Log 2309

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 28, 1991

In reply refer to: A-91-83 and -84

Honorable James B. Busey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 13, 1991, United Airlines (UAL) maintenance personnel were unable to electrically open the aft cargo door on a Boeing 747-222B, N152UA, at John F. Kennedy Airport (JFK), Jamaica, New York. The airplane was one of two used exclusively on nonstop flights between Narita, Japan, and JFK. This particular airplane had accumulated 19,053 hours and 1,547 cycles at the time of the occurrence.

The airplane was being prepared for flight at the UAL maintenance hanger. An inspection of the circuit breaker panel revealed that the C-288 (aft cargo door) circuit breaker had popped. The circuit breaker, located in the electrical equipment bay just forward of the forward cargo compartment, was reset, and it popped again a few seconds later. A decision was made to defer further work until the airplane was repositioned at the gate for the flight. The airplane was then taxied to the gate under its own power and work on the door resumed.

The aft cargo door was cranked open manually, the circuit breaker was reset, and it stayed in. The door was then closed electrically and cycled a couple of times without incident. With the door closed, one of the two "cannon plug" (multiple pin) connectors was removed from the J-4 junction box located on the upper portion of the interior of the door. The wiring bundle from the junction box to the fuselage was then manipulated while readings were taken on the cannon plug pins using a volt/ohm meter. Fluctuations in electrical resistance were noted. When the plug was reattached to the J-4 junction box, the door began to open with no activation of the electrical door open switches. The circuit breaker (C-288) was pulled and the door operation ceased. When the circuit breaker was reset, the door continued to the full open position, and the lift actuator motor continued to run for several seconds until circuit breaker C-288 was again pulled. At this time, a flexible copper conduit which covered a portion of the wiring bundle was slid along the bundle toward the J-4 junction box, revealing several wires with insulation breaches and damage.

UAL personnel notified the National Transportation Safety Board of the occurrence, and the airplane was examined at JFK by representatives of the Safety Board, United Airlines, and Boeing. After the wires in the damaged area were electrically isolated, electrical operation of the door was normal when the door was unlocked. When the door was locked (master latch lock handle closed), activation of the door control switches had no effect on the door. This indicated that the S2 master latch lock switch was operating as expected (removing power from the door when it was locked). The S2 switch is located on the lower end of the cargo door, and first movement of the lock sectors toward the locked position opens the switch and interrupts the 28 volt control power to the interior and exterior cargo door control switches. After the on-site examinations, the wiring bundle was cut from the airplane and taken to the Safety Board's materials laboratory for further examination.

The wiring bundle with the damaged wires contains all electric control wires (28 volt DC) and power wires (115 volt AC) that pass between the fuselage and the aft cargo door. From the forward side of the J-4 junction box, the bundle progresses in the forward direction, just above the forward pressure relief door, then upward, following the forward lift actuator arms. The bundle then enters an empty space between two floor beams, where the bundle has an approximate 180-degree bend when the door is closed. From this location, the wiring bundle progresses inboard, through a fore-to-aft intercostal between two floor beams. The wiring bundle then splits, with wires going in several directions. The bundle is covered by the flexible conduit approximately from the lower end of the lift actuator arms to the fore-to-aft intercostal between the floor beams.

The conduit covering the wiring bundle is a sealed flexible interconnector consisting of a convoluted helical brass innercore covered by a bronze braid. The innercore is soldered at every other convolute, and should be capable of withstanding pressures exceeding 1000 psi. Boeing has indicated that the conduit is an evolutionary improvement and has been installed on all 747 airplanes produced since 1981 (line number 489 and on). Airplane N152UA was delivered in April 1987.

Examination of the wires in the damaged area on the wiring bundle revealed that four of the wires were similar in appearance, with insulation breaches that progressed through to the underlying conductor. Adjacent to the breach on these four wires, the insulation was blackened, as if it had been burned. Another wire contained an extensive breach but no evidence of burned insulation. The damaged area was located on the bundle at a position approximately corresponding to a conduit support bracket and attached standoff pin on the upper arm of the forward lift actuator mechanism. This support bracket was bent in the forward direction. In addition, mechanical damage was noted on adjacent components in this area.

A second damaged area was noted on the wiring bundle at a position approximately corresponding to the conduit swivel clamp at the elbow between the two arms of the forward lift actuator mechanism. Wires in this area were missing portions of their exterior coating, but no breaches to the underlying conductors were noted.

The exterior braid on the conduit contained minor rub marks and was slightly kinked at a position corresponding to the area on the wires with breached insulation. Additional examinations revealed that the innercore of the conduit contained multiple circumferential cracks in the areas corresponding to the damage areas on the wires. The cracks were in the convoluted innercore directly adjacent to the inside diameter of the conduit.

The lock sectors, latch cams, and latch pins from the aft cargo door were examined on the incident airplane and were generally in excellent condition. There was no evidence to suggest that the cams had ever been electrically (or manually) driven into or through the lock sectors.

The Boeing Company has also informed the Safety Board that, in May of 1991, a 747 operated by Quantas was found to have chafing of the wires in the wiring bundle to the aft cargo door. This airplane also had a flexible conduit protecting the wires, and the chafing was located approximately at the standoff pin on the bracket at the upper arm of the forward lift actuator. Boeing is gathering additional facts on that incident.

The Safety Board believes that the chafing of the wires on the 747 airplane involved in the JFK occurrence is caused, or is greatly accelerated by, the circumferential cracks in the conduit and that the cracks in the conduit are caused either by repeated flexing of the conduit as the cargo door opens and shuts or by unusual stresses on the conduit generated concurrently with damage to the conduit guide bracket and attached standoff pin on the upper end of the forward lift actuator upper arm. Also, the Safety Board is concerned that there may be additional 747 airplanes with chafed wires within the flexible conduit for the aft cargo door, and that there is a possibility that these chafed wires may send an unintended signal to the actuator motors to open the door. Although the improved steel lock sectors should be capable of preventing a properly locked door from opening, the Safety Board believes that all reasonable precautions should be taken to ensure that chafed wires in the aft cargo door wiring bundle do not produce unintended electrical signals to the door operating mechanism.

A portion of the wiring bundle for the forward cargo door on many 747 airplanes is also covered by a flexible conduit that is very similar to the conduit for the aft cargo door. However, there are substantial differences between the orientation of the flexible conduits for the two doors, and the Safety Board is not aware of problems associated with the flexible conduit for the forward door. Nevertheless, the conduit for the wiring bundle for the forward cargo door is also subjected to repeated flexing and the Safety Board is concerned that it may also develop damage similar to that found on the airplane involved in the JFK occurrence.

Because of the concerns expressed in this letter, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Issue an Airworthiness Directive applicable to all Boeing 747 airplanes with a flexible conduit protecting the wiring bundle between the fuselage and aft cargo door to require an expedited inspection of:

(1) the wiring bundle in the area normally covered by the conduit for the presence of damaged insulation (using either an electrical test method or visual examination);

(2) the conduit support bracket and attached standoff pin on the upper arm of the forward lift actuator mechanism;

(3) the flexible conduit for the presence of cracking in the convoluted innercore.

Wires with damaged insulation should be repaired before further service. Damage to the flexible conduit, conduit support bracket and standoff pin should result in an immediate replacement of the conduit as well as the damaged parts. The inspection should be repeated at an appropriate cyclic interval. (Class II, Priority Action)(A-91-83)

Evaluate the design, installation, and operation of the forward cargo door flexible conduits on Boeing 747 airplanes so equipped and issue, if warranted, an Airworthiness Directive for inspection and repair of the flexible conduit and underlying wiring bundle, similar to the provisions recommended in A-91-83. (Class II, Priority Action)(A-91-84)

Chairman KOLSTAD, Vice Chairman COUGHLIN, and Members LAUBER, HART, and HAMMERSCHMIDT concurred in these recommendations.

Sincerely,

James L. Kolstad
Chairman

Log 2352

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 9, 1992

In reply refer to: A-92-21

Honorable Barry L. Harris
Acting Administrator
Federal Aviation Administration
Washington, D.C. 20591

On February 24, 1989, United Airlines flight 811, a Boeing 747-122 (B-747), N4713U, was operating as a regularly scheduled flight from Los Angeles, California, to Sydney, Australia, with intermediate stops in Honolulu, Hawaii, and Auckland, New Zealand. There were 3 flight crewmembers, 15 flight attendants, and 337 passengers aboard the airplane.[1]

The flightcrew's first indication of a problem was while the airplane was climbing between 22,000 and 23,000 feet at an indicated airspeed of 300 knots. They heard a sound, described as a "thump," which shook the airplane. This sound was followed immediately by a "tremendous explosion." The airplane had experienced an explosive decompression. Power was lost from the Nos. 3 and 4 engines because of damage from foreign object ingestion.

The airplane made a successful emergency landing in Honolulu, and the occupants evacuated the airplane. An examination of the evidence at the time revealed that the forward lower lobe cargo door had separated in flight, causing

[1]For more detailed information, read Aviation Accident Report--"Explosive Decompression--Loss of Cargo Door in Flight," United Airlines, Flight 811, Boeing 747-122, N4713U, Honolulu, Hawaii, February 24, 1989, (NTSB/AAR-92/02; supersedes NTSB/AAR-90/01)

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extensive damage to the fuselage and cabin structure adjacent to the door. As a result, nine of the passengers were ejected from the airplane and lost at sea.

A year after the accident, the Safety Board was uncertain whether the cargo door would be located and recovered from the Pacific Ocean. Therefore, the Board decided to proceed with a final report based on the available evidence without the benefit of an actual examination of the door mechanism. The original report was adopted by the Board on April 16, 1990, as NTSB/AAR-90/01.

Subsequently, on July 22, 1990, a search and recovery operation was begun by the U. S. Navy with the cost shared by the Safety Board, the FAA, Boeing Aircraft Company, and UAL. The operation was supported by U.S. Navy radar data that had tracked the separated cargo door, underwater sonar equipment, and a manned submersible vehicle. The effort was successful, and, on September 26 and October 1, 1990, the cargo door was recovered in two pieces from the ocean floor at a depth of 14,200 feet.

Before the recovery of the cargo door, the Safety Board believed that the door locking mechanisms had sustained damage in service prior to the accident flight to the extent that the door could have been closed and appeared to have been locked, when in fact the door was not fully latched. This belief was expressed in the original report and was supported by the evidence available at the time. However, upon examination of the door, the damage to the locking mechanism did not support this hypothesis. Rather, the evidence indicated that the latch cams had been back-driven from the closed position into a nearly open position after the door had been closed and locked. The latch cams had been driven into the lock sectors that deformed so that they failed to prevent the back-driving.

There are only two possible means for the latch cams to have been back-driven: electrically or mechanically. Examination of the cargo door manual latch cam drive port revealed that the decal installed over the drive port had been damaged by the forces of the door separation and the fall into the ocean. Close examination of the decal revealed that it had not been compromised by the insertion of a manual drive tool. Consequently, the only other possibility for the condition of the latch cams and lock sectors was that the latch actuator had been electrically activated after the door had been properly closed and locked.

The Safety Board attempted to determine if an electrical short circuit in the cargo door circuitry had caused the latch actuator to operate and drive the latch cams open. Analysis of the door wiring circuits and routing revealed certain wire pairs that could power the latch actuator if the wires shorted to each other. There were more possibilities for short circuits if the master latch lock handle S2 switch had failed in the "not locked" position. Moreover, if the S2 switch had failed, momentary actuation of the door switch to the open position by ramp personnel could have driven the latch cams open,

Examination of the electrical wires recovered with the cargo door revealed no evidence of arcing; however, tests indicated that even if arcing had occurred, such evidence might not be readily apparent. Unfortunately, not all of the electrical wires for the door were recovered from the ocean floor. As a result, the precise manner of electrical back-driving of the latch cams could not be determined.

Further evidence that electrical short circuits could have been the reason for this accident resulted from the June 13, 1991, incident at JFK Airport in which another UAL B-747's cargo door opened without actuation of the "door open" switch. Examination of that airplane revealed breaches in the door wiring insulation and a short circuit that caused the door latch cams to move uncommanded after the lock handle was pulled and the S2 switch closed.

The Safety Board remains convinced that the modifications per AD-88-12-04 to the B-747 cargo door lock sectors to prevent the latch cams from opening are valid and provide protection to preclude the inadvertent opening of a cargo door. However, the unacceptable and catastrophic nature of the loss of a cargo door in flight from a transport-category airplane requires redundant protection against a failure of the mechanical protection. Therefore, the Safety Board believes that switches or relays should be included in door power and control circuits to deactivate the electrical power to such cargo doors after they are properly closed, latched, and locked. Of course, the indicating systems to alert flight and groundcrews to the condition of the doors should remain active.

