The commander intended to turn initially to the right and then, once clear of the RJ100, to make a left turn

towards Holding Point Alpha. He taxied forward slowly and commenced a right turn, shortly after which the marshaller gave the 'stop' signal. The aircraft came to a stop on a heading of 013°(M). The marshaller connected his headset to the aircraft's intercom system and advised the commander that there was insufficient clearance between his aircraft's left wingtip and the right wingtip of the RJ100 on the left.

It was decided that D-AVRJ would be pushed back, to gain sufficient wingtip clearance, before taxiing again. A tug was attached and the aircraft was pushed back onto stand. The aircraft's heading was now 018°(M).

The tug was disconnected and the commander then began taxiing forward again. As before, he made a right turn under the guidance of the marshaller. Another airport staff member stood by the left wingtip to monitor the wingtip clearance with the RJ100. Shortly after commencing the taxi, the marshaller once again gave the 'stop' signal. During the right turn, the left horizontal stabiliser of D-AVRJ had moved to the left, passed under and then made contact with the right horizontal stabiliser of the RJ100, causing scoring of the RJ100's right elevator. The aircraft's final heading when stopped was 039°(M).

The sequence of events leading up to the collision is depicted in Figure 1.

Once aware of the situation, the commander of D-AVRJ shut down the aircraft. He kept the passengers on board to maintain weight on the aircraft and to prevent it from rising up on the landing gear oleos, which would have caused further damage. Additional ballast was then placed on the aircraft and the nosewheel tyres on the RJ100 were deflated to provide sufficient vertical clearance to allow the two aircraft to be separated

without causing further damage. The passengers were then disembarked.

Figure 2 shows a photograph of the contact between the two aircraft.

Aircraft initial positions

The RJ100 on Stand 11 had been parked 1 m to the right of the stand centreline but parallel to it, thus reducing the clearance from the RJ85, D-AVRJ, on Stand 10 by the same amount. D-AVRJ was initially parked on the stand centreline.

Airfield information

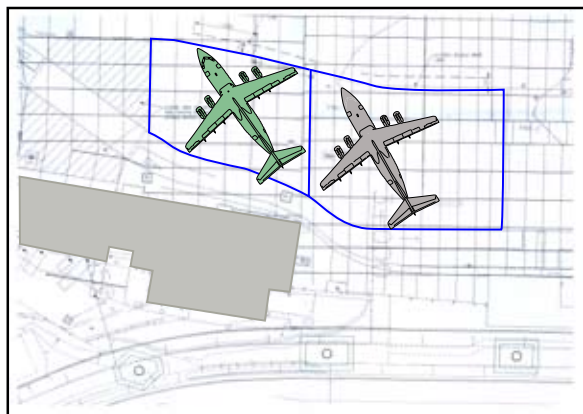
At the time of the incident there were 13 stands at London City (Figure 3). Stands 10 and 11 are smaller and non-uniform in shape when compared with Stands 1 to 9.

Stands 10 and 11 are approximately 38 m and 31 m wide respectively.

Airport operating procedures

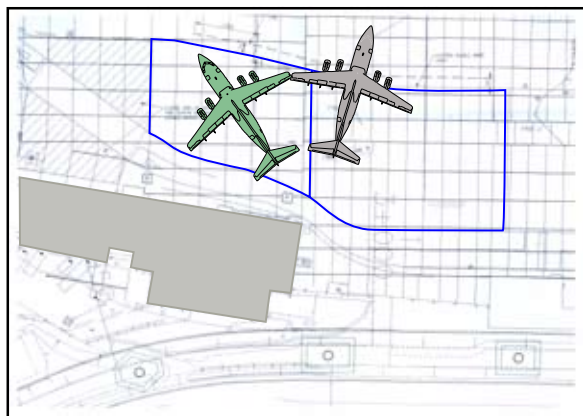
In 2005, London City Airport completed a programme of further development of the western apron. On 13 May 2005, an Operational and Safety Information Notice (OSIN) was issued, providing operating staff with comprehensive procedures for the movement of aircraft on Stands 11, 12, 13 and an additional Stand 14 that had not been developed.

Whilst 146/RJ-sized aircraft could self-manoeuvre onto and off Stand 10, only Dornier 328-sized aircraft were permitted to self-manoeuvre onto Stand 11, under the direction of a marshaller. Larger aircraft had to park on the taxiway, adjacent to Stand 11, and then be pushed back onto the stand using a tug and ground staff (GS) to monitor wingtip clearance.

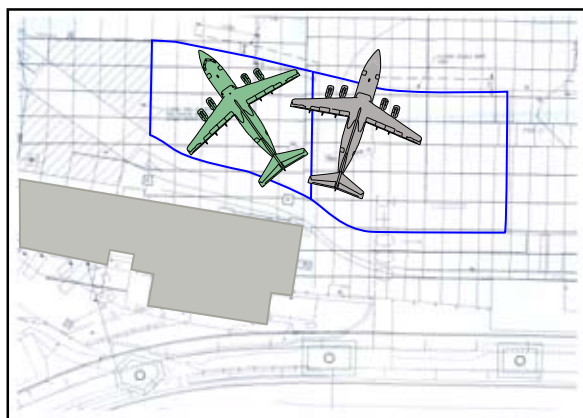


Location of the two parked aircraft.

