Boeing 737-436, G-DOCE

AAIB Bulletin No: 6/2004	Ref: EW/C2003/05/06	Category: 1.1
INCIDENT		
Aircraft Type and Registration:	Boeing 737-436, G-DOCE	
No & Type of Engines:	2 CFM56-3C1 turbofan engines	
Year of Manufacture:	1991	
Date & Time (UTC):	30 May 2003 at 1630 hrs	
Location:	In flight near Lyon, France	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew - 6	Passengers - 128
Injuries:	Crew - None	Passengers - 7 (Minor)
Nature of Damage:	Burnt wiring loom	
Commander's Licence	Air Transport Pilots licence	
Commander's Age:	34 years	
Commander's Flying Experience:	8,000 hours (of which 1,500 were on type)	
	Last 90 days - 100 hours	
	Last 28 days - 40 hours	
Information Source:	AAIB Field Investigation	

Synopsis

Whilst in the cruise the crew began to feel some discomfort in their ears. This was shortly followed by the cabin altitude warning horn which indicated that the cabin altitude had exceeded 10,000 feet and this was seen to continue to climb on the cockpit gauge. At the same time, the primary AUTO mode of the pressure control failed, shortly followed by the secondary STBY mode. The crew selected the first manual pressure control mode, but were unable to control the cabin altitude. An emergency descent and subsequent diversion to Lyon was carried out. The failure of the pressurisation control system was traced to burnt electrical wiring in the area aft of the aft cargo hold. The wiring loom had been damaged by abrasion with either a p-clip or 'zip' strap that, over time, resulted in the conductors becoming exposed, leading to short circuits and subsequent burning of the wires. There was no other damage. The wiring for all the modes of operation of the rear outflow valve, in addition to other services, run through this loom.

History of flight

G-DOCE was being operated from Marseille, France, to London Gatwick Airport (LGW). The initial stages of the flight had been without incident but a few minutes into the cruise, when at FL340, the crew felt discomfort in their ears, followed by the sounding of the cabin altitude warning horn. The crew checked the overhead pressurisation control panel (PCP) and confirmed that the cabin altitude was indeed climbing. At this stage the pressurisation primary AUTO control system failed, which was indicated to the crew by the illumination of the AUTOFAIL light, and the system automatically switched to its first back up system (STBY). The STBY light illuminated to indicate this but a few seconds later, the light extinguished, indicating that all automatic pressurisation control systems had now failed. The crew then selected the first manual control system, MAN AC. Despite operating the toggle switch, which directly controls the rear outflow valve (OFV), the position indication in the cockpit showed that it was fully closed with no apparent response to the control inputs. As a result, the crew put on their oxygen masks and initiated an emergency descent at 6,000 fpm to quickly attain an aircraft altitude below 10,000 feet. The aircraft then diverted to Lyon, France.

On arrival at Lyon several passengers were treated with ear and sinus problems as a result of the depressurisation. An investigation by the operator into the cause of the failure was initiated at Lyon. No circuit breakers (CBs) were found tripped and the OFV was operable in both the STANDBY and the MAN DC modes, although the OFV position indication to the cockpit was faulty. It was confirmed that the valve could not be operated in either AUTO or MAN AC.

The aircraft was ferried back to LGW in an unpressurised state with all the pressure control system CBs tripped and the OFV in the open position. After the flight to LGW, entries were made in the aircraft's technical log stating that the aft drain mast heater CB had tripped in flight and that when the CB was reset, it tripped again immediately.

Pressurisation System

The Boeing 737-400 cabin pressure control system is used to control the air outflow from the pressurised section of the fuselage, in flight, so that the cabin altitude is kept at a level suitable for the passengers and crew. Also, the difference between the pressure in the cabin and the ambient air is kept below a specified limit for structural considerations. This is achieved mainly by the use of the rear OFV, which bleeds air from the cabin in a controlled manner, and provides a balance between the inflow of air from the air conditioning system and the air outflow. (Additionally, a forward OFV is installed, but this is either in the open or closed position and is not modulated by the pressure control system.) To achieve this, the rear OFV is fitted with two motors, one DC powered, the other AC powered. In normal operation the single pressure controller operates in AUTO mode, which controls the OFV AC motor on the OFV with the positional feedback signal derived from a potentiometer. If the AUTO mode senses a problem, such as the cabin altitude rising in excess of 1,900 sea level feet per minute (slfpm) the controller automatically changes over to the back-up STBY mode, and this is indicated to the flight crew by AUTOFAIL and STBY lights on the PCP.

