SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 757-236, G-OOOZ
No & Type of Engines:	2 Rolls-Royce RB211-535E4 turbofan engines
Year of Manufacture:	1992
Date:	22 June 2009
Location:	En-route from Boa Vista, Cape Verde, to Manchester
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 8 Passengers - 230
Injuries:	Crew - None Passengers - None
Nature of Damage:	Engine fuel pipe ruptured
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	12,100 hours (of which 6,580 were on type) Last 90 days - 195 hours Last 28 days - 40 hours
Information Source:	Field Investigation, delegated by GPIAA, AAIB metallurgical examination of the ruptured pipe and extensive testing by the engine manufacturer

Synopsis

Approximately two hours into the flight, during a routine fuel check, the flight crew noticed a discrepancy in the fuel contents between the left and right tanks. They identified a fuel leak from the right engine, which was then shut down. The aircraft diverted to Porto Santo and landed without further incident. The passengers disembarked normally.

An investigation was initiated by the Gabinete de Prevenção e Investigação de Acidentes com Aeronaves (GPIAA) in Portugal. However, as the United Kingdom was the State of the Operator and the State of Design of the engine, the investigation was delegated to, and conducted by, the AAIB.

The cause of the fuel leak was a rupture in a section of flexible fuel pipe between the fuel cooled oil cooler (FCOC) and the High Pressure (HP) engine fuel pump. A redesign of the pipe is proposed by the manufacturer.

History of the flight

The flight was planned from Boa Vista, Cape Verde, to Manchester. At approximately 1820 hrs, passing reporting point BIMBO, approximately 202 nm north of Lanzarote, the crew carried out a fuel check which showed a fuel total 300 kg below the planned fuel quantity expected at this stage of the flight. The previous fuel check, 51 minutes earlier, had shown the fuel contents as slightly higher than planned. The co-pilot, who was the Pilot Handling (PH), re-checked the fuel calculations, and at this point noted that the centre tank contents had reduced to zero, an hour earlier than expected. The right fuel tank quantity also began reducing at a rate of around 300 kg per minute.

The flight crew checked the Quick Reference Handbook (QRH), and a visual inspection of the engine, carried out by the co-pilot from the cabin, did not reveal anything unusual. The right engine fuel flow was normal, however the right fuel tank contents were still reducing. A FUEL CONFIG message was displayed on the Engine Indicating and Crew Alerting System (EICAS), indicating a fuel imbalance. A second visual check of the engine by the co-pilot confirmed that fuel was leaking from the underside of the right engine nacelle.

The crew declared a MAYDAY and requested a diversion to Porto Santo (PXO) and they shut down the right engine as the aircraft descended through FL280. They informed the cabin crew and passengers of the situation and requested emergency services for their arrival at PXO.

The crew carried out a VOR approach to Runway 36 in good weather conditions and brought the aircraft to a stop on the runway without difficulties. No fire or abnormalities were noted by the AFRS personnel in attendance and the aircraft taxied to its stand. A fuel imbalance of 3,300 kg was noted at shutdown.

Post-flight examination revealed a rupture of a Low Pressure (LP) fuel pipe between the FCOC and the HP engine-driven fuel pump.

Engineering description

The fuel pipe, located on the right side of the engine (Figure 1), comprises an assembly of three rigid stainless steel tubes connected together by two flexible segments. The flexible segments have an inner core made of polytetrafluoroethylene (PTFE), within a closely fitting double-layer braided stainless steel sheath, enclosed within an outer silicone rubber sleeve to provide fire