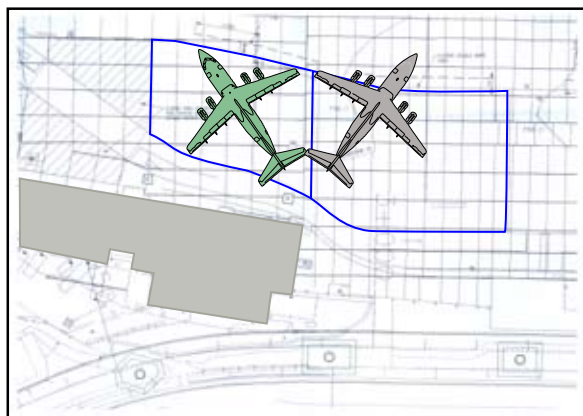
D-AVRJ is the aircraft on the right and is about to taxi off the stand



Position of the aircraft after the initial movement of D-AVRJ, which has stopped due to inadequate clearance between the left wing tip of D-AVRJ and the right wing tip of G-BZAT



Position of the aircraft after D-AVRJ has been pushed backwards by a tug to provide additional wing tip clearance



Position of the aircraft after D-AVRJ has taxied forward and contact has been made between the two horizontal tail planes

Figure 1

Sequence of events leading up to the collision



Figure 2

Photograph showing contact between D-AVRJ and G-BZAT

On 23 March 2007, the OSIN was updated to require GS to be provided to monitor wingtip clearance for an aircraft self-maneuvring off Stand 10 when another aircraft was parked on Stand 11. There was no requirement to monitor the tail clearance between similar types.

CAA Aerodrome Operating Standards requirements

Guidance for establishing aircraft parking stands at an airport is contained in Civil Aviation Publication (CAP) 168, Licensing of Aerodromes. The information pertinent to this incident is as follows:

'An apron is a defined area on a land aerodrome which is intended to accommodate aircraft for the purpose of loading or unloading passengers, mail or cargo, refuelling, parking or maintenance'

'An apron may be divided into stands in order to facilitate safe parking and movement of aircraft and people'

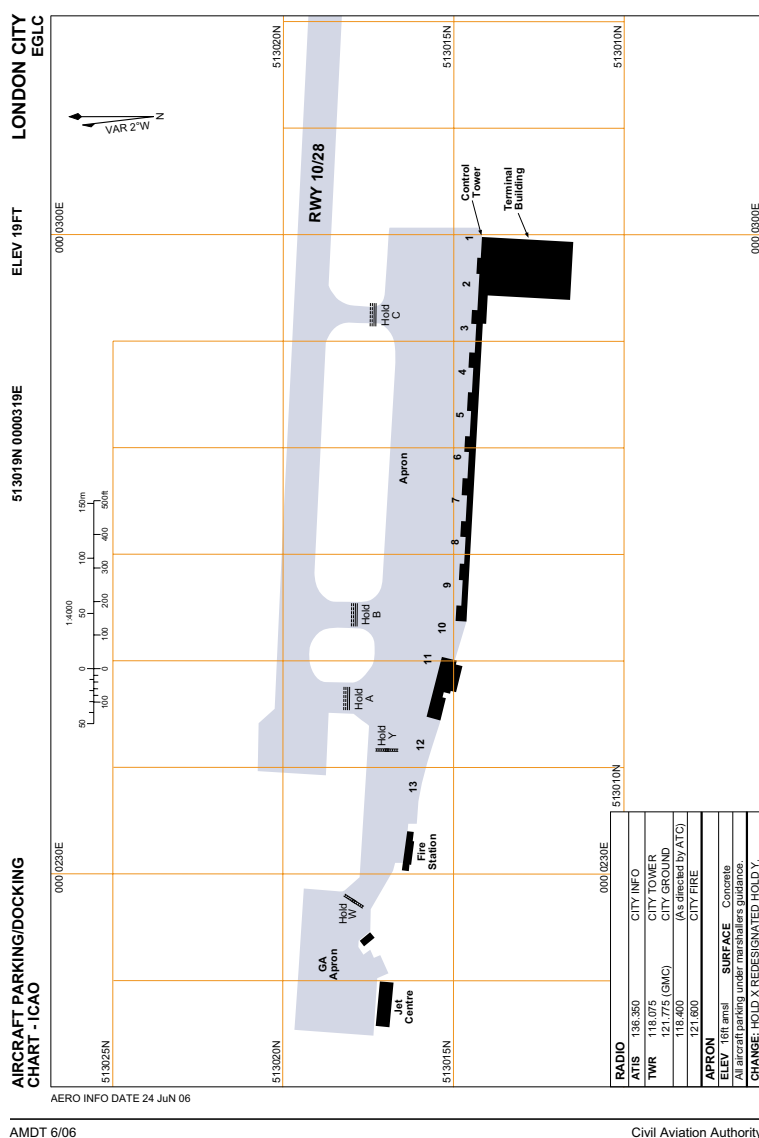
Size

'There should be room enough on the apron to provide for the number and types of aircraft expected to use it with adequate safety margins from obstructions including parked aircraft. The design of the apron should aim at facilitating the movement of aircraft and avoiding difficult manoeuvres which might require undesirable use of excessive amounts of engine thrust, or impose abnormal stress on tyres'.