As a result of the recovery and examination of the cargo door, the Safety Board's original analysis and probable cause were modified. The Safety Board's report adopted on March 18, 1992, (NTSB/AAR-92/02) incorporates these changes and supersedes AAR-90/01.

Therefore, the National Transportation Safety Board determines that the probable cause of this accident was the sudden opening of the forward lower lobe cargo door in flight and the subsequent explosive decompression. The door opening was attributed to a faulty switch or wiring in the door control system which permitted electrical actuation of the door latches toward the unlatched position after initial door closure and before takeoff. Contributing to the cause of the accident was a deficiency in the design of the cargo door locking mechanisms, which made them susceptible to deformation, allowing the door to become unlatched after being properly latched and locked. Also contributing to the accident was a lack of timely corrective actions by Boeing and the FAA following a 1987 cargo door opening incident on a Pan Am B-747.

As a result of its investigation of this accident, the Safety Board issued Safety Recommendations A-89-92 through -94 and A-90-54 through -64 addressing measures to improve the airworthiness of the B-747 cargo doors and other nonplug doors on pressurized transport-category airplanes, as well as recommendations affecting cabin safety.

As a result of its subsequent findings following the recovery and examination of the cargo door, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require that the electrical actuating systems for nonplug cargo doors on transport-category aircraft provide for the removal of all electrical power from circuits on the door after closure (except for any indicating circuit power necessary to provide positive indication that the door is properly latched and locked) to eliminate the possibility of uncommanded actuator movements caused by wiring short circuits. (Class II, Priority Action) (A-92-21)

Acting Chairman COUGHLIN and Members LAUBER, HART, HAMMERSCHMIDT, and KOLSTAD concurred in this recommendation.

By: Susan M. Coughlin
Acting Chairman

Overview: Incidents resulting from damage to electrical wiring

Contents

Introduction

A number of accident and incident reports in recent years have identified causal factors that include electrical arcing and damage to aircraft wiring. Significant accidents include a Boeing 747-131, N93119, near East Moriches, New York on July 17, 1996 (TWA 800 - NTSB/AAR-00/03), a Boeing 767-322ER N653UA at London Heathrow Airport on 9 January 1998 (AAIB/AAR 5/2000) and McDonnell Douglas MD-11 HB-IWF near Peggy's Cove, Nova Scotia on 2 September 1998 (Flight 111 - Canadian Report Number A98H0003). Ageing and maintenance related wiring incidents continue to occur despite, generally, an enhanced awareness of the problems associated with aircraft wiring systems. Four such incidents are presented together in this issue of the AAIB Bulletin; all feature damage to electrical wiring and identify similar causal factors. Although each incident may be read as a stand alone report, this overview document draws together the common issues and makes four additional Safety Recommendations. The four incidents are as follows:

EW/C2002/11/02	Boeing 737-436, G-DOCH	8 November 2002
EW/C2003/05/06	Boeing 737-436, G-DOCE	30 May 2003
EW/C2003/06/03	Concorde Type 1 V102, G-BOAC	13 June 2003
EW/C2003/07/07	Boeing 737-300, G-LGTI	30 July 2003

The Ageing Transport Systems Rulemaking Advisory Committee

Background

In 1996, the US President established the White House Commission on Aviation Safety and Security (WHCSS) which recommended that '*In co-operation with airlines and manufacturers, the FAA's ageing aircraft programme should be expanded to cover non-structural systems*.' The Commission was concerned that existing requirements, procedures, maintenance practices and inspections may not be sufficient to prevent safety related problems caused by the deterioration of aircraft systems, including wiring, as aircraft get older. The findings from this Commission formed the basis for the FAA Ageing Transport Non-Structural Systems Plan. This acknowledged that both maintenance and design issues should be investigated and, in January 1999, the FAA chartered an advisory committee, the Ageing Transport Systems Rulemaking Advisory Committee (ATSRAC), which included members from the FAA, DoD, NASA, JAA and industry. ATSRAC's primary task was *'to propose such revisions to the Federal Aviation Regulations (FAR) and associated guidance material as may be appropriate, to ensure that non-structural systems in transport airplanes are designed, maintained, and modified in a manner that ensures their continuing operational safety throughout the service life of the airplanes.'* The initial priority was given to electrical wiring systems.

Visual inspection was carried out on a number of in-service aircraft types and showed *'deterioration of electrical wire, wire bundles, earthing leads, clamps and shielding. Items such as improper clamp sizing, inadequate clearance to structure and accumulation of dust or debris were also common. Isolated cracking of outer layers of multi-layer electrical insulation and corroded electrical connectors were also found. The majority of the wiring discrepancies were found to be in areas of frequent maintenance activity, or related to housekeeping. Fluid contamination, dust and dirt accumulations were seen on the wiring on most of the aircraft.'*

In light of these findings, a number of areas were identified as meriting attention; these included new design requirements to mitigate known problems due to ageing, which will cover wire accessibility provisions and wire selection, and wire installation to minimise strain and to provide protection from damage.

A draft FAA Advisory Circular (AC), dated 15 July 2002, was produced which provides guidance on changes to existing maintenance practices and analysis methods which could be applied to both in-service aircraft and new design, to ensure adequate consideration of the potential deterioration of electrical wiring systems. An important element of this AC is an enhanced zonal analysis procedure (EZAP), which has been adopted into the latest revision of the Air Transport Association of America (ATA) Maintenance Steering Group (MSG) guidelines, MSG-3. This AC also identifies protection and caution information to be added to maintenance instructions designed to minimise contamination and accidental damage to electrical wiring whilst working on aircraft.

Another draft AC, dated 2 August 2002, provides guidance to manufacturers, operators, maintenance organisations and repair stations for developing an effective wiring systems training programme. This AC promotes the philosophy of training for all personnel who come into close proximity with wiring as part of their job and proposes tailoring of the training for each workgroup according to their needs. It also gives guidance on all essential elements of both initial and recurrent wire training programmes.

A further draft AC, dated 31 October 2002, gives advice on developing an electrical systems standard wiring practices manual. The information in this AC is derived from maintenance, inspection, and repair best practice and promotes a common format and minimum content for documents containing standard practices for electrical wiring.

ACs provide guidance material and the FAA proposes to publish all these ACs in the Federal Register.

The FAA is also proposing publishing the Notice(s) of Proposed Rulemaking (NPRM), by January 2005, for the package of 'ageing systems' Rules. Existing Type Certificate holders are likely to be given 24 months after the Rule goes into effect for completion of the EZAP analyses, development of the required inspection and maintenance instructions, and their incorporation into the Instructions for Continued Airworthiness. Operators would then have a further 12 months to incorporate the required inspection and maintenance instructions into their maintenance procedures and initiate EZAP according to the enhanced maintenance programme. To ensure early attention to the three areas identified by ATSRAC as being of particular importantance, ATSRAC advised the FAA to require a one-time cleaning and inspection of the cockpit, Electrical & Equipment bay, and power feeder cables within five years after the rule goes into effect. However, in order to avoid unnecessary increases in maintenance downtime, the FAA are considering not to require a one-time cleaning and inspection of these areas. Instead, these areas would receive the required attention at the appropriate periods defined by the EZAP analyses.

In further work conducted under ATSRAC, there is a general objective to develop strategies for technology transfer and implementation of the FAA research and development (R&D) products into the aviation community. The initial focus will be on Ageing Circuit Breaker recommendations and Arc Fault Circuit Breaker implementation.

European Ageing Systems Coordination Group

On 28 September 2003 the European Aviation Safety Agency (EASA) came into being and assumed responsibility for the certification and continued airworthiness of most aircraft manufactured and operated within the European Union. This responsibility includes continued airworthiness of all aircraft types covered by the ATSRAC work. The JAA, working on behalf of EASA, have recently started the European Ageing Systems Coordination Group (EASCG), which has the task of transcribing all the ATSRAC proposals into the European arena. The UK CAA chairs the EASCG, and it is highly likely that material in the FAA ACs will be adopted for use throughout the EU.

Damage to wiring

The visual inspections carried out by ATSRAC showed that aircraft wiring deteriorates with time and, particularly, in areas subject to high levels of maintenance activity. This is reflected in the incident to G-BOAC, where the airworthiness issues highlighted are not limited to Concorde, which is no longer in service, but reflect broader concerns on all aircraft types regarding wiring maintenance, particularly as aircraft age and modifications are introduced. The possibility for a wire to chafe was introduced during a maintenance input two years prior to this incident, when the wiring was last disturbed. This ultimately led to a short duration in-flight fuel fire.

Similar factors were identified in the incident to a B737, G-DOCH, where a maintenance input led to the mis-routing of the water supply line. This resulted in abrasion between the wires and the hose, and in the shorting and severing of a number of the wires. The hose was too long for this application and the excess length had been looped through the overhead area and then secured by a tie-wrap to adjacent wire bundles. It was most likely that that this was simply a short-term expedient while systems were being disconnected and disassembled and that the 'temporary' tie-wrap was then missed during reassembly.

Loss of the pressurisation system on another B737, G-DOCE, resulted from the abrasion of the insulation of two or more wires in the affected loom. As in the other incidents, there was the possibility that the loom may have been damaged whilst maintenance was carried out in the area, and that this may have started the process which led to the conductors being exposed.

The incident to B737 G-LGTI occurred prior to flight, when the flight crew became aware of an electrical burning smell and smoke. The aircraft was shut down and the passengers evacuated. Pre-existing damage to the electrical galley feeder cables was identified which provided for the possibility of electrical arcing. It is probable that the damage to these cables occurred at an earlier time, possibly during the replacement of the forward toilet service panel.

All these incidents show how prone electrical wiring is to damage, occurring over time or being introduced during maintenance or modification action. Periodic zonal inspections are carried out but damage and debris is often hidden within wiring bundles and is difficult to detect without disturbing the looms. The draft ACs, generated by the ATSRAC work, address wiring standards issues of the type identified by these incidents, notably by the EZAP procedure, and this has been adopted into the latest revision of MSG-3 guidelines. However, the draft ACs have not yet been published, despite draft documents having been developed and issued by ATSRAC in 2002.

Therefore the following recommendations are made:

Safety Recommendation 2004-18

It is recommended that the Federal Aviation Administration (FAA) accelerate the publication and adoption of the guidance material produced by the Ageing Transport Systems Rulemaking Advisory Committee (ATSRAC) on developing an electrical systems standard wiring practices manual, developing an effective wiring systems training programme and on changes to existing maintenance practices and analysis methods, which could be applied to both in-service aircraft and new design, to ensure adequate consideration of the potential deterioration of electrical wiring systems.

Safety Recommendation 2004-19

It is recommended that the European Aviation Safety (EASA) expedite the transcription by Agency the European Ageing Systems Co-ordination Group (EASCG) of the material in the FAA Advisory Circulars (ACs) produced by the Ageing Transport Systems Rulemaking Advisory Committee (ATSRAC), which gives guidance for operators and maintenance organisations on developing an electrical systems standard wiring practices manual, developing an effective wiring systems training programme and on changes to existing maintenance practices and analysis methods. This guidance should be applied to both in-service aircraft and new designs, to ensure adequate consideration is given to potential in-service deterioration of electrical wiring systems.

In response to this recommendation, EASA have stated that the EASCG have already drafted several documents, related to the four subject incidents, and that a meeting was scheduled for April 2004 to begin the Notice of Proposed Action (NPA) process within the EASA framework[1].

[1] NPA is similar to the Notice of Proposed Rule Making (NPRM) process followed by the FAA in the USA.

Circuit breaker design

However strenuous the efforts to avoid design and maintenance quality lapses, their essentially random natures make them very difficult to eliminate. There are many reports of wiring loom damage where sustained arcing within/between looms occurred, or probably occurred, where CBs have failed to operate, or to operate in sufficient time to prevent serious wiring damage and, in some cases, loss of the aircraft. The four incidents reported here present such examples of sustained arcing.

Electrical circuits are protected against electrical overheating of wires by thermal/mechanical types of circuit breaker. The 'thermal trip' type of circuit breaker is tripped, and thus the electrical circuit broken, by heat generated within the breaker from the current in excess of its rating. This is most suitable for a 'solid' and continuous short-circuit but less reliable for transient arcing faults, which develop high energy over a very short period of time insufficient to trip the circuit breaker. An 'intelligent' circuit breaker, which could directly replace the circuit breakers presently in widespread use, can recognise the rapid current and/or voltage signature associated with arcing faults. An extensive research programme has been sponsored entirely by the FAA, and has led to the development of such arc fault circuit breakers.

