Farnborough House
Berkshire Copse Road
Aldershot, Hants GU11 2HH

Tel: 01252 510300
Telex: 858119 ACCINV G
Fax: 01252 376999

Air Accidents Investigation Branch

Department for Transport

# AAIB Bulletin S1/2008
# *SPECIAL*

**ACCIDENT**

| | | |
|---|---|---|
| **Aircraft Type and Registration:** | Boeing 777-236 ER, 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)<br>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)<br>Last 90 days - 85 hours<br>Last 28 days - 52 hours | |
| **Information Source:** | Inspectors Investigation | |
| | All times in this report are UTC | |

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 investigation

The Air Accidents Investigation Branch (AAIB) was informed of the accident at 1251 hrs on 17 January 2008 and the investigation commenced immediately. The Chief Inspector of Air Accidents has ordered an Inspector's Investigation to be conducted into the circumstances of this accident 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, 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 cooperating with the investigation and providing expertise as required and the CAA and the EASA are being kept informed of developments.

Because of the interest within the aviation industry, and amongst the travelling public, it is considered appropriate to disseminate the results of the initial investigation as soon as possible. This Bulletin is in addition to the Initial Report, published on 18 January 2008, and a subsequent update published on 23 January 2008. As the investigation has developed, additional data has been derived from non-volatile memory within specific systems of the aircraft. This has allowed previously reported data to be refined.

One Safety Recommendation has been made.

## History of the flight

The aircraft was on a scheduled flight from Beijing, China, to London (Heathrow) and departed Beijing at 0209 hrs; the flight was uneventful until the later stages of the approach into Heathrow. During the descent, from Flight level (FL) 400 the aircraft entered the hold at Lamborne at FL110; it remained in the hold for approximately five minutes, during which time it descended to FL90. The aircraft was radar vectored for the ILS approach to Runway 27L at Heathrow and subsequently stabilised on the ILS with the autopilot and autothrottles engaged. At 1,000 ft the aircraft was fully configured for the landing, with the landing gear down and flap 30 selected. The total fuel on board was indicating 10,500 kg, which was distributed almost equally between the left and right main fuel tanks, with a minor imbalance of about 300 kg. The fuel cross-feed valves indicated that they were closed and they had not been operated during the flight. The first officer took control for the landing at a height of approximately 780 ft, in accordance with the briefed procedure, and shortly afterwards the autothrottles commanded an increase in thrust from both engines. The engines initially responded but, at a height of about 720 ft, the thrust of the right engine reduced. Some seven seconds later, the thrust reduced on the left engine to a similar level. The engines did not shut down and both engines continued to produce thrust at an engine speed above flight idle, but less than the commanded thrust. The engines failed to respond to further demands for increased thrust from the autothrottles, and subsequent movement of the thrust levers fully forward by the flight crew. The airspeed reduced as the autopilot attempted to maintain the ILS glide slope and by 200 ft the airspeed had reduced to about 108 kt. The autopilot disconnected at approximately 175 ft, the aircraft descended rapidly and its landing gear made contact with the ground some 1,000 ft short of the paved runway surface just inside the airfield boundary fence. During the impact and short ground roll the nose gear collapsed, the right main landing gear separated from the aircraft and the left main landing gear was pushed up through the wing. The aircraft came to rest on the paved surface in the undershoot area of Runway 27L. A significant amount of fuel leaked from the aircraft after it came to rest, but there was no fire. The cabin crew supervised the emergency evacuation and all occupants left the aircraft via the slides, all of which operated correctly; eight of the passengers received minor injuries and one suffered a broken leg.

**Aircraft information**

The aircraft was serviceable on departure from Beijing and there were no relevant reported defects. It departed with 79,000 kg of Jet A-1 fuel on board, and the planned arrival fuel at London (Heathrow) was 6,900 kg.

**Weather**

The recorded weather at Beijing, prior to departure, indicated no significant weather and a surface temperature of -7ºC.

The aircraft's flight plan required it to climb initially to 10,400 m (FL341) before descending back to 9,600 m (FL315) at POLHO (on the border between China and Mongolia) because of 'Extreme Cold'. However, to accommodate a request from ATC the crew accepted a climb to a cruise altitude of 10,600 m (FL348), and closely monitored the fuel temperature. The ambient temperature at FL348 was approximately -65ºC and the associated total air temperature[1] (TAT) was -37ºC. Shortly after crossing the Ural mountains, the aircraft climbed to FL380. There was a region of particularly cold air, with ambient temperatures as low as -76ºC, in the area between the Urals and Eastern Scandinavia. The Met Office described the temperature conditions during the flight as 'unusually low compared to the average, but not exceptional'. The lowest TAT recorded during the flight was -45ºC, and the minimum recorded fuel temperature was -34ºC. The fuel temperature in flight must not reduce to a temperature colder than at least 3ºC above the fuel freezing point of the fuel being used. The specified freezing point for Jet A-1 fuel is -47ºC; analysis of fuel samples taken after the accident showed the fuel onboard the aircraft had an actual freezing point of -57ºC.