'The dimensions of the apron should be such that the minimum clearance between a manoeuvring

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When taxiing off Stand 10, the commander of D-AVRJ commenced a right turn, to ensure sufficient clearance with the RJ100. The aircraft was stopped on a heading of 013°(M). The heading then increased further during the pushback to 018°(M). The net effect of this was to increase the wingtip clearance, whilst reducing the tail clearance between the two aircraft, which went unnoticed.

As D-AVRJ taxied forward again and turned to the right, its tail would have moved to the left, further reducing the tail clearance to the point where contact occurred.

The CAA guidance material in CAP 168 for establishing parking stands recommends that a manoeuvring aircraft should have a minimum clearance of 20% of the wingspan. For BAe 146/RJ aircraft with a wingspan of 26 m, the minimum recommended clearance is therefore approximately 5 m. When taxiing off Stand 10 with an aircraft on Stand 11, the clearance between two BAe 146/RJ or similar sized aircraft is reduced below this amount. The airport operator had addressed this potential hazard by introducing a requirement for a person to monitor wingtip clearance, but the possibility of tailplane contact had not been identified and thus no specific measures had been taken to prevent tail collisions.

Airport operator's safety actions

Following the incident, the airport operator introduced three safety actions to address the possibility of tail-to-tail contact between aircraft parked on Stands 10 and 11. These were:

1. *When a 146/135 aircraft is positioned on Stand 11 GS must provide wing-tip and tail fin observation for any aircraft self-maneuvring*

off of Stand 10. If for any reason the aircraft on Stand 10 is slightly out of parking alignment consideration must be given as to whether the aircraft should be towed off stand if an aircraft remains parked on Stand 11 during the departure.

2. *If the aircraft is to be towed off stand the GS marshaller must re-establish head set communication with the cockpit and all GS personnel undertaking wing tip/tail fin observation should also wear a headset to allow direct communications.*

3. *Operations will also endeavour to give consideration to which aircraft types are parked on Stand 10.*

Conclusion

The collision occurred due to a combination of the RJ100 on Stand 11 being parked 1 m to the right of its stand centreline, D-AVRJ on Stand 10 being pushed back onto a heading which further reduced the tail clearance, and the limited clearance between aircraft of this size when using these stands. The absence of a person monitoring the tail area meant that the inadequate tail clearance was not identified prior to the collision.

The safety actions already taken by the airport operator following this incident should reduce the risk of tail collisions between aircraft operating from Stands 10 and 11 at London City Airport. Therefore no Safety Recommendations are considered necessary.

INCIDENT

Aircraft Type and Registration:	Sikorsky S-76B Spirit, G-DPJR
No & Type of Engines:	2 Pratt & Whitney Canada PT6B-36B turboshaft engines
Year of Manufacture:	1989
Date & Time (UTC):	22 November 2007 at 0014 hrs
Location:	Approaching Coventry Airport
Type of Flight:	Commercial Air Transport (Non-Revenue)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Heat damage to plastic ducting and cabin trim
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	6,210 hours (of which 1,356 were on type) Last 90 days - 92 hours Last 28 days - 25 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional AAIB investigation

Synopsis

Whilst operating on a night positioning flight, the aircraft's auxiliary heater system overheated, melting the surrounding ducting and progressively filling the cockpit with smoke. The crew declared an emergency and expedited their landing. The smoke and heat subsided once the aircraft had been shut down on the ground. The electronic control box for the heater was removed and subsequently confirmed to have failed, probably disabling the overheat protection and cockpit controls for the system. One Safety Recommendation is made.

History of the flight

The aircraft was operating a positioning flight from Denham to Coventry, departing at 2345 hrs with the two pilots on board. The aircraft was established in the cruise some 30 miles from Coventry Airport when the PIC noticed an unusual smell which could not be identified. The crew began to troubleshoot the problem and switched off the heating system as a possible source. While the PIC continued to fly the aircraft, the second pilot used a torch to try and identify the cause of the rapidly increasing smell. As a precaution, at 15 miles out, the PIC made a PAN call to Coventry ATC, which was not acknowledged until the second attempt. At this point smoke began filling the aircraft and the PNF felt a hotspot developing to the left and rear of his seat. The

crew continued to attempt to isolate the problem, but there appeared to be no obvious issues with any of the electrical systems on board.

By this time the aircraft was about 8 miles from Coventry Airport. Given the increasing levels of smoke in the aircraft, the crew considered making an emergency landing, but decided it was safer to reach the airfield, where full fire cover had been placed on standby. As the aircraft crossed the airfield boundary, the pilot slowed the aircraft for an expedited landing, at which point the level of smoke increased significantly as did the level of heat below the left pilot seat. At 0013 hrs the PIC declared a MAYDAY and landed directly in front of the attending fire crew. The pilots then shut down the aircraft and evacuated immediately.

The attending fire crew monitored the aircraft and used a thermal imaging camera to confirm the source of the heat and smoke as being the ducting between the cabin and the cockpit on the left side of the aircraft. Eventually the smoke and heat dissipated and the aircraft was declared safe.

Aircraft examination

The cabin seating was removed and extensive heat damage was found around the auxiliary electric heater element located in the ducting on the left side of the aircraft. The plastic ducting had melted and the trim was severely scorched. Resistance checks of the heater element and thermistor did not identify any defects. The system control box was removed and sent to the vendor for further investigation. It was also noted that the vent blower circuit breaker had tripped. The vent blower is a fan located above the cabin which draws air from an external vent, through the heating ducts on either side of the aircraft to the cabin. These are the same ducts in which the auxiliary heating elements are located. The

vent blower circuit breaker was subsequently reset and no further failures have been recorded.