The findings of the ATSRAC research has shown that aircraft wiring does deteriorate with time. If wiring insulation material becomes damaged in some way, for example due to mechanical abrasion, so that the wire is exposed and a local external conductive path is available, then electrical arcing can occur. In response to previous incidents and accidents where arcing has been identified, and with regard to the development of arc-fault circuit breakers, the following recommendations are made:

Safety Recommendation 2003-108

It is recommended that the Federal Aviation Administration (FAA) expedite a requirement for the replacement of existing thermal/mechanical type circuit breakers by arc fault circuit breakers, in appropriate systems on in-service and new build Civil Air Transport aircraft for which they have issued type certificates, when these devices are judged to have been developed to an acceptable standard and where the Safety Objectives for the circuits would be enhanced.

Safety Recommendation 2003-128

It is recommended that European Aviation Safety Agency (EASA), on behalf of the member countries which have issued type certificates for Civil Air Transport aircraft, expedite a requirement for the replacement of existing thermal/mechanical type circuit breakers by arc fault circuit breakers, in appropriate systems on in-service aircraft and new build aircraft, when these devices are judged to have been developed to an acceptable standard and where the Safety Objectives for the circuits would be enhanced.

Concorde Type 1 V102, G-BOAC

AAIB Bulletin No: 6/2004	**Ref: EW/C2003/06/03**	**Category: 1.1**
INCIDENT		
Aircraft Type and Registration:	Concorde Type 1 V102, G-BOAC	
No & Type of Engines:	4 Rolls-Royce Olympus 593 turbojets	
Year of Manufacture:	1975	
Date & Time (UTC):	13 June 2003, time unknown	
Location:	Transatlantic cruise	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew - 9	Passengers - 98
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Fire damage in under wing area	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	55 years	
Commander's Flying Experience:	17,000 hours (of which 2,200 were on type)	
	Last 90 days - 60 hours	
	Last 28 days - 20 hours	
Information Source:	AAIB Field Investigation	

Synopsis

On 21 June 2003, during the routine maintenance investigation of a reported defect, a short circuit condition was detected on the Fuel Quantity Indication wiring for fuel tank No 7. Damage was found to an associated wire bundle which had been caused by a localised fire within the area enclosed by the wing/fuselage fairing area aft of the main landing gear (zone 198) below fuel tank No 3. Fuel seepage from this tank, in the area of the chafed wire, had collected in a box section fairing support member and had been ignited, resulting in a short duration, low intensity fire. The ignition source for the fire was identified as a chafed wire for the main tank No 3 fuel pump, which carries 115V AC power, arcing against the aluminium fairing. It was possible that the chafing of this wire had been precipitated during maintenance activity two years prior to the incident when this wiring had been disturbed. The fire probably occurred during a flight from LHR to JFK on 13 June 2003, although no indications were apparent to the flight crew at that time. Modifications have since been introduced to prevent the build up of fuel in the box section fairing support structure.

History of Flight

On 21 June 2003, the aircraft was to fly from London Heathrow (LHR) to New York (JFK) airport. Prior to the flight the failure flag for the No 7 fuel tank gauge had been in view, indicating that the gauge was unserviceable, and it was indicating 1,500 kg. However, the fuel tank, which holds 7,480 kg, was full. The gauge was interchanged with that for the No 5 fuel tank, but the defect remained. The fuel quantity packs were then interchanged, but the defect persisted. A description of the fault was entered into the aircraft's Technical Log and the aircraft departed with the No 7 tank gauge unserviceable, in accordance with the minimum equipment list (MEL). Approximately one hour after takeoff, the failure flag disappeared and the fuel gauge appeared to work correctly for the remainder of the flight.

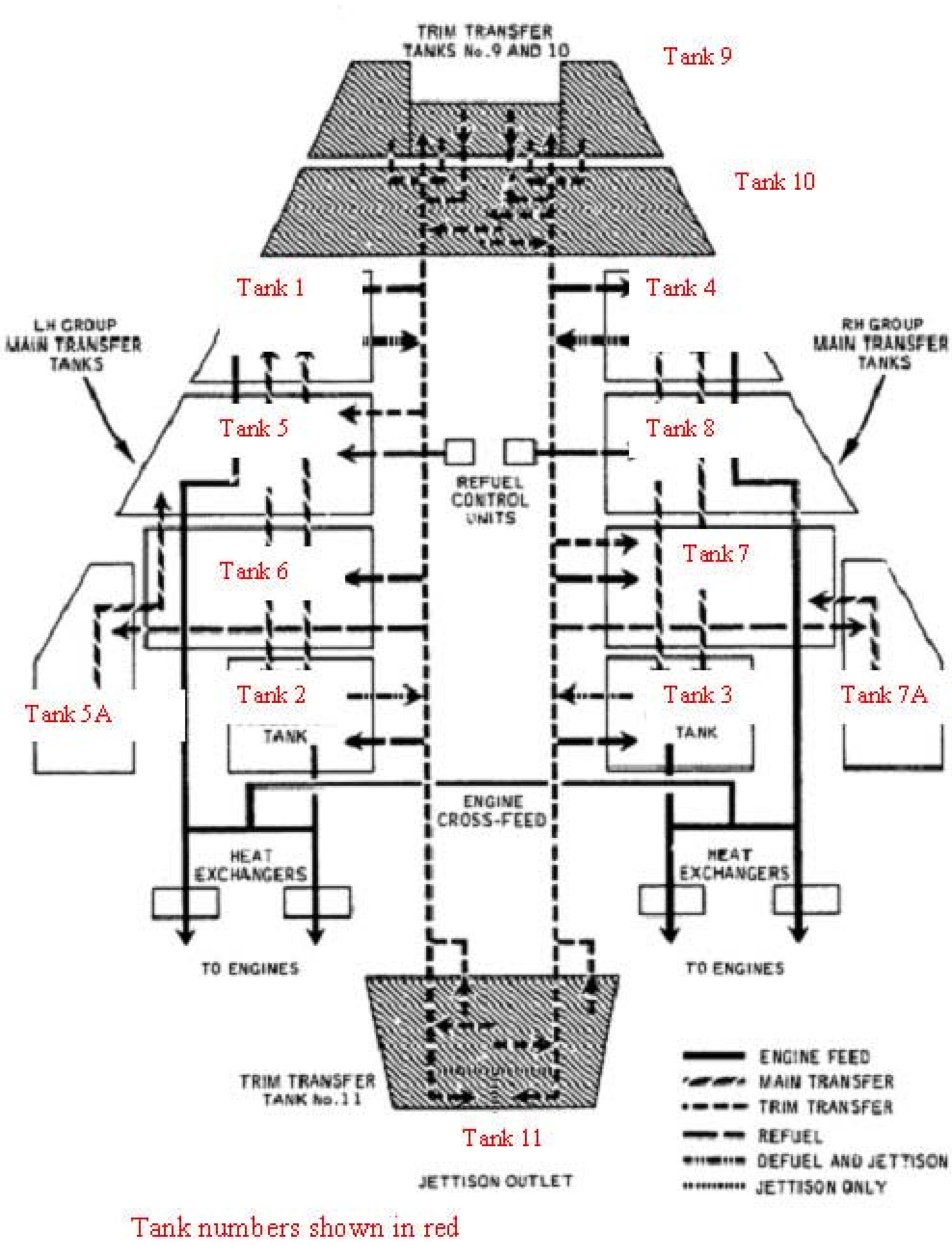
Prior to refuelling for the return flight, the contents of the No 7 fuel tank were physically checked and confirmed as being correct. After refuelling, with the No 7 tank full, the gauge again indicated a total of 1,500 kg but on this occasion there was no failure flag in view. There was now, however, a failure flag displayed on the No 5 tank fuel gauge. Once more, the No 5 and No 7 fuel gauges and fuel quantity packs were interchanged, but the defects remained. (Under the conditions of the MEL the aircraft was not permitted to depart with two fuel gauges unserviceable.) The centre of gravity (CG) computer also displayed a failure warning flag, although the indications appeared to be correct. Whilst the engineering analysis continued, the failure warning flags for the No 5 fuel tank gauge and the CG computer cleared and so the aircraft once again departed under the conditions of the MEL.

When in the supersonic cruise phase of flight, the No 7 fuel tank gauge began to indicate correctly. However, all other fuel tank gauges, except those for tanks 4, 5A, 9, 10 and 11, displayed failure flags intermittently for the remainder of the flight. At no time did any of the gauges fail. The failure flag for the CG computer also re-appeared but the CG reading corresponded closely with the calculated value. The failure flags for the No 2 and No 3 fuel tank gauges remained in view for most of the flight, although the indications on these gauges were considered by the crew to be accurate. During the flight the crew had contacted the operator's engineering control to advise them of the multiple fuel gauges failure flags. After flight, when the engines were shut down all of the failure flags disappeared from view and the flight engineer fully debriefed the ground engineering staff.

Fuel system

On Concorde, the fuel system has three functions; to supply fuel to the engines, to control the position of the aircraft CG and to act as a heat sink to absorb kinetic heating from the structure and to dissipate heat generated by the air-conditioning and hydraulic systems. Fuel is stored in thirteen integral tanks, as shown in Figure 1.

Figure 1: Fuel Tank locations



These are arranged in three groups; the left main transfer group, the right main transfer group and the trim transfer group. The left and right main transfer groups store fuel in the wings and sections of the centre fuselage, and both groups are comprised of three main tanks which supply two collector tanks per group, from which the engines are fed. The collector tanks on the right main transfer group are tank Nos 3 and 4, which feed engines Nos 3 and 4 respectively. The main fuel transfer system transfers fuel from the main transfer tanks to the collector tanks at a rate sufficiently high to ensure that the collector tanks are always maintained in a near full condition. Fuel is transferred from each tank by electrically driven pumps, which can be manually controlled, to match an automatic sequence of mechanically operated transfer valves which are governed by float sensors in the tanks receiving the fuel.

A fuel quantity indication (FQI) system shows the level of individual and total tank contents. The system is also used to provide an indication of the aircraft's CG. Tank Nos 5, 6, 7, 8, 9, 10 and 11 have magnetic fuel level indicators installed to provide an underwing method of manually checking the contents of these tanks. These indicators are intended to be used when a fuel quantity gauge has failed, or when the fuel quantity probes are suspected of giving incorrect signals. Gauge failure is indicated by the display of a warning flag.

Each collector tank is equipped with main and standby 115V AC electric motor driven pumps. The electrical loads of the fuel system are supplied from the aircraft's electrical power system via circuit breakers on the distribution busbars. The main AC and DC circuit breakers are located above the equipment racks on both sides of the flight compartment; the essential AC and DC circuit breakers are located forward of the racks on the left side.

Fuel leaks

The fuel tanks are formed as sealed cells integral with the wing, centre fuselage and rear fuselage structure. Intermediate ribs and spars within the tanks reduce fuel surging and sloshing. As a result of recent modifications, tank Nos 5, 6, 7 and 8 are fitted with liners on the wing lower surface, which limit fuel leakage to a minimum in case of foreign object damage. The tanks also have structural expansion joints, located on the lower surface between the wing and fuselage, to allow for expansion and contraction of the aircraft structure caused by the thermal cycle induced by the supersonic/subsonic flight profile. The expansion joints are formed from two top hat sections which ramp down to a flat surface at either end where they attach to the spar cap flanges. The inner expansion joint forms part of the aircraft fuel tanks.

As a result of these sealed cells expanding and contracting, as part of normal flight, cracks can develop, which results in fuel seepage/leakage from the tanks. Fuel leaks are continually assessed by engineering staff and monitored in accordance with the Aircraft Maintenance Manual (AMM). They are categorised as 'seepage' or a 'running leak'. Seepage is assessed for an area six inches square such that once the area is wiped clean, fuel should not flow or fall in droplets for a period of 15 minutes. For a 'running leak', fuel reappears immediately after the surface is wiped clean and falls in drops; the leak rate is assessed as the number of drops per minute. Allowable fuel leaks and seepage are classified by specific aircraft regions, according to risk, and are detailed in the AMM. For seepage or a running leak of less than 15 drops per minute, no immediate action is required for some areas, but frequent checks must be conducted to ensure that a leak is not worsening and repair work must carried out at the next scheduled maintenance check. For other, more critical areas with the same condition, repairs are required before the next flight.

There were no fuel leaks being monitored in the area of tank No 3 around the time of the incident.

History of reported defects in the FQI system

The aircraft flew a sector from LHR to JFK on 13 June 2003. During refuelling operations at JFK engineers noted that tank No 7 fuel gauge had failed. The tank was filled and the quantity checked using the tank No 7 magnetic fuel level indicator and the aircraft returned to LHR where the FQI probe in the tank was replaced. A functional check was performed satisfactorily.