In STBY mode, the pressure controller still automatically controls the OFV, but now uses the back-up DC motor to modulate the valve. Control of the cabin pressurisation is then based on inputs of differential pressure and cabin rates of climb/descent which the crew provide via the PCP. If the STBY mode should then fail, indicated by the STBY light extinguishing, there are still two back up manual modes of operation. In these modes the crew have direct control of the OFV position, via a toggle switch on the PCP, with reference to the OFV position indicator, cabin pressure gauge and differential pressure gauge. Manual control is either via the AC motor (AC MAN), previously used by the AUTO mode, or the DC motor (DC MAN) previously used in the STBY mode. OFV position feedback is signalled from the same potentiometer as when the system is operated under automatic control.

If the cabin altitude exceeds 10,000, feet a warning is given to the crew but if the cabin altitude continues to climb to over 14,000 feet, oxygen masks in the passenger cabin will automatically deploy.

Quick Access Recorder Data

G-DOCE was equipped with a quick access data recorder which, amongst the recorded parameters, was a signal derived directly from a cabin pressure sensor. This data showed that the cabin altitude had stabilised during the climb at approximately 7,000 feet and, some 43 seconds after the aircraft had reached its cruise level of FL340, that the cabin altitude began to climb rapidly. Within seven seconds this had reached an altitude in excess of 10,000 feet and the cabin altitude warning was signalled at this point. The cabin altitude continued to climb and reached a maximum of approximately 11,000 feet. As the aircraft made an emergency descent, at about 6,000 fpm, the cabin altitude also began to descend, indicating that there was a measure of control over the cabin pressure. The aircraft eventually levelled off at 7,000 feet with a cabin altitude around -1,000 feet.

Engineering Investigation

After the aircraft's arrival at LGW, the OFV was replaced. Whilst this was being carried out it was noticed that the over-pressure relief valve, on the left hand side of the airframe, had insulation blanket material trapped inside its mechanism, indicating that it had operated to prevent an excessive pressure in the fuselage at some point in the past. This valve was also replaced and a check for damage, following an over pressurisation event, was also carried out. No damage was found, except for a blow-out panel, which had dropped down in the aft cargo hold.

The replacement of the OFV failed to rectify the problem, and so the next course of action was to replace the pressure controller. The system, however, remained inoperative. The associated wiring was now inspected and it was during this check it was discovered that a wiring loom had became overheated and burnt. This was in an area just aft of the aft cargo hold where the wires ran across the top of the cargo hold but below the cabin floor. The burning damage on the loom extended from a 'p-clip', over a length of about 2 inches. In the centre of the damaged area was a 'zip' loom retaining strap, which had melted, and all damage was limited to the wiring loom, p-clip and 'zip' strap, shown in Figure 1. The wires were removed and the AAIB were then informed of the findings.