Controller examination

The controller was disassembled in the workshop by the manufacturer and several component defects were confirmed on the power supply circuit board. These would have resulted in a total system failure and shutdown of the controller during the incident.

Cabin environmental control system

The cabin Environmental Control System (ECS) is a modification for the S-76B which has been embodied in limited numbers across the world fleet. It provides an additional heat boost to the standard engine bleed air heating system by means of two 1,550 watt heating elements, located in the heating ducts on the right and left lower sections of the aircraft cabin. Electric fans are also installed next to each element to allow the auxiliary system to be used independently of the main bleed air system. A thermistor is located next to each of the elements to provide overheat protection. Two 'single-membrane' switches, located in the cabin and the cockpit, control selection of the heaters.

The system can be selected OFF, HI or LO. With LO selected the heating elements are set to half their rated power. The control panel in the cockpit overrides the cabin controls and allows the system to be armed such that the controls in the cabin become active, without the heaters necessarily being switched on. It also has OVERHEAT and FAN FAIL warning lights for each side of the cabin. The control box for the system is located in an equipment bay in the fuselage behind the cabin. Power to the heating elements is supplied via the aircraft 115 volt ac supply and the controller is powered by the aircraft 28 volt dc supply.

Analysis

Component failures within the control box for the cabin ECS resulted in the controller shutting down. This probably prevented operation of the left fan and the overheat protection system, but did not isolate power to the left heating element, which continued to operate. As a consequence of the lack of airflow over the heating element, the surrounding plastic ducting and trim overheated and generated smoke which slowly filled the cabin and cockpit of the aircraft. The crew were unable to isolate power to the heating element due to the loss of authority of the cockpit switches following the controller failure. As the aircraft slowed, the flow of ram air which had been flowing through the heating duct reduced and overheating of the ducting and surrounding trim became more severe. The resulting increase in smoke forced the crew to make an emergency landing.

Tripping of the circuit breaker for the vent blower may have been unrelated to the cabin ECS control box failure. However, the loss of the auxiliary system fan, in addition

to the vent blower, meant that the airflow through the duct was significantly reduced from normal operation, contributing to the severity of the overheat.

As the existing design does not provide for either automatic or crew-selected isolation of this system, the aircraft manufacturer has considered a number of options to resolve the issue. There are a limited number of these systems still in service and one option would be to disable these, pending a design change. The following Safety Recommendation is therefore made:

Safety Recommendation 2009-033

It is recommended that the Federal Aviation Administration require Sikorsky Aircraft to provide the flight crew with the means to isolate the 115 volt ac power supply to the auxiliary heater elements in the event of failure of the cabin Environmental Control System (ECS) controller fitted in S-76B helicopters, and that the power supply to the auxiliary heater is disabled until that means is provided.

ACCIDENT

Aircraft Type and Registration:	Luscombe 8A Silvaire, G-AKTN	
No & Type of Engines:	1 Continental Motors Corp A65-8 piston engine	
Year of Manufacture:	1946	
Date & Time (UTC):	24 December 2008 at 1345 hrs	
Location:	Clacton Airfield, Essex	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - 1 (Minor)	Passengers - N/A
Nature of Damage:	Buckled wings, damage to rear fuselage and cockpit area	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	44 years	
Commander's Flying Experience:	164 hours (of which 2 were on type) Last 90 days - 4 hours Last 28 days - 2 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The pilot, who had approximately 60 hours experience on tailwheel aircraft but only two hours on type, had completed a check flight on the Luscombe 8A a few weeks earlier. He reported that on this landing the aircraft had floated much longer than he had previously experienced and did not slow down as quickly as expected after touchdown. He applied the brakes towards the end of the landing roll, at an estimated speed of about 20 mph.

Initially there was no response, then the brakes locked up, pitching the aircraft over onto its back. Weather conditions at the time of the accident were good, with the wind variable at less than 5 kt and a QNH of 1029 mb. The pilot considered that the long float prior to touchdown and his inexperience on this type, which is not equipped with flaps, were contributory factors.

INCIDENT

Aircraft Type and Registration:	1) Piper PA-28-161 Cherokee Warrior II, G-LAZL 2) Rockwell Commander 112B Commander, G-IMPX
No & Type of Engines:	1) 1 Lycoming O-320-D3G piston engine 2) 1 Lycoming IO-360-C1D6 piston engine
Year of Manufacture:	1) 1981 2) 1976
Date & Time (UTC):	10 December 2008 at 0950 hrs
Location:	Old Sarum Airfield, Wiltshire
Type of Flight:	1) Private 2) N/A
Persons on Board:	1) Crew - 1 Passengers - None 2) Crew - None Passengers - None
Injuries:	1) Crew - None Passengers - None 2) Crew - N/A Passengers - N/A
Nature of Damage:	1) Damage to right wingtip 2) Damage to left aileron and flap
Commander's Licence:	1) Private Pilot's Licence 2) N/A
Commander's Age:	1) 61 years 2) N/A
Commander's Flying Experience:	1) 191 hours (of which 16 were on type) Last 90 days - 1 hours Last 28 days - 1 hours 2) N/A
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

G-LAZL was parked facing the left side of G-IMPX. The pilot of G-LAZL started the aircraft and, after conducting his initial checks, began to taxi the aircraft. He then undertook a brake check before commencing a turn to the left, to avoid G-IMPX. During the turn he realised

that his right wingtip would not clear G-IMPX's left wing and he attempted to tighten the turn, while applying the brakes and reducing the power to idle. Before he could bring it to a stop, G-LAZL's right wingtip struck the rear of G-IMPX's left aileron.

