

Boeing 737-236 series 1, G-BGJL: Main document

Aircraft Incident Report No: 8/88

Report on the accident to Boeing 737-236, G-BGJL at Manchester International Airport on 22 August 1985

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Operator:	British Air tours
Aircraft Type:	Boeing 737-236 series 1
Nationality:	British
Registration:	G-BGJL
	Manchester International Airport
Place of Accident:	Latitude 53° 21' N
	Longitude 002° 16' W
	22 August 1985 at 0613 hrs
Date and Time:	All times in this report are in UTC

SYNOPSIS

The accident was notified to the Air Accidents Investigation Branch (AAIB) on the morning of 22 August 1985 and an investigation began that day. The AAIB team comprised Mr D F King (Investigator in Charge), Mr M M Charles (Operations), Mr S W Moss (Engineering, Powerplants), Mr C A Protheroe (Engineering, Fire), Mr E J Trimble (Engineering, Evacuation/Survival), Mr C J Ford (Operations), Mr D J Mearns (Operations), Mr R A Davis (Cockpit Voice Recorder) and Mr P F Sheppard (Flight Data Recorder).

At 0612 hrs G-BGJL, carrying 131 passengers and 6 crew on a charter flight to Corfu, began its take-off from runway 24 at Manchester with the co-pilot handling. About thirty six seconds later, as the airspeed passed 125 knots, the left engine suffered an uncontained failure, which punctured a wing fuel tank access panel. Fuel leaking from the wing ignited and burnt as a large plume of fire trailing directly behind the engine. The crew heard a 'thud', and believing that they had suffered a tyre-burst or bird-strike, abandoned the take-off immediately, intending to clear the runway to the right. They had no indication of fire until 9 seconds later, when the left engine fire warning occurred. After an exchange with Air Traffic Control, during which the fire was confirmed, the commander warned his crew of an evacuation from the right side of the aircraft, by making a

broadcast over the cabin address system, and brought the aircraft to a halt in the entrance to link Delta.

As the aircraft turned off, a wind of 7 knots from 250° carried the fire onto and around the rear fuselage. After the aircraft stopped the hull was penetrated rapidly and smoke, possibly with some flame transients, entered the cabin through the aft right door which was opened shortly before the aircraft came to a halt. Subsequently fire developed within the cabin. Despite the prompt attendance of the airport fire service, the aircraft was destroyed and 55 persons on board lost their lives.

The cause of the accident was an uncontained failure of the left engine, initiated by a failure of the No 9 combustor can which had been the subject of a repair. A section of the combustor can, which was ejected forcibly from the engine, struck and fractured an underwing fuel tank access panel. The fire which resulted developed catastrophically, primarily because of adverse orientation of the parked aircraft relative to the wind, even though the wind was light.

Major contributory factors were the vulnerability of the wingtank access panels to impact, a lack of any effective provision for fighting major fires inside the aircraft cabin, the vulnerability of the aircraft hull to external fire and the extremely toxic nature of the emissions from the burning interior materials.

The major cause of the fatalities was rapid incapacitation due to the inhalation of the dense toxic/irritant smoke atmosphere within the cabin, aggravated by evacuation delays caused by a door malfunction and restricted access to the exits.

1 Factual Information

1.1 History of events (see Appendix 1)

The two pilots and four cabin crew, (one male purser and three stewardesses), reported for flight KT28M, Manchester to Corfu, at 0500 hrs on the morning of Thursday 22 August 1985, with a scheduled departure at 0600 hrs. The pilots, the commander (a training captain) and a senior first officer, completed their pre-flight preparation. The purser briefed the cabin crew, allocating their duties before boarding the aircraft.

Upon reaching the aircraft, the commander carried out an external check while the co-pilot completed the pre-flight checks on the flight deck. The purser checked the safety equipment in the cabin, which was being prepared for the arrival of the passengers. The aircraft documents on the flight deck were examined and an entry in the technical log (entered on the previous day) relating to slow acceleration of No 1 (left) engine was discussed, the co-pilot having been a member of the crew on that occasion. As there had been no reported problems on the two flights after remedial action had been carried out, the commander signed his acceptance of the aircraft in the technical log.

It had been arranged that the co-pilot would fly the aircraft on this sector and a comprehensive discussion of their respective duties and the actions to be taken in the event of an emergency during take-off, before or after V1* (146 knots (kt)), took place between the pilots as part of the "Captain's Briefing".