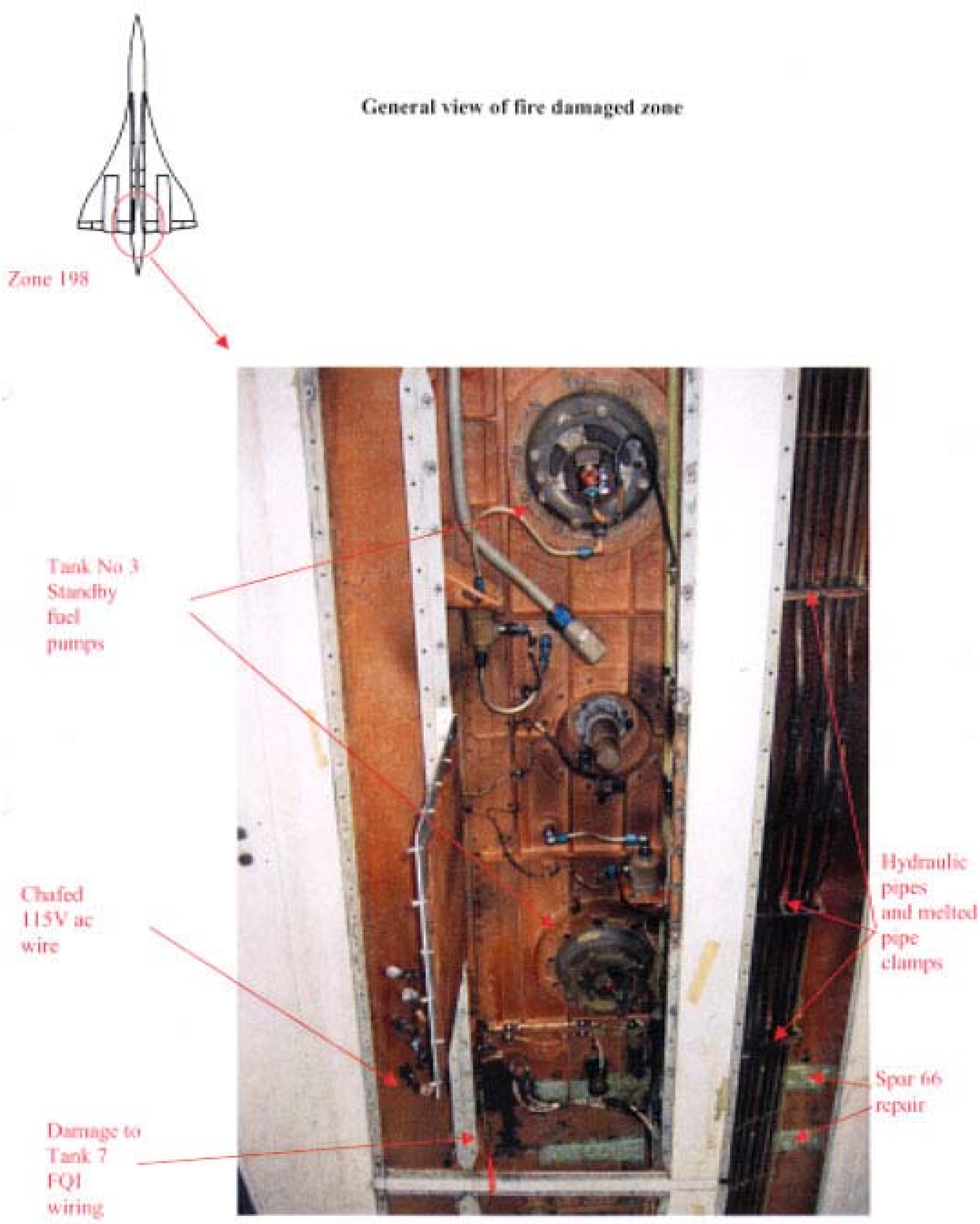
The aircraft next flew to JFK on 20 June 2003, subsequent to which it was reported that the FQI gauge had a 'fail' flag visible and that it read incorrectly. The aircraft was dispatched from JFK on 21 June 2003 with this allowable deferred defect but, during the return flight the crew reported multiple 'fail' flags on several fuel gauges (as described in the 'History of Flight'), and that fuel was slow to transfer from tank No 3 to tank No 7A during the descent.

During investigation of the reported defect on tank No 7 FQI, a short circuit condition was identified in the wiring. Further investigation revealed that this had been caused by a short duration, low intensity fire inside the wing to body fairings below fuel tank No 3 on the right side of the aircraft.

Aircraft examination

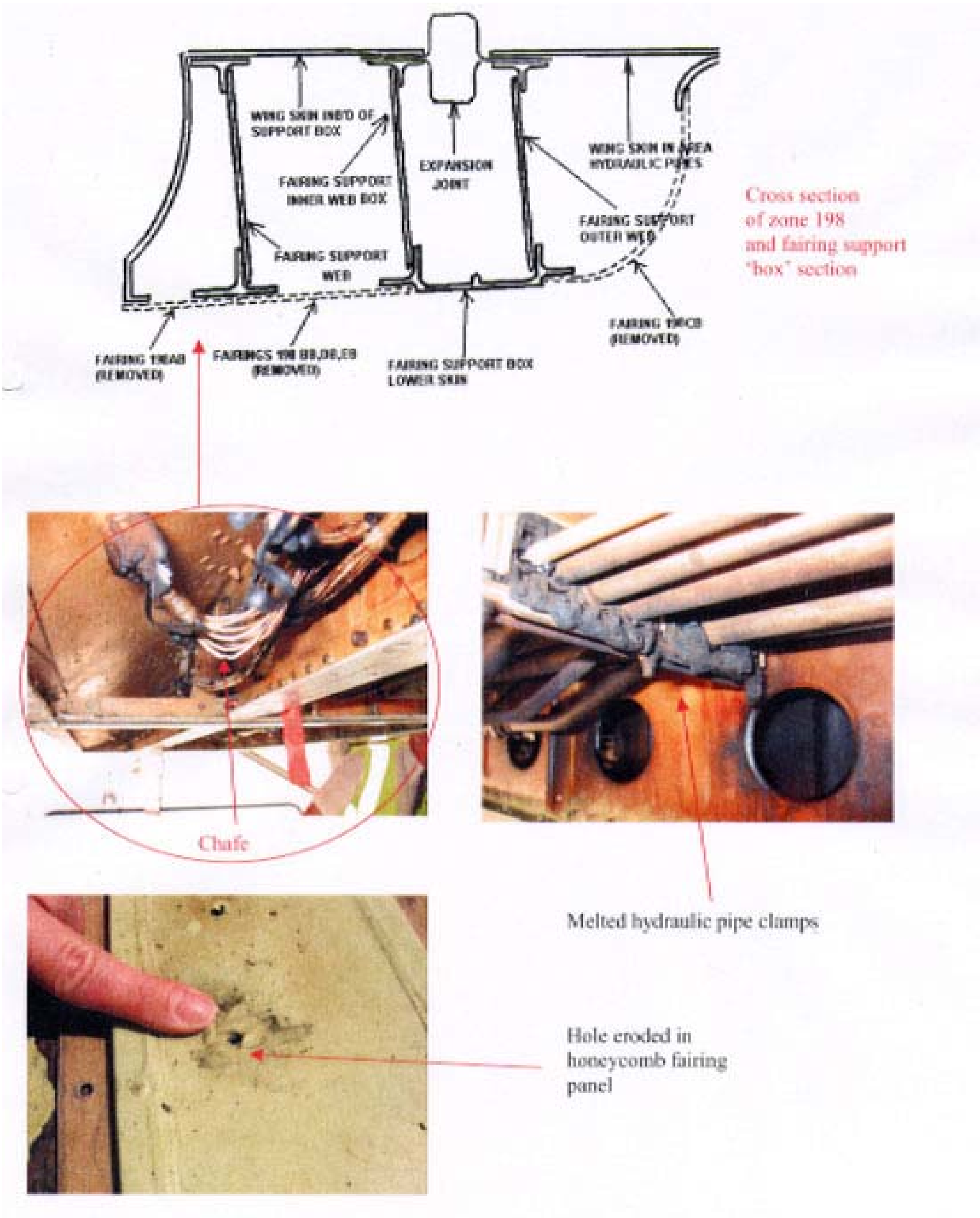
The area damaged by the fire was contained within the wing/fuselage fairing area aft of the main landing gear, below and adjacent to tank No 3 (zone 198), Figure 2.

Figure 2: General view of fire damaged zone



This area contains a number of hydraulic pipe runs, together with wiring for the fuel pumps and FQIs. There was little overall evidence of sooting, indicating that only a small quantity of fuel had been consumed. There was more localised evidence of sooting within a 'box' fairing support structure, and this also showed evidence of a ventilation airflow direction through the area, indicating that the fire was likely to have occurred during flight. Conductivity testing on the aluminium 'box' fairing structure showed this area had been heat affected. There was little damage to the paint and thus the temperature of the fire was estimated to have been approximately 400°C. Tank No 3 115V AC main fuel pump wiring, from the rear fuselage, was found to be loose within its bundle in this zone and one wire had chafed on fairing panel 198AB, Figure 3.

Figure 3: Cross section of Zone 198



The chaffing of the wire on the inner aluminium skin of the honeycomb filled panel eventually led to an electrical arc of a 115V AC supply, which ignited the fuel/air mixture. The fire had also caused damage to the FQI wiring, leading to the reported defects, initially on tank No 7 FQI system and then on other tank FQI systems and the CG computer. Although there was fire damage to the FQI and No 3 fuel pump wiring, there was no evidence of arc-tracking along the length of the wires. Arc tracking is not a feature associated with the Concorde PTFE wiring insulation.

The fire had damaged a number of nylon clamp blocks supporting hydraulic pipes. The hydraulic pipe clamps are made from Polyamide (Nylon) 66, which has a heat distortion temperature (ie the temperature at which the material will flow) of between 150°C and 180°C, and a melting temperature of 264°C. Around the area of the 'box' section of the fairing support structure outboard of the chaffed wire, the pipe clamps displayed varying thermal effects. Some clamps had been completely consumed while others had been burnt and the material had flowed. Below one group of hydraulic pipes a 'pool' of burnt pipe clamp material had formed by melting and then flowing onto the inside of the fairing panel 198CB. The surface of the burnt material was black and smooth, indicating flow had continued after the burning had finished, although one small area had a rough texture indicating that the burning had continued here for a longer period. Around the 'pool' there was evidence of plastic spatter on the fairing. The lack of damage to the fairing panel suggested that burning of the hydraulic pipe clamps was localised and of low heat intensity. There was no apparent damage to the inner painted surface of the fairing panel and no delamination had occurred.

During the flight, tank No 3 main fuel pump circuit breaker did not trip and the pump had continued to operate, despite the chafed wire and arcing to the panel. The circuit breaker was of the conventional thermal/mechanical type, and this was removed and later tested satisfactorily. (This type of circuit breaker is designed to protect against electrical overheating of wires and does not protect against transient arcing faults, which develop high energy over a very short period of time.)

The area under tank No 3 in the region of the fire, was cleaned and examined for fuel leaks. At the forward end of the expansion joint at wing spar 66, one drip of fuel occurred every 6 minutes and an additional drip every 1 minute 40 seconds from the area of the lower panel support structure, Figure 3. The bolts on a repair plate on spar 66 were damp but did not form droplets. There was also a drip every minute at the aft end of the expansion joint at spar 68. Zone 198, the region in which the fire occurred, is classed as 'zone two' for fuel leakage purposes and seepage only is permitted before repairs are required.

Airworthiness requirements for areas adjacent to fuel tanks

Concorde is certificated to Supersonic Transport TSS requirements. TSS 6.1, paragraph 4.7.3, specifically states *'To prevent the accumulation of flammable fluids or vapours, spaces adjacent to tanks shall be ventilated and drained.'* This requirement is consistent with current JAR 25 requirements for Large Aeroplanes.

Ventilation in the wing/fuselage fairing area aft of the main landing gear is provided by means of an air conditioning supply which is shared with the main landing gear bay. The airflow is routed through the fairing area and any fuel which leaks into this region is expelled through a dedicated shrouded external port. Ventilation holes were also originally provided in this area. However, flight testing by the manufacturer showed that the pressures in the adjacent rear equipment bay were such that vented fuel, in the form of spray, could find its way into the bay and constitute a fire hazard. Therefore, a mandatory Service Bulletin (SB) SST-53-053) was issued in August 1983, which introduced improvements to the venting, sealing and drainage in the area of the rear equipment bay but also specifically required twelve additional ventilation holes in panels 197GB and 198GB to be blanked.