ACCIDENT

Aircraft Type and Registration:	Piper PA-28R-200 Cherokee Arrow II, G-AXCA	
No & Type of Engines:	1 Lycoming IO-360-C1C piston engine	
Year of Manufacture:	1969	
Date & Time (UTC):	4 October 2008 at 1215 hrs	
Location:	North Weald Airfield, Essex	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Damage to nose leg, cowling and propeller	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	43 years	
Commander's Flying Experience:	649 hours (of which 178 were on type) Last 90 days - 2 hours Last 28 days - 1 hour	
Information Source:	Aircraft Accident Report Form submitted by the pilot and engineering investigation conducted by the repair agency	

Synopsis

On landing the aircraft's nose gear collapsed. The pilot reports he had confirmed three green lights during gear extension and no gear unsafe warnings had been observed prior to touchdown. No failure of the gear could be identified by the repair agency after the incident.

History of the flight

The pilot was conducting a short flight from Southend Airport to North Weald airfield. The weather was fine, but with a wind of 18 kt from the southwest. The aircraft joined the circuit on the downwind leg and the pilot reported that he carried out his usual landing checks including lowering the gear and checking for three green

lights to indicate the legs were down and locked. He had experienced turbulence throughout the flight, but it became quite severe during the base leg of the circuit, to the extent that he hit his head on the roof of the aircraft. The pilot then continued to final approach and executed what he recalled as being "an exceptionally good landing" on the main gear, whilst maintaining a nose-up attitude with power and aft elevator. Shortly after the nosewheel contacted the runway the nose landing gear leg collapsed, bringing the propeller and front cowling into contact with the ground and slowing the aircraft quickly to a halt. The pilot then shut down the aircraft and exited normally. When the nose of the aircraft was

lifted during the recovery process, the nose gear leg extended without assistance.

Engineering examination

The aircraft was removed from the airfield and sent to a local repair agency. They reported that no failure could be identified on the gear or its retraction/extension system. A small amount of hydraulic fluid was found to be bypassing the hydraulic piston which actuates the gear up or down. This may have affected the time taken for the gear to extend and lock, but should not have prevented it from happening. The piston was replaced as a precaution. The three green landing gear indication lights were confirmed to be operating, though it had not been identified in the course of the repair work whether these or the gear red and amber warning lights were functioning correctly through a full retraction and extension cycle.

Nose gear description

The nose gear leg is hydraulically moved by a piston attached to an over-centre hinge. When fully extended this prevents the gear from retracting, until the piston is operated backwards again to the retracted position. A downlock hook also retains the gear in the down and locked position. The leg is braced by a drag strut which, when fully extended, prevents the nose leg from collapsing backwards when weight is applied. The gear is protected from inadvertent retraction on the ground by a 'squat' switch which isolates the hydraulic pump until the main gear leg is fully extended. In the cockpit there are three green lights which illuminate when the gear down limit microswitches are 'made'. There is an amber GEAR IN TRANS light and a red WARN GEAR UP light which illuminates when the engine manifold pressure drops below 14 in Hg and the gear is not in the down and locked position. There is also an associated configuration warning horn which sounds when the WARN GEAR UP light is illuminated.

Discussion

The pilot reported that he had observed three green lights when extending the gear on the downwind leg, but could not be certain that they were still illuminated on final approach. The down position microswitches, if correctly rigged, should not illuminate the green gear lights until the gear is down and locked. Once down and locked, the failsafe design of the nose gear should prevent it unlocking prior to a retraction command. Had the nose gear switch not 'made', a variety of warnings should have been seen and heard before the aircraft finally landed, which the pilot reports he did not experience during the accident.

Given the reported lack of a confirmed failure within the gear itself and the mechanical features which prevent the nose gear collapsing after it has locked, it is probable that the nose gear was not fully locked in the down position prior to the aircraft touching down on the runway. This may have been related to the minor fault identified in the hydraulic piston, although the severe turbulence experienced cannot be ruled out as a contributory factor. It could also have been associated with a late selection of the landing gear.

It is conceivable that the down limit microswitch on the nose gear may have been out of alignment, resulting in contact being made before the nose leg was fully extended. If the main gear switches had also 'made' at this point, then the hydraulic pump would have shut off, all three green gear lights would have illuminated and the gear unsafe warnings not activated, despite the nose leg not reaching its locked position. The repair agency has not, however reported finding any evidence of a misalignment of the microswitch during their repair work on the aircraft.