The engines were started by the co-pilot and no abnormalities were observed during the start sequence. The commander requested clearance to taxi at 0608 hrs and, when cleared, taxied the aircraft to the holding point of runway 24 (Appendix 2). The cabin crew carried out the safety equipment demonstration to the passengers, after which the purser reported to the commander that there were 129 passengers plus 2 infants, a total of 131 passengers on board. A child and one of the infants were seated on their parents' laps at the aisle seats of row 10 (10C, 10D), the row adjacent to

the overwing exits, using child lap straps provided by the cabin crew. The two aisle seats of row 11 (11C,11D) were left empty.

The purser and the No 4 stewardess working in the forward part of the aircraft strapped themselves into their seats, each with a full harness. They were sitting on a stowable bench seat in the left forward galley with their backs to the forward bulkhead, facing rearwards. Stewardess No 4 was in the outboard position adjacent to the left front (L1) door and the purser was in the inboard position nearer the centre of the galley and the cabin aisle; both were forward of a galley bulkhead resulting in a restricted view of the cabin. It is assumed that stewardesses Nos 2 and 3 were occupying the crew seats in the rear galley, also on the left side of the aircraft, but facing forward with an unobstructed view of the passenger cabin (Appendix 3 Fig a).

The aircraft was cleared to line up on runway 24, and as full nose-wheel steering was available only through a tiller on the left (commander's) side of the flight deck, the co-pilot assumed control after the commander had lined the aircraft up on the runway. Limited nose wheel steering is available through the commander's and co-pilot's rudder pedals. The aircraft was then cleared for take-off at 0612 hrs with the wind reported as 250° at 7kt (para. 1.7), and the co-pilot requested take-off power. The commander advanced the throttles and commented that the No 1 engine acceleration was acceptable - the first officer agreed that it was better than on the previous day, the auto throttle was selected and the engines achieved the required take-off power. During the take-off run the commander made the routine call of "eightyknots" which was confirmed by the co-pilot, and 12 seconds later a 'thump' or 'thud' was heard.

Immediately, the commander ordered "stop", closed the throttles and selected reverse thrust on both engines. He then checked that the speed brakes (spoilers) were extended. The maximum Indicated Air Speed (IAS) achieved was 126 kt. The commander thought that they had suffered a tyre burst or a bird strike.

Both reverser systems deployed and the right Engine Pressure Ratio (EPR) peaked briefly at 1.32 before settling at 1.25 for approximately 5 seconds, after which reverse was de-selected on both engines at a speed of about 70 kt; only the right engine reverser buckets retracted. The left engine EPR fell to zero within 2 seconds of the 'thud', and it remained at zero thereafter. The left engine high pressure spool speed (N2) decayed more gradually, with the result that the reverser buckets on the left engine were able to deploy fully. However, by the time reverse was de-selected the N2 had decayed to the point where falling engine oil pressure inhibited the reverser operating system, locking-out the left engine system with the buckets fully extended.

The co-pilot had applied maximum wheel braking, however, because the commander considered a possible cause of the 'thud' to be tyre failure, and as there was considerable runway remaining ahead of the aircraft, he said "Don't hammer the brakes, don't hammer the brakes." The co-pilot responded by modulating the braking effort. At 45 seconds after the start of the take-off run, 9 seconds after the 'thud', as the aircraft decelerated through 85 kt ground speed the commander started to inform Air Traffic Control (ATC) by a Radio Telephone (RTF) call that they were abandoning the take-off. The fire bell on the flight deck started ringing almost coincident with the start of this transmission and he added as he cancelled reverse thrust, "it looks as though we've got a fire on number 1". Following a 3 second pause, 19 seconds after the 'thud' and before the crew had inhibited the fire bell, ATC transmitted, "right there's a lot of fire, they're on their way now." Coincident with the end of this transmission the fire bell was inhibited and as the ground speed reduced below 50 kt the commander queried with ATC whether he needed to evacuate the passengers. The controller replied "I would do via the starboard side." This message was passed 25

seconds after the 'thud', 20 seconds before the aircraft stopped, as it decelerated through 36 kt groundspeed.

Some 6 seconds later, 14 seconds before the aircraft stopped, as the commander initiated the turn into link Delta he warned his crew of an evacuation from the right side of the aircraft by making a broadcast over the cabin address system; "Evacuate on the starboard side please." As the aircraft's groundspeed reduced through 17 kt, 10 seconds before it stopped, the purser opened the flight deck door and said, "Say again", seeking confirmation of the evacuation order. The commander repeated, "Evacuate on the starboard side", 8 seconds before the aircraft came to a halt.