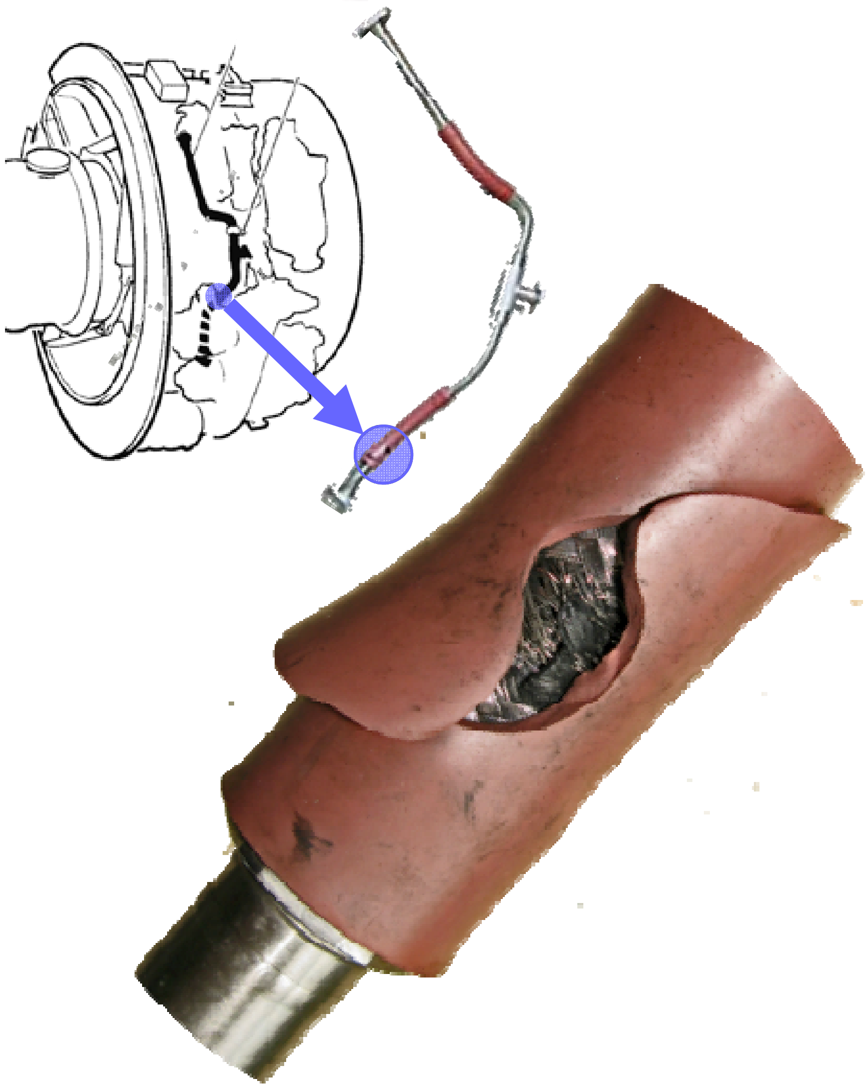


Figure 1

LP fuel pipe failure – G-OOOZ

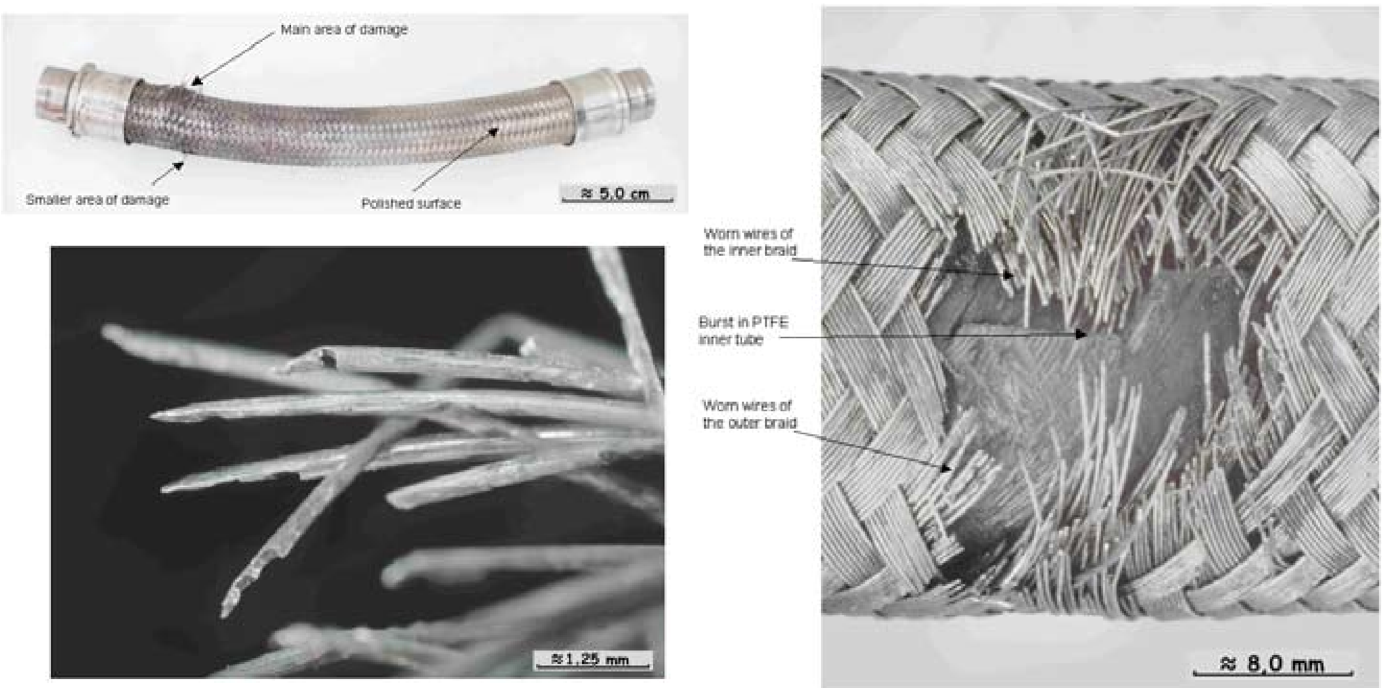
protection. The braiding consists of a weave of two strands; there are nine wires in each strand in the outer braid and eight wires in each strand in the inner braid.