On arrival at Heathrow, the surface wind was from 210º at 10 kt, the visibility was greater than 10 km, the cloud was scattered at 800 ft and broken at 1,000 ft, the surface temperature was +10ºC and the dew point was +8ºC. The flight crew reported that they were visual with the runway at about 1,000 ft agl.

**Recorded data**

The aircraft was fitted with a Digital Flight Data Recorder (DFDR), a Cockpit Voice Recorder (CVR) and a Quick Access Recorder (QAR). The CVR and DFDR were successfully downloaded at the AAIB laboratories at Farnborough and both records covered the critical final stages of the flight. The QAR was downloaded with the assistance of British Airways and the equipment manufacturer. Data from the non-volatile memory of various systems were also available.

The recorded data indicates that there were no anomalies in the major aircraft systems. The autopilot and the autothrottle systems behaved correctly and the engine control systems were providing the correct commands prior to, during, and after, the reduction in thrust.

**Engineering examination**

The aircraft was recovered from the accident site to a

**Footnote**

[1] TAT is measured by a specially designed temperature probe, on the surface of the aircraft, that brings the air to rest causing an adiabatic increase in temperature. TAT is higher than static (or ambient) air temperature and is the value to which the fuel temperature will drift.

secure location for detailed examination. There were no indications of any pre-existing problems with any of the aircraft systems.

During the impact the right main landing gear separated from the aircraft rupturing the rear right wall of the centre fuel tank. The two front wheels of the right main landing gear broke away and struck the rear right fuselage penetrating the cabin at seat height adjacent to rows 29/30. Additionally, the right main landing gear damaged the wing-to-body fairing and penetrated the rear cargo hold, causing damage to, and leakage from, the passenger oxygen cylinders.

The engines, their control systems and the fuel system were the focus of a detailed examination.

*Engines*

Examination of the engines indicated no evidence of a mechanical defect or ingestion of birds or ice.

Data, downloaded from the Electronic Engine Controllers (EECs) and the QAR, revealed no anomalies with the control system operation. At the point when the right engine began to lose thrust the data indicated that the right engine EEC responded correctly to a reduction in fuel flow to the right engine, followed by a similar response from the left EEC when fuel flow to the left engine diminished. Data also revealed that the fuel metering valves on both engines correctly moved to the fully open position to schedule an increase in fuel flow. Both fuel metering units were tested and examined, and revealed no pre-existing defects.

Both engine low pressure fuel filters were clean. The fuel oil heat exchangers (FOHE) in both engines were free of blockage. The right FOHE was clear of any debris, however the left engine FOHE had some small items of debris on its fuel inlet bulkhead. The high pressure filters were clean. The variable stator vane controllers and the fuel burners were examined and found to be satisfactory.

Detailed examination of both the left and right engine high pressure fuel pumps revealed signs of abnormal cavitation on the pressure-side bearings and the outlet ports. This could be indicative of either a restriction in the fuel supply to the pumps or excessive aeration of the fuel. The manufacturer assessed both pumps as still being capable of delivering full fuel flow.

*Fuel system*

Several fuel samples were taken from the fuel tanks, pipe lines and filter housings prior to the examination of the fuel system and these are currently being examined at specialist laboratories. Initial results confirm that the fuel conforms to Jet A-1 specifications and that there were no signs of contamination or unusual levels of water content. A sump sample taken from the left and right main fuel tanks shortly after the accident revealed no significant quantities of water. Samples from the centre tank had been contaminated by fire fighting foam and hydraulic fluid: this contamination was a consequence of the rupture of the right rear wall of the centre tank.

A detailed examination of the fuel tanks revealed no pre-existing defects except for a loose union in the left main tank at its inner wall; the union formed part of the centre tank to left main tank fuel scavenge line. Some small items of debris were discovered in the following locations:

1. Right main tank – a red plastic sealant scraper approximately 10 cm x 3 cm under the suction inlet screen.

2. Left main tank, water scavenge inlet - a piece of black plastic tape, approximately 5 cm square; a piece of brown paper of the same size and shape, and a piece of yellow plastic.

3. Right centre tank override pump – a small piece of fabric or paper found in the guillotine valve of the pump housing.

4. Left centre tank water scavenge jet pump – small circular disc, 6 mm in diameter, in the motive flow chamber.

The relevance of this debris is still being considered. Examination of the fuel surge tanks showed no signs of blockage of the vent scoops and flame arrestors. Neither pressure relief valve had operated; the relief valves were tested and found to be operate normally.