ACCIDENT

Aircraft Type and Registration:	Robinson R44 Raven II, G-IGJC	
No & Type of Engines:	1 Lycoming IO-540-AE1A5 piston engine	
Year of Manufacture:	2008	
Date & Time (UTC):	22 November 2008 at 1550 hrs	
Location:	Liverpool Airport	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 3
Injuries:	Crew - 1 (Minor)	Passengers - 1 (Minor)
Nature of Damage:	Aircraft damaged beyond economic repair	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	48 years	
Commander's Flying Experience:	104 hours (of which 21 were on type) Last 90 days - 20 hours Last 28 days - 17 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

When the collective was raised on takeoff the helicopter began to rotate quickly. Unable to regain control in flight the pilot lowered the helicopter to the ground where it rolled over.

History of the flight

The pilot and three passengers boarded the helicopter with the intention of conducting a local flight from the general aviation apron at Liverpool Airport. After completing normal starting procedures the pilot commenced the takeoff. In doing so, he raised the collective control more quickly than normal, causing the aircraft to lift very rapidly and yaw. Judging that the yaw was to the left the pilot applied right yaw pedal but with this input the helicopter span faster.

The pilot was thrown repeatedly against the right cockpit door during this manoeuvre and found it difficult to remain in his seat or control the helicopter. Because of the risk of colliding with parked aircraft nearby, he decided to lower the helicopter gently to the ground. He realised that this would probably result in it turning over. His next recollection was that the helicopter was lying on its left side with substantial damage to the rotor blades and left cockpit area. Pieces of the main rotor had also caused damage to the engine cowling of an aircraft parked approximately 100 m away.

Several witnesses went to assist the occupants, who vacated the aircraft through the topmost (normally the right) cabin door. The aerodrome fire and rescue service

also attended although, despite some fuel leakage, there was no fire. The pilot and one passenger received minor injuries and the others were unhurt.

Other information

Viewed from above, the main rotor of the R44 rotates anticlockwise. Consequently, in the absence of pilot inputs, the helicopter would tend to rotate clockwise (or to the right as viewed from the cockpit) as the collective was raised and power applied to the main rotor. Instructors familiar with the type commented that a swift upward application of the collective might cause considerable yaw to the right, but that this tendency could be controlled easily with the application of opposite (left) yaw pedal, even after rotation had developed.

The pilot stated that in retrospect he was not certain of the direction of yaw of the helicopter immediately after takeoff. An instructor with whom he discussed the

accident had heard from several witnesses that rotation had in fact been to the right. Other witnesses contacted by the AAIB were unable to recall the direction of rotation.

Technical records indicated that the aircraft had flown for 14 hours since receiving a scheduled maintenance inspection on 24 October 2008. The next check was due in 34 flying hours or on 23 April 2009, which ever occurred first. There was no record of any maintenance activity or mechanical defect that might have affected the accident.

Discussion

It is likely that the helicopter yawed right as the collective was raised. It might have been possible to recover the aircraft to controlled flight by applying left yaw pedal but application of right yaw pedal probably increased the rate of rotation.

ACCIDENT

Aircraft Type and Registration:	Mainair Blade, G-CEGM	
No & Type of Engines:	1 Rotax 582-2V piston engine	
Year of Manufacture:	1994	
Date & Time (UTC):	18 September 2008 at 1300 hrs	
Location:	Huthswaite (Baxby) Airfield, Yorkshire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - 1 (Serious)	Passengers - 1 (Minor)
Nature of Damage:	Damaged beyond economic repair	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	42 years	
Commander's Flying Experience:	468 hours (of which 46 were on type) Last 90 days - 69 hours Last 28 days - 13 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

The aircraft lost power shortly after takeoff and struck a hedge. The loss of power was probably caused by contamination of the fuel, which was of unknown age and origin.

History of the flight

On a previous visit to another airstrip the pilot had partially filled the fuel tank with motor gasoline (mogas) of unknown age and origin. On the day of the accident the aircraft was operating from the north-westerly grass runway at Huthswaite in Yorkshire with the pilot and one passenger on board. Shortly after takeoff, at a height of approximately 25 ft and with insufficient runway remaining to land the aircraft within the boundary of the airstrip, the engine

lost power. During the subsequent forced landing the aircraft struck a hedge at the end of the airstrip and was substantially damaged. Despite considerable fuel leakage there was no fire, but the pilot was seriously injured and taken to hospital by air ambulance. The passenger suffered only minor injuries.

Other information

The pilot operated this aircraft regularly from Huthswaite. The north-westerly runway is approximately 320 m long and bounded by hedges at both ends. A survey conducted by North Yorkshire Police immediately after the accident noted that the surface was mown dry grass approximately 5 cm long. The underlying surface was free from mud

and standing water and was mostly firm with softer patches sufficient to support road vehicles.

No official weather reports were available for the location but information from the pilot and police indicated that the day was “fine and dry” with no wind, good visibility and an air temperature at or below 15°C.

An examination of the engine conducted after the accident by the aircraft manufacturer revealed no evidence of a pre-existing mechanical defect. The carburettor contained some water, which may have collected during open storage of the wreckage prior to collection, and there was also a dark brown residue in the fuel filter which indicated some form of contamination.

Safety Sense Leaflet SSL04 - ‘*Use of Mogas*’, published by the Civil Aviation Authority, discusses the use of

motor gasoline in aircraft. Issues explored include the greater risk of carburettor icing and vapour lock and the importance of using fresh fuel from a supplier with high turnover of fuel supply. SSL04 can be obtained from the CAA and is available on their website at www.caa.co.uk.

The AAIB has previously reported on several occurrences in which the use of mogas may have been a factor.