Figure 1: Loom damage

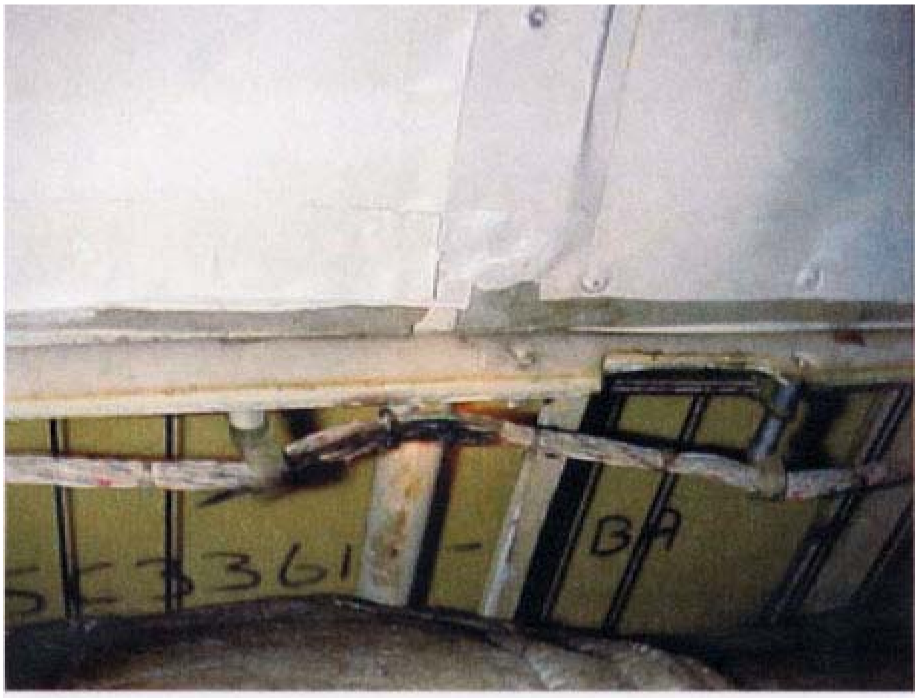

Figure 1 Loom Damage

The wire loom that was damaged, W298, contained all the wires between the pressure controller and the OFV. This meant that the wiring associated with all four modes of operation was included in the same loom. Wires which connected to the aft drain mast heater, the aft door warning system and the water tank quantity system were also routed in this loom, and these wires carried either 28V DC, 115V AC, a signal voltage, or were grounded (earthed).

The wires were collected and subjected to a detailed examination. In addition to the wires being examined, the units removed during the troubleshooting process were also sent for testing at the operators overhaul facility. No reported faults were found with the OFV. The pressure controller, however, failed the bench tests and this was attributed to damaged diodes in the AC motor feedback circuit for the AUTO mode. The over-pressure valve, despite ingesting the insulation blanket material, tested satisfactorily once the blanket material had been removed.

Wiring loom examination

The wires contained within the failed area of the loom were all marked with the wire specification W51F, which relates to Boeing Material Specification BMS 13-51F. The wires were constructed of multi-stranded copper conductors that were insulated with two layers of a fluropolymer coated aromatic polyimide tape (Kapton).

The damaged wires were examined in detail, in conjunction with the AAIB, by a specialist organisation. It was concluded that the failure had most likely been initiated by long term fretting of the wire bundle at a fixed point in the aircraft, such as a 'p-clip' or 'zip' strap. The fretting had resulted in abrasion of the cable jacket and insulation, and exposure of the conductors, with subsequent short circuits leading to failures of the associated circuits and burning of the loom. The initiating area of the failure could not be established due to the damage, but copper deposits on the 'p-clip' indicated that it started either close to, or within, the 'p-clip' area. There was no evidence of 'carbon arc tracking'.

Maintenance Records

From the maintenance records, the last time that the area of the failure would have been disturbed was during the aircraft's last major service, 7C, completed in December 2001. This was also the last time the area of the failure would have had a routine surveillance inspection, which includes wiring, as required by the aircraft maintenance schedule. There were no defects recorded during this major service to indicate any problem with the wiring.

Analysis

From the evidence it is clear that the de pressurisation event on G-DOCE resulted directly from a wiring failure in a loom at the rear of the aft cargo hold. The initiation of the failure was probably due to fretting of the wiring insulation against a 'p-clip' or 'zip' strap, which allowed the conductors to become exposed and short to each other. It is likely that this allowed erroneous signals to be sent to the OFV, causing it to start to open, thus increasing the cabin altitude. The AUTO system then failed and passed control to the STBY system. However, as the cabin altitude continued to climb, the STBY light extinguished which indicated that this system had also failed. As the wires for the STBY system run through the same loom as those for the AUTO system, it was likely that an erroneous signal was picked up by the pressure controller, causing it to fail the back-up system. AC MAN was then selected but, as the OFV AC feedback wire was damaged, the indicator on the PCP appeared to show that the valve was closed and not responding to any switch inputs, whereas the valve was probably operating. The QAR data showed that the OFV must have been partially closed, as the cabin pressure remained in excess of ambient during the ensuing descent; if the valve had remained in the position associated with the de-pressurisation, the cabin altitude would eventually have matched the aircraft altitude.