Safety action

The aircraft wiring in the area of the fire was installed at original manufacture in 1975. In 2001, routine inspection of the wing structure had detected cracks in the area of spar 66, Figure 2, and in order to complete the structural repair, it was necessary to disturb the wiring. It is likely that in reinstating the wiring the possibility for the chafe to occur was introduced. This area is not routinely inspected and, given the low number of hours flown by each aircraft, is unlikely to have been inspected within the period since the repair to spar 66. The operator carried out a visual inspection on the remaining aircraft to inspect for any similar wiring defects which could result in chafed wire, but none were identified. The operator also introduced a modification to introduce additional 0.25 inch diameter drain holes in the underside of the wing/fuselage fairing 'box' support structure aft of the main landing gear (zones 195, 196, 197 and 198). All five aircraft in the fleet were modified prior to the aircraft leaving service.

This incident highlighted airworthiness issues which were not limited to Concorde, but which reflected broader concerns on all aircraft types regarding wiring condition, particularly as aircraft age and modifications are introduced. The broader concerns are addressed in the overview document included in this issue of the AAIB Bulletin.

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.

Boeing 737-436, G-DOCH

Contents

Report Information

AAIB Bulletin No: 6/2004	**Ref: EW/C2002/11/02**	**Category: 1.1**
INCIDENT		
Aircraft Type and Registration:	Boeing 737-436, G-DOCH	
No & Type of Engines:	2 CFM56-3C1 turbofan engines	
Year of Manufacture:	1991	
Date & Time (UTC):	8 November 2002 at 1458 hrs	
Location:	Near Clacton, Essex	
Persons on Board:	Crew - 6	Passengers - 68
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage and shorting within electrical wiring loom in cabin ceiling and associated failure of water supply hose	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	35 years	
Commander's Flying Experience:	4,400 hours (of which 4,150 were on type)	
	Last 90 days - 144 hours	
	Last 28 days - 52 hours	
Information Source:	AAIB Field Investigation	

Synopsis

Whilst climbing through FL240 the flight crew noticed a small amount of smoke appear on the flight deck, accompanied by a smell of electrical burning. They decided to carry out a diversion but were hampered by difficulties in communications with the cabin crew and locating the appropriate checklist, since it was not clearly identified on the index page of the QRH. Fire damage had occurred to electrical wiring in the area of the 'drop-down' ceiling panel immediately aft of the flight deck door. A braided steel water supply hose to the forward galley had been attached by means of a simple electrical 'tie-wrap' to a wiring loom, and there was evidence of abrasion and arcing between the wires and the hose. This had resulted in the severing and shorting of a number of wires. It was determined that the hose was too long for this application and that the excess length had been looped through this overhead area and then secured by the tie-wrap to adjacent wire bundles. It was not conclusively determined when this had been done but it was most likely that the attachment was simply a short-term expedient while systems were being disconnected and disassembled, and that the error was then missed during reassembly.

History of the flight

The flight was operating from London (Heathrow) to Kiev and took off at 1445 hrs with the first officer (FO) as the handling pilot. The departure was uneventful until 1458 hrs when, climbing through FL240, the commander heard three or four electrical 'crackling' sounds. Shortly afterwards the cabin call aural warning sounded on the flight deck, but despite several attempts neither pilot was able to establish contact with the cabin crew via the interphone. At about this time the FO noticed a small amount of smoke in the area behind the commander. The commander could not see the smoke but was aware of an electrical burning smell and therefore instructed the FO to don his oxygen mask. The commander put on his own mask and re-established communication with the FO, thus completing the recall items for the *'Electrical Smoke / Fumes or Fire'* checklist. He then took control of the aircraft whilst the FO retrieved his Quick Reference Handbook (QRH) in order to complete the remainder of the checklist.

Both pilots were aware of continued banging on the locked cockpit door, which had commenced after their failed attempts to reply to the cabin crew on the interphone. This heightened the pilots' concerns about what was happening, since they were unable to either communicate with the cabin crew or establish the cause of the smoke.

The commander was unsure whether his oxygen hose was long enough to allow him to reach the flight deck door. Therefore, in the absence of any visible smoke, and having briefed the FO, he cautiously removed his mask. He could still smell the smoke but had no difficulty breathing and decided that it was safe to leave his mask off. He went to the door and checked through a peephole for signs of fire or possible intruders. Seeing neither he opened the door and was met by a flow of water coming from a panel in the roof between the forward toilet and the galley. The cabin services director (CSD), who had been the person banging on the door, explained that about fifteen minutes after takeoff he had seen sparks and flames coming from the panel, followed shortly thereafter by a continuous stream of water.

The CSD had attempted to notify the flight deck at the time by using the cabin interphone and had initially heard the commander's voice reply, but the interphone had then ceased working. One of the cabin crew working at the rear of the aircraft then reported to him that the rear galley and some of the cabin lights were no longer working. Another member of the crew turned the water isolation valve off but, despite this, water continued to pour from the roof. Concerned that the water might find its way into the avionics bay the crewmember plugged the gap under the flight deck door with towels. The CSD had then started to bang on the flight deck door in an attempt to get the pilots' attention and, looking through the peephole, could see that both pilots were wearing their oxygen masks. Still unable to establish communications with the flight deck the CSD gathered the cabin crew together in the forward galley to explain the situation and to brief them for an anticipated return to Heathrow. It was at this point that the commander opened the flight deck door.

After satisfying himself that he was fully informed of the situation in the cabin, and that there was no longer any fire, the commander briefed the CSD that they would be returning to Heathrow and advised him to prepare for a possible emergency evacuation. The commander also told him that he would make an announcement to the passengers.

Before the commander left the flight deck in order to check the cabin, the aircraft had been levelled at FL260 and ATC notified that they had a "technical problem". No emergency had been declared at this point since the flight crew were still unsure of the situation in the cabin. However, whilst the commander was in the cabin ATC asked whether they wished to declare an emergency. The FO replied that they did and on a further suggestion from the controller agreed to commence a turn towards Stansted Airport, which was then about 55 nm to the west.

When he returned to his seat the commander decided to leave his oxygen mask off since there was now no smell of any smoke. He instructed the FO to remove his oxygen mask, in order to facilitate communications, before briefing him on the situation in the cabin. The commander then declared a

MAYDAY, requesting an immediate diversion to Heathrow. This was acknowledged by ATC and new vectors were given for them to fly. The crew then completed the remainder of the smoke checklist from the QRH and the commander briefed for a monitored approach for an ILS to Runway 27R at Heathrow, with the FO flying the approach and the commander taking control for the landing.

Meanwhile, after being informed of their intention to return to Heathrow the CSD had commenced briefing the passengers for a precautionary landing. Since the cabin interphone was not working he decided the most expeditious method was to arrange for the four cabin crew members to walk through the cabin personally briefing the passengers. Having done this they isolated the cabin electrical services and the CSD went onto the flight deck to inform the commander that the cabin had been secured for landing. The commander had previously explained the situation to the passengers, successfully using the public address (PA) system but he told the CSD that should the system subsequently fail and in the absence of any other instruction the doors should be left in 'auto' after landing. The CSD then returned to the cabin and the cabin crew took their seats for landing.

During the approach the commander requested that the ILS be protected so that they would be able to carry out an autoland should the smoke return and their view be restricted. ATC replied that a CAT III ILS would be available but that protection could not be guaranteed: they also advised that a surveillance radar approach would be available if necessary. The approach was continued and the commander took control at 1,000 feet and completed a normal landing, bringing the aircraft to a halt on the runway, as requested by ATC. The FO, as briefed, then went immediately into the cabin to check for any more signs of fire. There were none, and the commander relayed this information to the fire services who were now at the aircraft and speaking to the commander on a discreet frequency.

The fire service requested that the engines be shut down before carrying out an external check for signs of fire or damage. None were found and they boarded the aircraft and used thermal imaging equipment to look for hot areas in the ceiling. Again none were found but, on pulling down the damaged ceiling panel, a burnt wiring loom could be seen. Next to this was the water supply hose to the forward galley, from which water was still pouring. Whilst the fire crews were investigating the source of the fire the passengers were disembarked from the rear of the aircraft onto awaiting buses, following which the aircraft was towed clear of the runway.

Flight Recorders

There were three recorders fitted to this aircraft. The tape-based CVR and DFDR were replayed by the AAIB whilst the Quick Access Recorder (QAR) was replayed by the operator and all were successful in providing data for the investigation. Relevant data is described below.

The CVR tape, being of half-hour duration, had been overwritten at the beginning of the event and recording effectively began 12 minutes after its onset. The DFDR and QAR both recorded in excess of 300 parameters, but the only one that related to the electrical problem encountered on the aircraft was 'lavatory smoke', a discrete parameter. At 1458 hrs, whilst passing FL240, this parameter changed to an indication of 'smoke detected' and this indication remained for the rest of the recording. No other alerts or warnings were recorded.

The ILS approach and landing (at 1527 hrs) were uneventful and the aircraft came to a halt on the runway. Both engines were shut down and the APU was started. This action cut power to the CVR, terminating the recording. Total flight time was 42 minutes.

Flight Deck Door

The flight deck door fitted to this aircraft was a 'Phase 1' door and since September 2001, it has been a CAA, and latterly a DfT (Transec) requirement that during flight, the flight deck door should be secured, in advance of the ICAO standard, effective November 2003. The policy of keeping the door secured during flight is strictly enforced but, during an emergency, the door may be opened at the commander's discretion, in order to enhance communication between the flight deck and cabin crews. However, such action could clearly compromise the security of the flight deck. Ultimately, it is the responsibility of the flight crew to assess the situation at the time and take what action they feel appropriate to best secure the safety of the aircraft. The door on G-DOCH was fitted with two 'peepholes', one allowing the pilots to look into the cabin and one allowing the cabin crew to look into the flight deck. Thus, in this instance, in the absence of any verbal communication, the cabin crew could at least check on the state of the pilots on the flight deck and the pilots, in turn, could check for signs of fire in the cabin. Faced with smoke from an undetermined source coupled with a failure of the cabin interphone system, the commander determined that his only option was to unlock the flight deck door and speak directly to the CSD.

All of the larger public transport aircraft registered in the UK are now fitted with a door that, amongst other changes, has been significantly strengthened; this is designated a Phase II door.

Checklist

Until October 2001 the operator used its own QRH, which had been evolved over several years of use within the fleet. The index for each of the non-normal procedures in this QRH was printed on the front cover with the title *'Smoke'* appearing in a bolder and larger type face than other titles on the index page, thus making it distinctive. Items that required immediate action from memory were contained in a clearly identified box at the start of each checklist. The single checklist for *'Smoke'* then guided the pilot to the appropriate procedure depending upon whether the smoke was suspected to be from either the air conditioning system or from an electrical source.

In October 2001 the operator adopted the QRH produced by the aircraft manufacturer, as part of an effort to standardise on the use of manufacturer supplied Operations Manuals and Handbooks. Again, the index was printed on the front cover but the title *'Smoke'* did not appear. Instead, the relevant checklists came under titles of either *'Unannunciated Checklists' or 'Fire Protection'*. Neither title led intuitively to the checklist for smoke events, and neither was prominent in the index, appearing as it did in the same size and style of font as the other titles. In addition, there were two separate checklists for smoke, one headed *'Air Conditioning Smoke/Fumes'* and the other headed *'Electrical*

Smoke/Fumes or Fire'. Whilst the memory items were 'boxed' for the checklist related to electrically generated smoke, they were not for the check list related to air conditioning smoke.

The pilots stated that they had trouble locating the appropriate section in the QRH and expressed concern about how difficult it would be to read through and action effectively in a cockpit contaminated with a significant amount of smoke.

As a result of this incident the operator has revised the manufacturer's original QRH and the relevant checklists now come under the title of *'Smoke'* on the index page. This title is in large (20 pt) bold text and the associated numbered tab is printed in reverse print (yellow number on a black tab) to clearly differentiate it from other pages; checklists related to smoke should thus be easier to locate in a smoke filled environment. Memory Recall items for both smoke related checklists are now boxed and the typeface used throughout is larger than for other checklists, making them easier to read.

Damage to the aircraft

The visible damage to the aircraft was found principally in the area above the 'drop-down' ceiling panel immediately aft of the flight deck door, Figure 1, in the forward vestibule of the cabin: this panel is hinged on the left side and secured by two latches on the right side. There was also some scorching and sooting of this panel and around the top of the cockpit door frame.