In this design of flexible hose, pressure-induced hoop stresses in the wall of the inner PTFE tube are reacted primarily by the stainless steel braid; this type of design is common on a variety of applications operating at pressures significantly greater than those involved in this case.

The rupture in the segment of flexible hose had occurred close to the HP fuel pump inlet. The HP fuel pump has a gear-type design and there are two types of pump available which can be fitted to the engine, with different numbers of gear teeth.

Detailed analysis

Microscopic inspection of the rupture site revealed a pattern of localised but extensive inter-braid fretting in both the inner and outer braids. The stainless steel braid wires were worn and notched; the damage had been caused by relative movement between overlaying strands. In many cases this process had completely severed the wire strands (Figure 2). It was evident that the resulting loss of hoop integrity had left the inner core of the pipe unsupported, allowing the inner tube wall to rupture and burst through the compromised region of braid. Damage, probably caused by relative movement of the braid, was apparent to the outer surface of the PTFE core tube, sufficient to cause significant weakening.



Images courtesy Rolls-Royce

Figure 2

Detail of fuel pipe failure

Wear of the braid wire was evident throughout the length of the lower flexible hose; there was no evidence of similar wear on the upper flexible hose section.

Design history

At the time of the entry into service of the B757 in 1983, the design standard was a rigid pipe. In 1994 a tube with two flexible sections and simple flanged end fittings was introduced; in-service experience with tube failures at high operating hours (approximately 18,000 to 22,000 hrs) resulted in a recommended life of 15,000 hrs being introduced by Non Modification Service Bulletin (NMSB) 72-E355 in June 2004. Further failures, occurring below 15,000 hrs service, but high operating cycles, resulted in NMSB 73-E355 being revised in March 2009 to recommend a cyclic life limit of 4,750 cycles.

There is a repair approved by the engine manufacturer, Field Repair Scheme (FRS) 6887, which involves replacement of both flexible hose sections.

The engine manufacturer identified 11 previous events since June 1999, five of which had led to in-flight engine shutdowns. The failed tube from G-OOOZ had completed 5,986 hrs and 1,657 cycles, significantly below the current recommended life for the component. It was an original part and had not been subjected to rework.

Manufacturer's testing

The engine manufacturer proposed a series of engine runs on their test bed in order to investigate the effect of vibration and fuel pump pressure ripple levels on the fuel lines. Engine runs were carried out on both types of fuel pump in order to determine the magnitude and peak of any vibrations and pressures, and also whether there were particular engine running conditions which produced these peak levels. One of the pumps used in the test was that removed from G-OOOZ following the incident.

The results showed that the HP fuel pump created a 'pump ripple' in the operational speed range (85% to 95 % N3) and which decayed with axial distance from the fuel pump inlet. The pump ripple was present with either pump but the two pumps created different fundamental frequencies based on the number of gear teeth. The fuel pump from G-OOOZ produced the highest levels of pressure ripple, indicating that the wear mechanism would have been accelerated.

The pressure peak harmonics recorded during the test were found to be coincident with the peak acceleration data recorded in the fuel tube assembly. This confirmed that the maximum fuel tube vibrations occurred as a result of the fuel pump pressure harmonics (pressure ripple) effects.

Summary and safety action

The testing confirmed that the fretting which had led to the failure of the pipe was a result of high-frequency vibrations driven by the HP fuel pump pressure ripple. Extended time spent in the critical N3 speed range could accelerate the wear and the effect of an individual pump could cause additional variability in the time to failure.

From the history of previous events the associated risk assessment predicts an event rate of up to 1.5 per year, which would include minor leaks discovered on the ground. A hardware redesign has been initiated by the manufacturer with a design definition planned before the end of May 2011.