The fuel boost pumps, and their associated low pressure switches, were tested and examined and found to be satisfactory. A pressure and suction test of the engine fuel feed manifold, from the fuel boost pumps to the engine, did not reveal any significant defects. Similarly, a visual examination of the fuel feed lines, using a boroscope, did not reveal any defects or restrictions. A test of the fuel quantity processor unit (FQPU) was satisfactory and its non-volatile memory did not reveal any defects stored prior to the accident. A test of the fuel temperature probe, located in the left main fuel tank, was satisfactory.

*Maintenance*

The aircraft's fuel tanks were last checked for water[2] in the fuel on the 15 January 2008 at Heathrow; this was prior to its refuelling for the outboard sector to Beijing.

Access by maintenance personnel, to the aircraft's fuel tanks, had last taken place during maintenance activity in 2005. The last scheduled maintenance activity on the aircraft was on the 13 December 2007.

*Spar valves*

On examination, both of the engine spar valves were found to be OPEN, allowing the fuel leak evident at the accident site.

The spar valves are designed to shut off the fuel supply to the engines following the operation of the fuel control switches or after operation of the fire handles in the cockpit. Their function is to cut off the fuel flow to the engine in the event of an engine fire or an accident. Each valve has two separate electrical wire paths which can be used to supply power to shut the valve; the first is via a run/cut-off relay, controlled by the fuel control switches, the other is directly from the fire handles.

The wiring on G-YMMM was as originally designed and manufactured, and such that when the fire handle was operated, it isolated the power supply to the run/cut-off relay. When tested, the run/cut-off relays for the left and right engines were still in the valve OPEN position, despite the fuel control switches being set to cut-off. The fire handles had also been pulled and the engine fire bottles had been fired. Therefore the fire handles had been operated prior to the fuel control switches.

The left spar valve circuit breaker (CB) had been tripped. This was due to damaged wiring to the valve as a result of the left main landing gear being forced upward through the conduit at the initial impact. The tripping of the CB meant there was no means of electrically closing the left spar valve. Similar damage was also evident to the right spar valve wiring, however, in this instance the CB had remained set.

**Footnote**

2 A check for water in the fuel tank is carried out by draining fluid from the sump drains located at the lowest point of each fuel tank in its 'on-ground' attitude.

Examination and tests of the wiring identified that, in the case of the right engine, the valve CLOSE wire from the run/cut-off relay was still continuous. This could have allowed the valve to operate had the fuel switch been operated before the fire handle.

Boeing had issued a Service Bulletin (SB 777-28-0025) which advised the splicing together of the wires for the fuel control switches and the fire handles to avoid the need to sequence their operation. An FAA airworthiness directive requires this SB to be completed by July 2010. This had not yet been incorporated on G-YMMM; however, had it been incorporated, the right spar valve should have closed when the fuel control switch was operated.

The evacuation checklist for the Boeing 777, issued by Boeing, shows operation of the fuel control switches to cut-off prior to operation of the fire handles. This sequence allows for both CLOSE paths to the spar valve to be exploited and increases the likelihood that the spar valves close before electrical power to the spar valves is isolated. However, if the fire handle is operated first, then only a single path is available.

The operator's evacuation checklist, for which Boeing had raised no technical objection, required the commander to operate the fuel control switches whilst the first officer operated the fire handles, this was in order to reduce the time required to action the checklist. These actions were carried out independently, with no measure in place to ensure the correct sequencing. The evacuation drill was placarded on the face of the control column boss, directly in front of each pilot.

An evacuation checklist with the division of independent tasks between the crew leaves a possibility that the fire handles could be operated before the fuel control switches which, with fire handle to spar valve wire damage, could leave the engine fuel spar shut-off valves in an OPEN position. This occurred in this accident, and resulted in the loss of fuel from the aircraft. This was not causal to the accident but could have had serious consequences in the event of a fire during the evacuation. It is therefore recommended that:

**Safety Recommendation 2008-009**

Boeing should notify all Boeing 777 operators of the necessity to operate the fuel control switch to cut-off prior to operation of the fire handle, for both the fire drill and the evacuation drill, and ensure that all versions of its checklists, including electronic and placarded versions of the drill, are consistent with this procedure.

Boeing has accepted this recommendation. On 15 February 2008 Boeing issued a Multi Operator Message, which advised operators to ensure that "evacuation and engine fire checklists specifiy that the fuel control switches are placed in the cut-off position prior to the operation of the fire handles". This advice only relates to those aircraft that have not had Boeing SB 777-28-0025 incorporated. Boeing also recommends that operators review their engine fire and evacuation checklists (Quick Reference Handbook, Electronic and Placard) to make sure that they are consistent with this advice.

**Continuing investigation**

Investigations are now underway in an attempt to replicate the damage seen to the engine high pressure fuel pumps, and to match this to the data recorded on the accident flight. In addition, comprehensive examination and analysis is to be conducted on the entire aircraft and engine fuel system; including the modelling of fuel flows taking account of the environmental and aerodynamic effects.

*Published February 2008*