Figure 1: Damaged loom and hose, G-DOCH

Figure 1 Damaged loom and hose, G-DOCH

Within this area, damage had occurred to a wiring loom where a braided steel hose had been secured by means of a single electrical 'tie-wrap' strap (the generic cable tie system formed of nylon-type UV-resistant material). It appeared that there had been abrasion and arcing between the wires and the hose, resulting in the severing and shorting of a number of the wires. The braided steel hose was lying against the frame of the ceiling panel and it appeared that there had also been electrical shorting to this portion of the airframe.

The hose involved was a water hose which supplied potable water from an aircraft connection in the crown of the fuselage, to the back of the No 1 galley; this was located at the right-hand side of the forward cabin. An area of this hose in which the steel braid appeared to have melted, was apparent, and at least two holes had been created in the PTFE inner hose, Figure 2, which resulted in the substantial water leak.

Figure 2: Damaged hose, G-DOCH

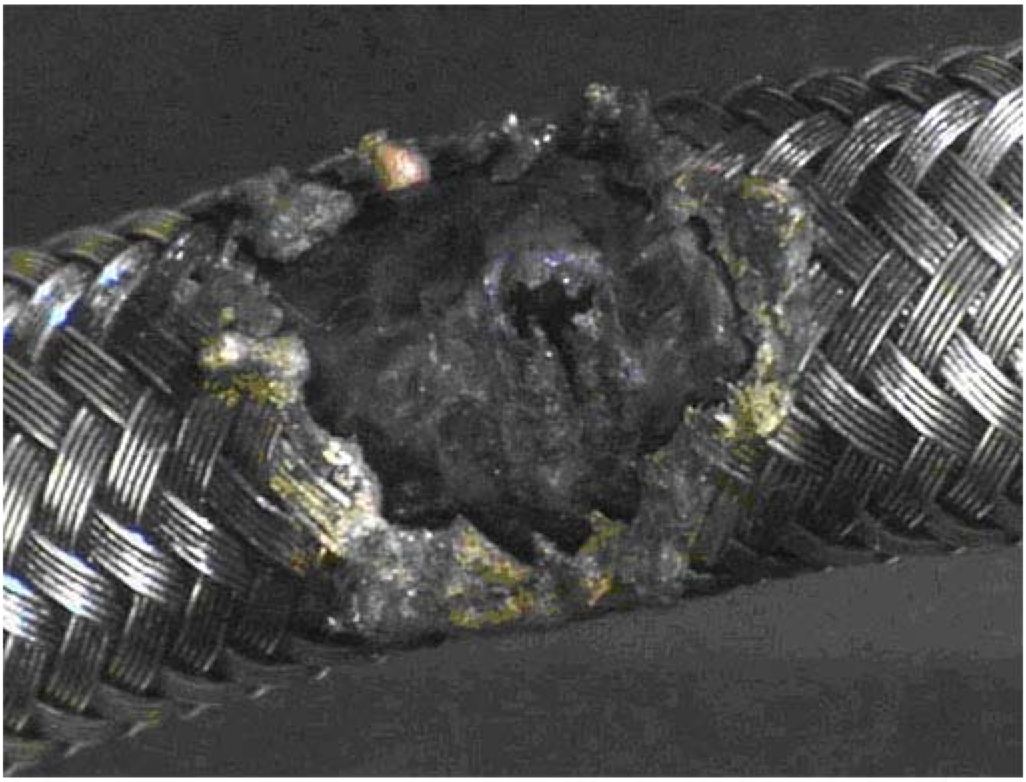


Figure 2 Damaged hose, G-DOCH

Comparison with a sister aircraft, G-DOCW, indicated that the hose was too long for this application and that the extra length in G-DOCH had been looped through this overhead area and then only secured by a tie-wrap to adjacent wire bundles. Part of the hose was protected by plastic spiral wrap but this did not extend to the portion of the hose in contact with the wire bundles.

Some 25 circuit breakers on the P18 panel in the flight deck were found to have tripped. These were principally circuits providing passenger services, such as cabin lighting, but included the cabin interphone system. It was considered likely that the lavatory smoke alert, recorded by the FDR, was due to the relevant circuit breaker having tripped.

Supply hose details

The water supply hose was removed from the aircraft for examination. The galley, Figure 3, was designed and manufactured by the JAMCO manufacturing company in Japan as buyer-furnished equipment (BFE), specified by the customer but fitted, in this case, at the time of the aircraft's manufacture.

Figure 3: Illustration from galley Component Maintenance Manual

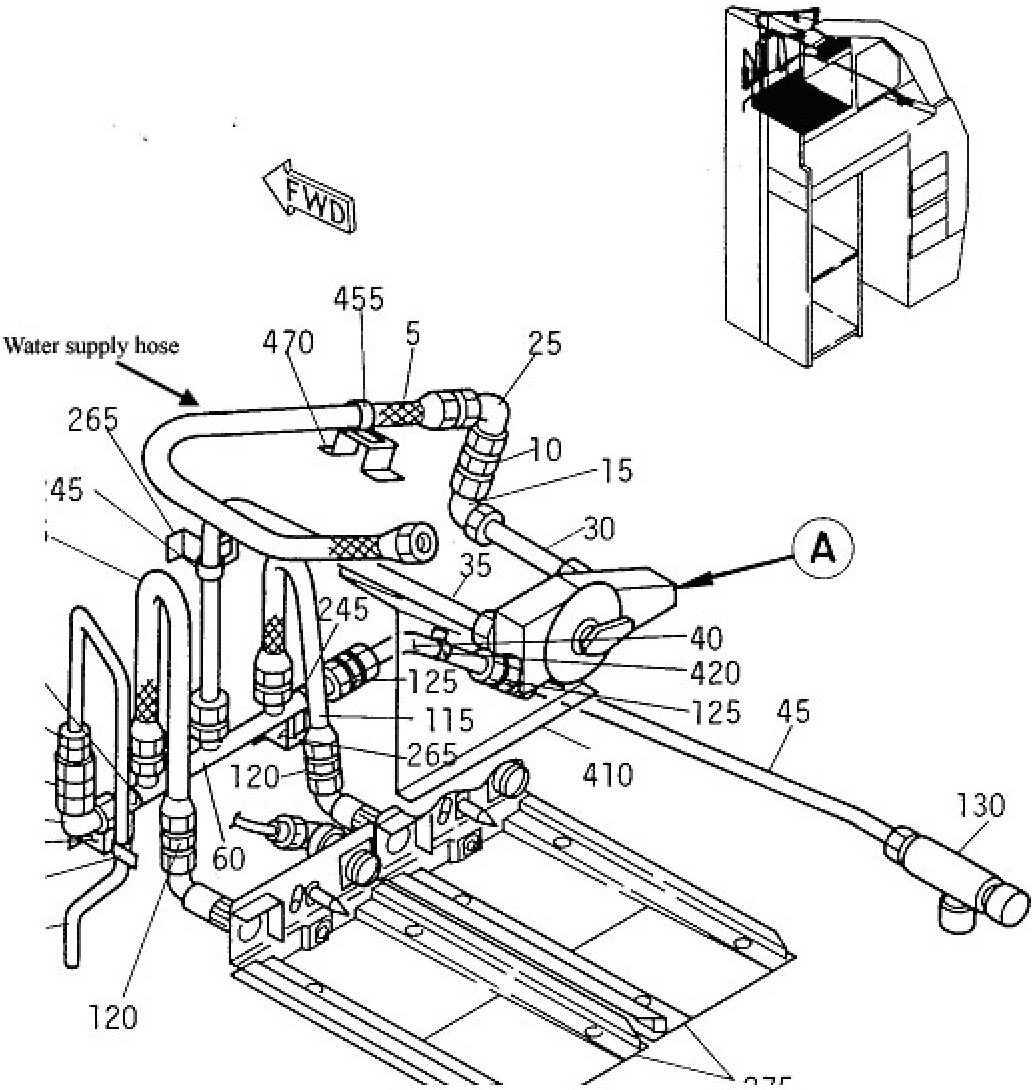


Figure 3 Illustration from galley Component Maintenance Manual

In this installation, the supply hose is considered to be a part of the galley unit and does not, therefore, appear in the aircraft Maintenance Manual. It was approximately 1,500 mm long and carried a band which designated its part number as 124027-8CR0593 (the last three digits of the part number (593) refer to its length in inches, ie, $59^3/_8$ inches = 1,510 mm), which was the hose part number as specified in the JAMCO component Maintenance Manual. This length, however, seemed excessive for the installation, especially when compared with measurements taken from other aircraft, which suggested that the required length should have been closer to 600 mm. From the parts stores records it was established that the hose was fitted to G-DOCH in August 1998 and that it had been manufactured by the Stratoflex Division of Parker Hannifin.

A review of the other 737-400 aircraft in this operator's fleet, all equipped with the same hose, showed that, in general, the excess length of hose had been accommodated by allowing it to lie looped behind the galley. Viewed from the area above the 'drop-down' ceiling panel, this extra length was not visible.

The same operator also flies the -300 and -500 version of the B737 aircraft and measurements were made of the actual and, approximate, required hose lengths on these models. This showed that the length needed between the aircraft and galley connections was some 500 mm greater in these aircraft, than in the -400 aircraft, but that the hoses were only 1,170 mm in length, in comparison with the 1,510 mm found in the -400 aircraft. The length of the hose on G-DOCH was, therefore, much better suited to the operator's B737-300 and -500 aircraft.

As noted above, the water supply hose is part of the galley BFE and would have been specified as part of the design of that galley. As such, it would have been included in the reviews between the operator, Boeing and JAMCO, so that that the design would meet the specification from Boeing and comply with their interface and safety issues. This specification states that there should be six inches of slack in the supply line but neither Boeing nor JAMCO were aware that an over-long hose had been specified for the installation in the B737-400 aircraft.

Previous maintenance

G-DOCH received scheduled maintenance at Heathrow Airport over the period 25 to 27 September 2002, but there were no activities recorded in the area above the galley or the flight deck door. A review of ramp maintenance in the Technical Log over the preceding months showed two entries related to reports of water around the No 1 galley, but both of these were minor, easily rectified and could not be linked to the routing of the water supply line.

The maintenance input during which it was considered most probable that the water supply line was misrouted and attached to the electrical looms, was a major check at another maintenance station between 29 June and 15 August 2002. During this period, a number of structural inspections took place, which necessitated the removal of cabin furnishings, such as the No 1 galley. During the time of these structural inspections the galley was sent away for refurbishment.

Interviews were conducted with a number of the engineering staff involved in the maintenance work during the time the No 1 galley was refitted and the surveillance inspections carried out prior to the aircraft returning to service. The engineer who had removed the galley had performed this task a number of times previously and stated that he would always make the disconnection at the aircraft connection, and remove the hose with the galley, as this was the more accessible point. On the other hand, the engineers who had refitted the galley considered it more likely that the hose would have been disconnected at the galley end and thus the hose would have remained in the aircraft while the galley was being refurbished elsewhere. There was no apparent reason why it would have been necessary to secure the excess hose length by the use of electrical tie-wraps, but it was considered most likely that this occurred as a short-term, and unrecorded, expedient during disassembly of the aircraft interior. There was, clearly, variation in the way the disconnection of the water supply hose would be made prior to removal of the galley unit and one factor in this was that the Aircraft Maintenance Manual (AMM) did not state precisely how this should be done. The text stated:

> *'S 084-061*
>
> *Disconnect the electrical power and water supply at the connections in the ceiling above the galley',*

but the associated diagram, Figure 4, showing a generic galley unit, labelled the water connection as being on top of the galley and did not indicate any hose between this connection and the point in the aircraft ceiling at which it should be disconnected.