Conclusion

The aircraft was serviceable prior to the accident and took off from a runway suitable for its operation. It is likely that the loss of power was caused by contamination of the fuel, which was of unknown age and origin.

ACCIDENT

Aircraft Type and Registration:	MW6-S (Modified) Merlin, G-MYIE	
No & Type of Engines:	1 Rotax 532 piston engine	
Year of Manufacture:	1993	
Date & Time (UTC):	21 September 2008 at 1430 hrs	
Location:	4 miles from City Airport Manchester	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - 1 (Minor)	Passengers - 1 (Minor)
Nature of Damage:	Damage to nose landing gear and fuselage	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	49 years	
Commander's Flying Experience:	180 hours (of which 9 were on type) Last 90 days - 3 hours Last 28 days - 3 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

The pilot was carrying out a local flight when the aircraft developed a tendency to drop its right wing. He elected to carry out a 'power on' forced landing, at a higher speed than normal, but, on touching down, the aircraft turned over and damaged its nose landing gear and fuselage.

The pilot considered that a dislodged flying control cable was the most likely cause of the wing drop. However, while it was being recovered from the field, the aircraft sustained further damage and, consequently, this could not be confirmed. The pilot and his passenger received minor injuries.

History of the flight

The pilot and his passenger were conducting a local flight from City Airport Manchester in good weather conditions. The pilot reported that he had been flying, without incident, for approximately 25 minutes when the aircraft developed a tendency to drop its right wing. Initially, he was able to recover the aircraft to straight and level flight using the flying controls but, after about four minutes, the right wing dropped again and his attempts to recover the aircraft to straight and level flight became progressively less effective. The pilot found that the tendency for the wing to drop was reduced by decreasing power but he was then unable to maintain altitude. He identified a suitable field for a forced landing, with power, and flew a steeper than normal approach to retain maximum control, accepting

a faster speed at touchdown. During the landing, the combination of the aircraft's speed and the rough stubble surface of the field caused the aircraft to turn over, damaging its nose landing gear and fuselage. The pilot and his passenger received minor injuries and exited the aircraft through the right door. There was no fire.



All three emergency services attended the accident site.

Aircraft information

The MW6-S is a conventional three axis aircraft fitted with ailerons, rudder and an elevator with an anti-balance/trim tab. It has a rigid structure with fabric-covered flying surfaces.

Conclusion

The pilot considered that the accident was probably caused by a dislodged control cable. However, during the recovery of the aircraft from the field it received further significant damage and it was not possible to establish whether the control cables had been correctly connected at the time of the accident.

INCIDENT

Aircraft Type and Registration:	Pegasus Quantum 15-912, G-BZMI	
No & Type of Engines:	1 Rotax 912 piston engine	
Year of Manufacture:	2000	
Date & Time (UTC):	13 September 2008 at 1820 hrs	
Location:	7 miles East of Sandy, Bedfordshire	
Type of Flight:	Training	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Front strut upper supporting bracket failed and monopole bent	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	54 years	
Commander's Flying Experience:	1,300 hours (of which 1,250 were on type) Last 90 days - 58 hours Last 28 days - 21 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot and AAIB inquiries	

Synopsis

The bracket which secures the front strut to the monopole had been orientated upside down. It subsequently failed in flight, causing the monopole to bend rearwards at the overcentre catch location. The pilot made a successful precautionary landing in a field.

History of the flight

The aircraft was kept in the hangar at the airfield with the wing removed from the trike. On the morning of the incident the aircraft was rigged and flown by two different instructors on six trial lessons and two training flights. During the eighth flight the instructor and student had performed six to seven 60° banked turns and

the aircraft was in a 30° banked turn to the right when they heard a loud 'bang'. The instructor reported that he could see that the bracket securing the top of the front strut to the monopole had failed and that the trike had adopted an attitude approximately 10° more nose-down than normal. He took control of the aircraft from the student and made a precautionary landing in a field.

Engineering investigation

The bracket¹ which connects the front strut to the monopole consists of a 'U' channel which is attached

Footnote

¹ Front strut channel upper ZCH-011.

to the monopole by an 8 mm (M8) bolt. The front strut is secured to the bracket by a keep pin and locking ring, and an over-sleeve assembly connects the bottom of the front strut to the lower strut assembly. To enable the wing to be fitted to the monopole, the monopole can rotate about its connection point on the trike keel. Once the wing has been fitted to the aircraft, the monopole is locked in position by an overcentre catch at the top of the seat frame.

On the incident aircraft both side faces of the bracket had failed where they join the rear face (Figure 1). The rear face of the bracket had also failed across the M8 securing bolt hole. The distortion of the bracket and the direction of failure of the side faces indicated that the bracket had been orientated upside down and had been pulled away from the monopole. There was also a dent in the rear face of the monopole adjacent to the overcentre locking catch and the monopole had bent

rearwards, about this point, by approximately 2°. The securing holes in the front strut and over-sleeve were all slightly elongated.

When the microlight is correctly rigged the front strut is aligned with the upper bracket (Figure 2).