The quick actions of the crew to recognise the pressurisation failure and to initiate a descent prevented the cabin altitude climbing over 14,000 feet and thus prevented the automatic deployment of the cabin oxygen system masks. The injuries sustained by several passengers were relatively minor and would have been related to the initial rapid decrease in cabin pressure when the OFV opened in response to a false signal.

The results of the wiring loom examination revealed that its failure was most likely triggered by the abrasion of the insulation of two or more of the affected wires. This may have been caused by the 'p-clip' or the loom 'zip' straps in response to normal vibration and associated movement of the loom, especially if they had not been correctly installed. It is also possible that the loom may have been damaged whilst maintenance was carried out in the area, and this may have started the process which led to the conductors being exposed.

The insulation blanket material that had become trapped in the over-pressure relief valve indicated that the aircraft had suffered an excess pressure event at some point in the past. This could possibly have been due to the failing wiring causing the OFV to initially close and raise the cabin pressure above normal, but there was no evidence that this had actually occurred. During the Certificate of Airworthiness air test at some point prior to this de-pressurisation, pressure in the fuselage would have been deliberately raised to check the function of the over-pressure relief valves. It is possible that during this test the blanket material was ingested and that it had remained undetected as these valves are not clearly visible from the outside of the aircraft.

Thermal/mechanical CBs do not necessarily operate when wires short together or to ground and the wisdom of not attempting to re-set such CBs (as was reported with the drain mast heater CB on G-DOCE) on systems that are not essential for safe continued flight is generally accepted. To do so risks, potentially, adding energy into a failure situation, thereby possibly turning a contained situation into a critical one that may be associated with multiple systems failures and/or fire. Early detection of wiring faults involving arcing, and rapid isolation of the affected systems, should be achievable with the use of the 'arc fault interrupters' now being developed. However, potential problems presently remain with such devices from unwanted interruption, especially from a common-mode perspective.

Safety Recommendations

This incident on G-DOCE has highlighted the problem of routing of the wiring for redundant systems, in this case the primary (AUTO) and secondary (STBY) systems for control of the aircraft's pressurisation, in the same loom. This defeats the object of having such alternative systems should a single point failure of the wiring loom occur.

The close proximity of wiring looms in most aircraft also render them vulnerable to collateral damage from a loom wiring failure, where molten copper is likely to be sprayed over adjacent looms, thereby degrading the benefits of physically segregating wires. This subject was addressed in AAIB report AAR 5/2000, which concerned a loom failure in a B767-332ER aircraft precipitated by maintenance induced damage. A relevant section of this report is reproduced below:

> *'Installed wires are required to conform to codes of separation in order to enhance system survivability. These separation codes are intended to ensure that the critical functions of redundant power systems, and/or flight essential systems, are preserved by preventing all redundant channels of the same system from being damaged by a single threat event. The effects of electrical wiring faults are thus intended to be minimised, with isolation of fault damage and prevention of propagation between redundant systems.'*

The failure on G-DOCE rendered the pressurisation control system unusable, as far as the crew were concerned, and caused a relatively rapid decompression, with consequent injuries to passengers. Although the pressurisation system may not be considered a 'flight essential system', in the sense that loss of this system does not render the aircraft unflyable and flight crew procedures are in place to cope with such an event, the potential for crew incapacitation and injuries to passengers exists. Had the wiring for the AUTO and STBY pressurisation mode commands, and the position feedback wire, to the OFV been suitably separated, then it is less likely that the failure of one loom would have resulted in the effective failure of all control modes. The following recommendation is therefore made:

Safety Recommendation 2004-33

It is recommended that in order to prevent failure of the cabin pressure control system in the event of damage to wiring loom W298, the Boeing Commercial Airplanes should consider, on the Boeing 737-436 and similarly configured models, separating or protecting the wiring associated with the different modes of operation of this system, which connects the cabin pressure controller to the rear outflow valve, such that any single point failure of the loom would not result in effective failure of the pressurisation control system.

This incident has highlighted airworthiness issues which reflect broader concerns on all aircraft types regarding wiring condition, particularly as aircraft age, modifications are introduced and maintenance carried out. These broader concerns are addressed in the overview document included in this issue of the AAIB Bulletin.