Figure 4: Illustration from aircraft Maintenance Manual

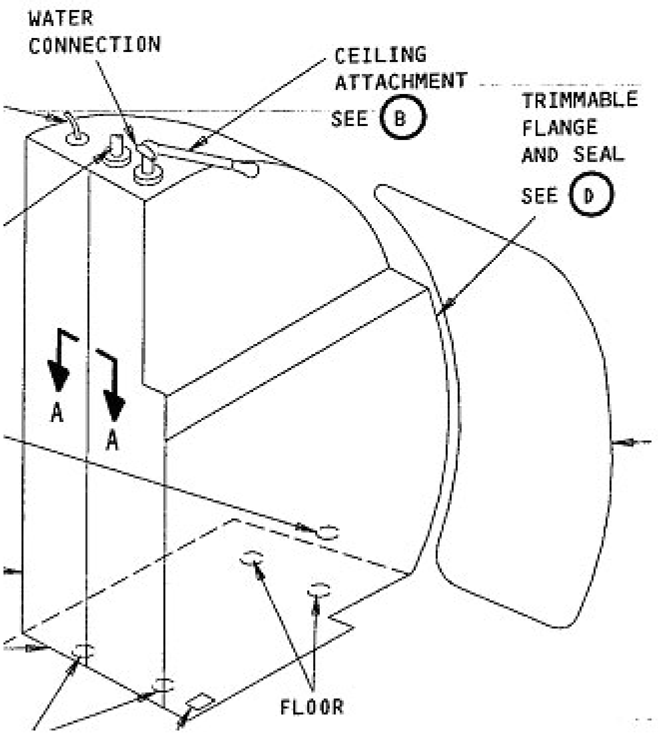


Figure 4 - Illustration from aircraft Maintenance Manual
Generic diagram identifying water connection. No information concerning supply hose or its method of installation

In summary, when the galley had been removed from the aircraft, it was not possible to identify positively whether the water supply hose had been disconnected at the aircraft connection or at the galley.

Detail examination - hose and electrical wires

An analysis of the cable and hose failures was commissioned by the AAIB from ERA Technology, an organisation with expertise in electrical and power system failure investigations. Their work included optical, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) examinations of the components and a series of calculations. These calculations were performed to determine the order of magnitude of the energy released during the arcing events and also to determine the current required to melt the conductors without arcing.

The calculation of the energy released during the fault arcing was made from an estimate of the amount of metal (steel braid and copper conductor) melted. A number of simplifying assumptions were made and it was acknowledged that the total energy release calculated by this method (1.8 kJ) would certainly be an underestimate. For instance, the process was assumed to be adiabatic, some of the cables had only one melted end and there was no account for metal heated above its melting point, or even vaporised. The probable current involved was also estimated, based on event times of 1.0 sec and 0.1 sec.

The analysis indicated that the probable sequence of failure was that one or more wires chafed against the steel braid of the water hose. The wire's insulation was worn through to the point of establishing an arcing fault with the steel braid portion of the hose, which is effectively earthed at both ends, and this initial arcing would have damaged the insulation on surrounding conductors. The process of arcing would then spread through the bundle. The arcing on some conductors would then stop, either due to the circuit breaker tripping or melting of the conductors. It is also possible that arcing may have stopped at some stage and then restarted as some movement occurred between wires with damaged insulation. Polyimide (Kapton) was used for the insulation on some of the wires and this, when subjected to arcing, will degrade to produce conductive carbon, allowing additional tracking paths to be formed ('carbon-arc tracking'). This could have contributed to the spread of the fault within the wiring bundle.

Circuit breakers

The investigation by ERA also considered the effect of this arcing mechanism on the circuit breakers for the wires involved. The specification for the circuit breakers identifies them to be of the 'thermal trip' type, where the circuit breaker is tripped, and the electrical circuit broken, by heat generated within the breaker from the current in excess of the rating. The specification includes a set of limits for time and current: this is most suitable for a 'solid' and continuous short-circuit but less reliable for arcing faults, where high currents, insufficient to trip the circuit breaker, may exist for very short periods. For instance, currents required to operate the breaker within one second could be between three and six times the rating of the device being served by the wires.

Operational analysis

General

The flight crew was presented with a situation where smoke was present on the flight deck whilst they were unable to communicate with the cabin crew. They had problems in locating the appropriate checklist since it was not clearly identified on the index page, but in the absence of any significant smoke they were able to complete the drill effectively. Afterwards the flight crew expressed concern about how difficult it would have been to read through the non-normal procedure in an environment filled with smoke. Smoke on the flight deck should have an associated checklist that is easy to locate and follow, even in a smoke filled environment.

In the event of smoke or fire in the air the commander should accomplish a landing at the nearest suitable airfield unless he has positively determined that the smoke has been eliminated and the fire has been extinguished. In this instance the commander believed that the source of the smoke had been identified and that there was no longer a fire. He therefore decided that his best option was to return to Heathrow rather than brief for an instrument approach, in poor weather, at an unfamiliar airfield.

Unbeknown to the commander, his decision to return to Heathrow rather than accept a diversion to Stansted created significant problems for ATC. Nevertheless, ATC complied fully with the commander's request and organised a safe and expeditious recovery. A brief telephone conversation between ATC and the commander or operator, after such events, would serve to keep both sides aware of the problems involved and resolve any misunderstandings that may arise.

Diversion

The commencement of the diversion was delayed by the crew's desire to have a full understanding of the situation before deciding upon a course of action. It was indeed only a suggestion from ATC four minutes after the onset of the incident that induced the FO to accept a turn back towards Stansted. At this point the aircraft was about 55 nm due east of Stansted. When the commander returned to the flight deck and requested a diversion to Heathrow some five minutes later they were advised that they were then 80 nm from touchdown at Heathrow.

Despite the aircraft being considerably closer to Stansted the commander stated that he chose to return to Heathrow because it was their home base and both pilots were familiar with the procedures. Neither pilot was familiar with Stansted and, with low cloud cover over the area, a more thorough briefing for the instrument approach would have been required. All indications were that the fire was out and with the communication problems being experienced it made sense to reduce their workload where possible. It did however leave the aircraft vulnerable should fire have unknowingly spread or re-ignited, and it also resulted in the aircraft over-flying London prior to landing.

Air Traffic Control

The initial diversion was commenced four minutes after the start of the event at the suggestion of the ATC controller. Had this suggestion not been made, it is conceivable that the diversion would not have commenced until after the return of the commander to the flight deck, some five minutes later. The controller then advised the FO of the proximity of the nearest suitable airfield and gave him vectors towards it, as well as advising him of a suitable descent point. In the absence of the commander, the FO was happy to accept a turn towards Stansted but was unwilling to commence a descent. On returning to the flight deck and having suitably assessed the situation the commander then declared a "MAYDAY" and requested a diversion to London Heathrow. ATC accepted this without question and provided vectors and descent guidance to the new diversion destination, thereby considerably reducing the pilots' workload.

However, the handling of the incident posed problems for ATC. Controllers are trained to appreciate the dangers associated to aircraft from onboard fires and to advise crews of the nearest achievable airfield. The original call from the crew of G-DOCH, announcing they had a problem was clearly made with the crew wearing oxygen masks and the controller expected that the aircraft was likely to require an immediate landing. To the controller the suggested diversion to Stansted was achievable and its acceptance by the FO logical. There was surprise, therefore, when some five minutes later the crew made a further call, this time without the use of oxygen masks, requesting a diversion to Heathrow. Considerable work had already gone into co-ordinating an unimpeded descent for an expeditious approach to Stansted.

At the time, there was a holding period of between 30 to 45 minutes for aircraft landing at Heathrow. In itself, the volume of traffic did not cause any particular concern to ATC but any increase in the complexity of dealing with this traffic represented, to them, an increase in risk. This is because they were now not only having to co-ordinate an unimpeded approach for G-DOCH to Heathrow, but they were also having to deal with other inbound aircraft diverting due to the significant increase in holding time that resulted. There can be no doubt that ATC acted correctly throughout, offering practical assistance and accepting crew requests without question. Without being aware of the true situation on board the aircraft there was, however, an atmosphere of some scepticism as to why the crew had chosen to reject Stansted in favour of a diversion to their home base of Heathrow.

This incident is a reminder that the handling of emergencies can create additional risks, increasing as it does the complexity of controlling traffic in an already busy airspace. Current ATC training enables the controllers to provide suitable assistance to flight crews but ultimate control over decisions must lie with the flight crew since only they are fully aware of the on-board situation.

In-flight communications

Communication played a key role in the handling of this incident. Following the terrorist attacks on aircraft in the USA on 11 September 2001 flight deck doors on the larger UK registered, public transport aircraft have been reinforced and strict procedures have been adopted to ensure that they remain secured during flight. This response, however, introduced additional problems related to communication between the flight deck and the cabin, in this incident, as the interphone system was rendered unserviceable by the damage to the wiring. Having discovered smoke and other indications of burning both the flight crew and cabin crew were initially hampered in their efforts to deal with the incident promptly due to their inability to communicate with each other across the locked flight deck door.

Analysis of recorded data shows the incident probably commenced at 1458 hrs. However, it was a further four minutes before any effective communication could be established between the flight deck and the cabin. Whilst some of this time was taken up in completing the appropriate non-normal checklist, the inability to communicate led to a feeling of isolation and urgency on both sides of the locked door. During this time neither the flight crew nor the cabin crew could ascertain the true extent of the problem and therefore did not know whether their initial actions had been correct.

This in turn led to a delay in declaring an emergency to ATC. The first report made to ATC, two minutes after the smoke was first identified, described simply a "technical problem". Only after being prompted by ATC four minutes after the event, and in the absence of the commander, did the FO declare "an emergency". However, it was not until the commander's return to the flight deck some nine minutes after the event that a full "MAYDAY" was declared. Had either the interphone been working or the flight deck door not been locked then there is little doubt that the decision to declare an emergency and commence a diversion could have been made considerably earlier.

Effective communication between the cabin crew at either end of the cabin and between the cabin crew and passengers, was further hampered by the failure of the cabin interphone. Whilst a loud hailer was available, the CSD considered that briefing the passengers personally would be more effective since some of the passengers had a poor understanding of the English language. The cabin crew subsequently stated that the use of the company's standard procedures had been valuable, since each person knew exactly what they had to do and this significantly reduced the need for additional communication.

When the smoke initially appeared on the flight deck the pilots had correctly donned their oxygen masks. The commander's decision to subsequently remove his mask had been driven by the uncertainty that his oxygen hose was long enough to allow him to reach the flight deck door. (It has subsequently been demonstrated that both pilots' oxygen hoses were indeed long enough to allow them to reach the door.) It was only on his return from the cabin that he considered it safe for both pilots to dispense with their masks. Although the oxygen masks allow communication between each pilot and with ATC, such communications are awkward. It is therefore understandable that the commander wished to be without this extra limitation, especially considering the other communication problems prevalent at the time. There is, however, a significant risk when breathing, without protection, in an atmosphere that has been contaminated by smoke or fumes of an unknown nature[1]. Even a low concentration of contaminants might lead to impaired performance and potential incapacitation, although no ill effects were apparent on this occasion.

Finally, the commander also reported that he had been concerned as to whether the public address system and emergency evacuation alarm were still operable from the flight deck. With his over-riding priority being to complete an expeditious diversion he did not have the time or opportunity to test them, but was mindful of the potential problem of initiating an evacuation should neither be working when required.

[1] This subject is addressed in AAIB Aircraft Accident Report 1/2004

Engineering analysis

In this particular instance there were three principal causal factors for the initial shorting around the overhead wire loom in G-DOCH. These were:

- the excessive length of the steel braided water hose to the forward galley
- the lack of an established routing or restraint of this extra hose
- the unexplained securing of this hose to the electrical loom

Despite an extensive series of interviews with maintenance personnel, it could not be determined how or when the hose came to be attached to the electrical loom. It is most likely that it occurred during the period of maintenance from 29 June and 15 August 2002 and that the attachment was simply a short-term expedient while systems were being disconnected and disassembled, and that the 'temporary' tie-wrap was then missed during reassembly.

In each of these three cases (excessive length, informal routing, inappropriate securing), the hazard created was inadvertent and in each case there existed, in principle, a procedure to avoid this type of hazard. In principle, the interface documents between the airframe manufacturer and the suppliers of customer-specified equipment (such as galleys) should have prevented the JAMCO galley being supplied with a hose of excessive length. In principle, the quality processes of the maintenance organisation should have identified the hazard consistently posed by the excessive hose length and the lack of routing or restraint; the same quality processes should, in principle, have prevented the securing of the water hose to the electrical loom and identified the hazard after it occurred.

However strenuous the efforts to avoid these design and maintenance quality lapses, their essentially random natures make them very difficult to eliminate. This has been apparent in the AAIB investigations of a number of recent accidents and serious incidents, where a range of circumstances have led to electrical arcing failures, where conventional circuit-breakers have not tripped. The approach of reducing or eliminating the hazardous effects of these failures by the introduction of some form of 'intelligent' circuit-breaker, has been persued, but a number of factors, including cost and the lack of a mature technology has, so far, generally prevented this solution being carried forward to Civil Air Transport aircraft.

Safety Recommendations

The flight crew were presented with a situation where smoke was present on the flight deck whilst being unable to communicate with the cabin crew. They had problems in locating the appropriate checklist, since it was not clearly identified on the index page of the QRH, and they had concerns that it would not have been possible to accomplish this had the flight deck been filled with smoke. Subsequent action by the operator has addressed these issues but in order to widen the safety action to include other operators the following safety recommendation is made.