When rigging the aircraft it is possible for the upper bracket to rotate about the M8 securing bolt, such that the bracket is then orientated upside down. During the investigation a bracket on another Quantum aircraft was orientated upside down and an attempt was made to fit the front strut without the wing attached to the monopole. With the bracket in this orientation the distance between the keep pin holes in the bracket and the lower strut assembly was greater than when the bracket was correctly orientated and it was not possible to fit the keep pins. However, the manufacturer has stated that with the wing fitted to the monopole, the



Figure 1

Failed front strut bracket on G-BZMI

structure can flex sufficiently to allow the pins to be fitted with the upper bracket orientated upside down. In this configuration the front strut would then be subject to a tensile preload when the monopole overcentre catch is moved to the engaged position.

Loading in front strut

On the Pegasus Quantum, the Centre of Gravity of the trike is forward of the monopole and in flight the lift loads from the wing are shared between the front strut and monopole, such that there is a tensile load in both of these structures. If the front strut should fail in flight, the front of the trike will drop and a rearwards bending moment will be applied to the monopole, causing it to bend rearwards at the overcentre catch location.

Previous occurrences

Bracket failure in flight

In 2006 a similar incident occurred in Australia when the bracket which secures the front strut to the monopole on a Quantum 912 failed whilst the pilot was carrying out steep turns. The pilot carried out a precautionary landing. The only other damage to the aircraft was to the monopole which had bent rearwards.

The aircraft manufacturer investigated the failure and concluded that the bracket had been fitted upside down. During that investigation, load tests were carried out on two brackets: one was incorrectly fitted and the second was fitted in the correct orientation. On the bracket which had been fitted upside down the rear face started to bow when a load of 310 kgf was applied and there was evidence of cracking along the side faces when the load reached 610 kgf. Both side faces



Figure 2

Correct orientation of bracket

subsequently failed when the load reached 640 kgf. On the bracket which had been correctly orientated there was evidence of very slight bowing of the rear plate when the load reached 750 kgf. However, at a load of 1,100 kgf, which was the maximum that could be applied by the test rig, there was no evidence that the bracket was about to fail.

The damage to the brackets which failed during the manufacturer's testing was very similar to the damage on the bracket which failed on G-BZMI.

Incorrect fitting of bracket

Following this incident the British Microlight Aircraft Association (BMAA) was informed by one of their members that he had also fitted and flown his Quantum with the bracket orientated upside down, although on that occasion the bracket had not failed. The AAIB was informed of other occasions when individuals had incorrectly orientated the brackets on the Quantum and other models of flexwing aircraft, but it had been noted by instructors and corrected before the aircraft were flown.

Safety actions

Immediately following this incident, the BMAA advised their inspectors and members owning Quantum aircraft of the consequences of flying with the front strut upper bracket orientated upside down. The aircraft manufacturer is considering introducing a modification to prevent the aircraft from being rigged with the bracket incorrectly orientated.

the aircraft manufacturer have shown that a correctly orientated bracket can sustain a load 2.25 times greater than a bracket that has been fitted upside down. When fitting the front strut it is likely that an additional tensile load was introduced into the incorrectly orientated bracket. It is probable that this additional tensile load, when combined with the flight loads, caused the bracket to fail in flight.

Comment

The evidence indicates that the incident occurred as a result of the aircraft being flown with the bracket orientated upside down. Calculations and tests by

BULLETIN CORRECTION

AAIB File:	EW/C2007/07/02
Wing:	Paramania Revolution 23
Paramotor Unit:	Modified H & E Paramotores R120 series
Date & Time (UTC):	8 July 2007 at 1950 hrs
Location:	Middle Barn Farm, Bexhill, East Sussex
Information Source:	AAIB Field Investigation

AAIB Bulletin No 2/2009, page 119 refers

In the Section of the published account titled ‘**Examination of damaged aircraft**’ the sentence appears:

‘The lift arms attached to this paramotor unit were not those originally fitted to it by the manufacturer and these arms had then been further modified.’

Since that time further information has become available to the AAIB demonstrating that the arms were those originally fitted to this paramotor unit. The sentence should, therefore, read:

‘The lift arms attached to this paramotor unit were those originally fitted to it by the manufacturer and these arms had then been further modified.’

FORMAL AIRCRAFT ACCIDENT REPORTS ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

2008

1/2008	Bombardier CL600-2B16 Challenger 604, VP-BJM 8 nm west of Midhurst VOR, West Sussex on 11 November 2005. Published January 2008.	5/2008	Boeing 737-300, OO-TND at Nottingham East Midlands Airport on 15 June 2006. Published April 2008.
2/2008	Airbus A319-131, G-EUOB during the climb after departure from London Heathrow Airport on 22 October 2005. Published January 2008.	6/2008	Hawker Siddeley HS 748 Series 2A, G-BVOV at Guernsey Airport, Channel Islands on 8 March 2006. Published August 2008.
3/2008	British Aerospace Jetstream 3202, G-BUVC at Wick Aerodrome, Caithness, Scotland on 3 October 2006. Published February 2008.	7/2008	Aerospatiale SA365N, G-BLUN near the North Morecambe gas platform, Morecambe Bay on 27 December 2006. Published October 2008.
4/2008	Airbus A320-214, G-BXKD at Runway 09, Bristol Airport on 15 November 2006. Published February 2008.		

2009

1/2009	Boeing 737-81Q, G-XLAC, Avions de Transport Regional ATR-72-202, G-BWDA, and Embraer EMB-145EU, G-EMBO at Runway 27, Bristol International Airport on 29 December 2006 and 3 January 2007. Published January 2009.
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