Safety Recommendation 2004-16

It is recommended that the Boeing Commercial Airplane Company review the B737 non-normal checklist for '*Smoke*' to ensure that the procedure for smoke on the flight deck is unambiguous and clearly identified in order to give flight crews the best opportunity to locate it in conditions of low visibility.

In response to this recommendation, the manufacturer has stated that they recognise there are issues with the current checklist(s) for smoke identification and resolution. As such, they are currently conducting an in-depth review and are applying human factor research to improve the checklist selection via the indexes in the QRH.

There is no positive evidence as to whether the galley illustration in the airframe Maintenance Manual, Figure 4, was used as reference in the disconnection of the water hose in G-DOCH. The illustration does, however, have the potential to mislead in suggesting that the connection is made adjacent to the galley unit rather than at the interface with the aircraft water system in the crown of the fuselage. The following recommendation is therefore made:

Safety Recommendation 2004-17

It is recommended that the Boeing Commercial Airplane Company review the illustration and text material of the Maintenance Manual relating to the installation of the forward galley installation in the B737-400, and any other affected model, to give clear instruction as to where the galley water supply hose disconnection should be made when removing the galley.

In response to this recommendation, the manufacturer has made the following comments:

> *Due to the wide variety of installations of the subject galley (for example, the operator of G-DOCH has some six different installations in their B737-300/400/500 fleet alone), the water lines are unique for each galley installation. The manufacturer's main concern, therefore, has been to ensure the proper removal/installation of each galley in accordance with intended fit and function. As such, it has been acceptable for maintenance personnel to disconnect the water hose from any fitting in the system that is appropriate for a particular installation. Thus, the AMM instructions are often generic in nature for this type of application. However, the manufacturer plans to review this hose installation to ensure the security of the extra length of hose and validate any necessary changes to the galley installation and/or its procedures. This review will include the necessary specific instructions for securing the extra length of hose, or consider alternative solutions.*

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.

Boeing 737-300, G-LGTI

AAIB Bulletin No: 6/2004	Ref: EW/C2003/07/07	Category: 1.1
INCIDENT		
Aircraft Type and Registration:	Boeing 737-300, G-LGTI	
No & Type of Engines:	2 CFM56-3B2 turbofan engines	
Year of Manufacture:	1988	
Date & Time (UTC):	30 July 2003 at 0500 hrs	
Location:	Newcastle Airport, Tyne and Wear	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew - 6	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Fire damage to electrical wiring and insulation material	
Commander's Licence:	Airline Transport Pilot's Licence	
Information Source:	AAIB Field Investigation	

Synopsis

During the pre-flight preparation the crew noticed that both of the ground service circuit breakers were out, attempts to reset these were unsuccessful. The commander became aware of an electrical burning smell and smoke and asked the engineer to shut the aircraft down, ordered an evacuation and requested that the fire service be called. A short duration flash fire had apparently occurred below the cockpit floor on the right side, forward of the Electrical and Electronics compartment. Examination of the galley power feeder cables in the area showed evidence of some pre-existing damage consistent with the insulation material having being torn away from the wires. The galley feeder cables carry a three phase 115V providing the possibility for arcing, and this could eventually have started the arc tracking of polyimide insulated wires. It is probable that the damage to the galley feeder cables occurred at an earlier time, possibly during the replacement of the forward toilet service panel in November 2002. It could not be determined why arcing occurred on this particular occasion.

History of flight

The flight crew boarded the aircraft to prepare it for a scheduled morning flight to London Gatwick Airport. At the time the Auxiliary Power Unit (APU) was running, although the external ground power was plugged in and powering the electrical systems. During the pre-flight preparation of the flight deck the crew noticed that both of the ground service circuit breakers were out. There was a company engineer on board so, in the presence of the crew, he attempted to reset the circuit breakers. The two breakers would not reset and during the attempt the ground power tripped off and two further circuit breakers popped. APU electrical power was then selected onto the aircraft and a further unsuccessful attempt to reset the breakers was made.

At this stage the flight crew left the engineer to continue to rectify the problem and waited in the aircraft cabin. The commander then went into the terminal area for a short time to advise the passengers of the reason for the delay. On his return he was informed by the engineer that during the fault finding process further circuit breakers had popped. He waited in the forward part of the cabin and after a while became aware of an electrical burning smell. He returned to the flight deck to discover increasing amounts of smoke, whereupon he asked the engineer to shut the aircraft down and ordered all persons on board to evacuate.

When outside the aircraft smoke could be seen coming from both the forward electronic bay and airstairs hatches. The commander went up into the terminal to find the nearest telephone. He spoke to the call centre operator and requested that the fire service be called, but also that only one vehicle should attend so as not to alarm the waiting passengers. The operator repeated back his instructions to confirm they were correct and then called the Tyne and Wear Metropolitan Fire Brigade in accordance with her written procedures. Although it was not required by the procedures she then called Air Traffic Control (ATC) to advise them of the incident. ATC then contacted the Airport Fire Service (AFS) and a ground incident was declared. The AFS deployed in response and arrived at the aircraft ten minutes after the original call by the commander to the call centre. They used a thermal imaging camera in the flight deck and around the aircraft to check for heat sources. The camera detected a heat source indicating 800°C near the forward electronics bay.

Airport procedures

The written procedures for the call centre operators in the event of being notified of a fire incident included the following: 'to inform Tyne and Wear Metropolitan Fire Brigade'. There was not any instruction to notify the Airport Fire Service (AFS) or ATC.

The normal policy of the AFS is to deploy their whole fleet of fire vehicles when notified of any incident and to subsequently downgrade the attendance if required.

Aircraft Examination

The circuit breakers which had tripped initially were the three 28V AC Ground Service A, B and C phases (Circuit Breakers D13, D14 and D15) and the 28V AC Transfer Bus #1 (E15). After the resetting attempt the two further circuit breakers that tripped were the 28V AC Transfer Bus #2 (F15) and the Alternate Trailing Edge Flap Drive (D10).

Some fire damage was observed inside the fuselage on the right side of the aircraft, in the area of the forward toilet service panel, beneath the cockpit floor and forward of the Electrical and Electronic compartment (see Figure 1). The area contains the toilet servicing ducts as well as inertial reference units and numerous wiring bundles. Included in the list of systems affected by the damage were; autothrottle system, digital stall warning system, engine idle control, engine ignition, thrust reverser control (No 2 Engine), right wing slat and flap indicating systems, altitude information from Air Data System No 2, Inertial Reference Systems, EFIS power and weather radar.

Figure 1: Fire damage to wiring and insulation material viewed from nose landing gear bay

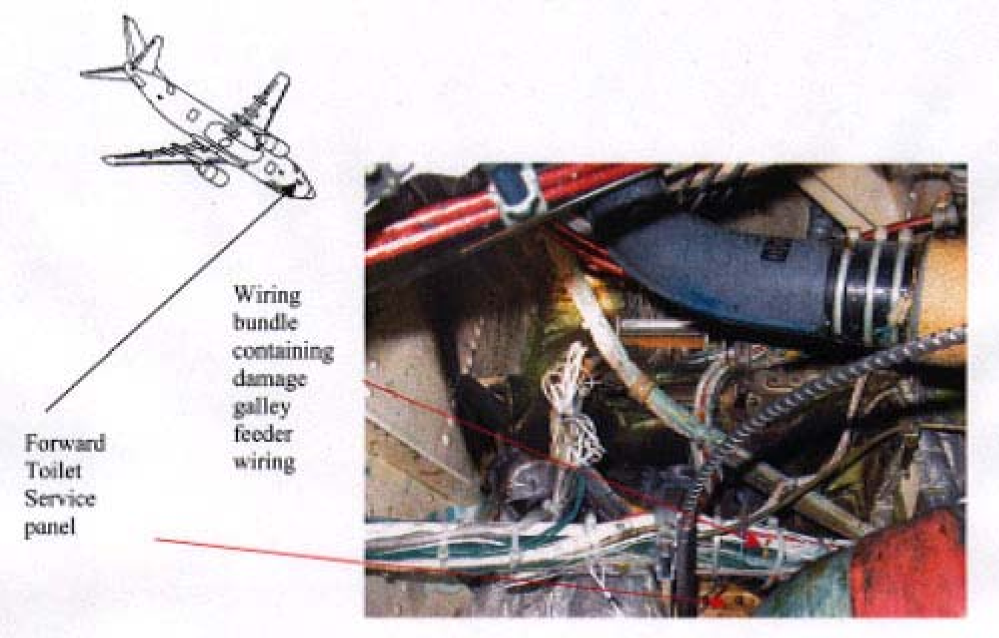


Figure 1 – Fire damage to wiring and insulation material viewed from nose landing gear bay

There was evidence of dried blue fluid (toilet sanitising fluid) contamination indicating that there had been leakage from the toilet charge pipe in the area of the forward toilet service panel. The ground engineer also reported that the area has been wet from the ingress of moisture from rainfall the previous night when the integral airstairs had been used. The APU had been run for a period of 20 minutes in order to dry the underfloor area before resetting the Circuit Breakers.

A short duration flash fire had apparently occurred; there was evidence of fire having consumed some of the aircraft insulation material. The majority of the wiring bundles from this area were insulated with polyimide (Kapton). Some of these wires had separated and examination showed evidence of damage from heat and arcing but there was no evidence that the wires had been contaminated or chafed prior to the fire. Similarly, there was no evidence on the adjacent structure that chafing or arcing had occurred. However, examination of the 10 gauge Boeing Material Specification (BMS) 13-31 3-Phase 115V AC galley power feeder cables did show evidence of some pre-existing damage (see Figure 2). The insulation material for these cables is a mineral filled polytetrafluoroethylene (ie Teflon).

Figure 2: Damage to galley power feeder cables

Photograph courtesy of Boeing Commercial Airplanes

Figure 2 - Damage to galley power feeder cables

Laboratory analysis of wiring segments removed from the aircraft was carried out by the aircraft manufacturer. They concluded that there was evidence that some insulation material from the galley feeder cables had been missing prior to the incident; the exposed edges of the insulation contained 'grooves' along its length and some of the wire strands appeared mechanically damaged. Tests on undamaged wires showed that damage similar to the 'grooves' could be caused by the insulation being torn away rather than cut from the wire.

Maintenance history

The operator had taken over the lease for this aircraft in March 2001. In November 2000 maintenance work had been carried out to replace the forward toilet service panel by a third party maintenance organisation behalf of the previous operator. The upper latch of the servicing panel door was replaced on 9 March 2003. No maintenance work had been carried out in the area above the forward toilet service panel highlighted by this incident by the current operator and none prior to this flight. There were no reports of any previous electrical problems on this aircraft.

Analysis

The galley feeder cables carry a three phase 115V AC giving a 200V potential between the exposed wires of the damaged cables, thus providing the possibility for arcing. It is probable that the arcing between the galley feeder cables eventually started a process of arc tracking of the polyimide insulated wires, which would have continued until the circuit breakers tripped and started again when the electrical power was reapplied. It could not be determined when the damage to the galley power feeder cables occurred or why arcing sufficient to cause the fire occurred on this particular occasion.

Damage consistent with the insulation material being torn away from the wires was identified on at least two of the wires. It is probable that this damage occurred at some earlier time, possibly during the replacement of the forward toilet service panel in November 2002. The ignition source of many previous occurrences of on-board fires has been attributed to mechanical damage to wiring as a result of aircraft maintenance.

The AFS airside location means they are the most immediate source of fire cover airside for the airport. The local service is off airport, takes longer to deploy to the airport and has less direct airside access, but is able to provide extra manpower and equipment if required. It is therefore inappropriate that instructions to telephone operators, or other personnel, should require a local fire service alone to be contacted for an airside fire alert. The action of the call centre operator in contacting ATC ensured that there was an AFS deployment even though the callout was delayed by ten minutes as a result of the procedures.

Safety action

The operator has since carried out visual inspections of the wiring in the area above the forward toilet service panel highlighted by this incident on a sample of six other B737 aircraft. No wire damage or interference between wire bundles and aircraft structure was found.

Since this incident the procedures in the Emergency Orders for Newcastle Airport have been revised to include an instruction to call centre operators to notify the AFS directly as well as Tyne and Wear Metropolitan Fire Brigade in the event of a fire alarm or incident. As a result no specific safety recommendations have been made by the AAIB. This incident has highlighted airworthiness issues which reflect broader concerns on all aircraft types regarding wiring condition, particularly as aircraft age and modifications are introduced. These broader concerns are addressed in the overview document included in this issue of the AAIB Bulletin.