Immediately the aircraft stopped the commander ordered the engine fire drill to be carried out on the left engine by the co-pilot, and as the passenger evacuation was to be carried out on the righthand side, shut down the right engine.

The passenger evacuation drill, a non-memory drill was called for by the commander and was read from the Quick Reference Handbook by the co-pilot. Before they were able to complete the drill the commander saw fuel and fire spreading forward on the left side of the aircraft, opened the co-pilot's sliding window on the right side of the flight deck and ordered him to evacuate the aircraft. This the co-pilot did by means of a fabric escape strap secured above the sliding window and he was followed down to the ground by the commander.

Passengers in rows 1-3 appear to have been initially oblivious of the fire which issued from the engine after the 'thud'. However, most of those seated aft of row 5, and in particular those aft of row 14 on the left side, were immediately aware of an intense fire. The flames were seen to cause some 'cracking and melting' of the windows, with some associated smoke in the aft cabin before the aircraft stopped. These effects, with the accompanying radiant heat, caused some passengers to stand up in alarm. A male passenger shouted "sit down, stay calm". Similar calls were then made by others seated mainly on the right side of the aircraft. Many sat down, but some found the pressure to move into the aisle irresistible.

The purser and stewardess seated in the left of the forward galley area during the take-off run heard a 'thud' which they too thought was a tyre burst. They were aware that the take-off had been abandoned and that reverse thrust had been selected. There were sounds of distress in the cabin and the purser leaned inboard in an attempt to improve his view and saw passengers standing up. He made a Public Address (PA) announcement for passengers "to sit down and to remain strapped in", released his harness and went into the forward part of the cabin. He saw fire outside the aircraft on the left side coming up over the leading edge of the wing and flowing back over the wing's top surface. There was no smoke or fire apparent to him in the cabin at that time.

After the purser had confirmed the evacuation with the commander he repeated the evacuation call a number of times over the PA system. Then, as the aircraft was coming to a halt, he went to the right front (R1) door to open it and release the inflatable escape slide. The door unlocked normally but as it was moving out through the aperture the slide container lid jammed on the doorframe preventing further movement of the door. After spending a short time trying to clear the restriction he postponed further effort and crossed to the L1 door. He cracked it open, ascertained that the forward spread of the fire was slow enough to allow evacuation from that door, opened it fully and confirmed the inflation of the slide manually. This was achieved about 25 seconds after the aircraft had stopped and coincident with the initiation of foam discharge from the first fire vehicle to arrive. Evacuation began on the left side under the supervision of the No 4 stewardess, who had to pull free some passengers who had become jammed together between the forward galley bulkheads in order to start the flow.

The purser returned to the R1 door, lifted the slide pack in order to close the slide container lid, and cleared the obstruction. He succeeded in opening the door about 1 minute 10 seconds after the aircraft stopped and again confirmed the automatic inflation of the slide by pulling the manual inflation handle. Evacuation was carried out from this exit supervised by the purser.

Smoke emanating from the cabin quickly reached the galley area and became rapidly more dense and acrid. When the smoke began to threaten severe incapacitation, the forward cabin crew vacated the aircraft by the slides at their respective doors.

As the aircraft came to a halt and at the instigation of other passengers, a young woman sitting in row 10 seat F (10F), beside the right overwing exit, attempted to open it by pulling on her right hand arm-rest which was mounted on the exit hatch. Her companion in seat 10E, the centre seat of a row of three, stood up and reached across to pull the handle located at the top of the hatch marked "Emergency Pull". The hatch, weighing 48 lbs, fell into the aircraft, pivoting about its lower edge to lay across the passenger in 10F, trapping her in her seat. With the assistance of a man in row 11 behind the women, the hatch was removed and placed on vacant seat 11D. The passengers in 10F and 10E then left the aircraft cabin through the overwing exit onto the wing followed by other survivors. This exit was open about 45 seconds after the aircraft stopped.

During the latter stages of the abandoned take-off, and just as the aircraft turned towards taxiway link Delta, the right rear (R2) door was seen by external witnesses to be open, with the slide deployed and inflated. A stewardess was initially visible in the doorway but the door and slide were obscured by thick black smoke as the aircraft stopped. No one escaped through this door. Two passengers remember seeing one of the two stewardesses from the rear of the aircraft struggling to direct passengers in the rear aisle. Neither rear stewardess survived.

The left rear (L2) door was opened by firemen some time after the fire had been extinguished.

In total, 17 surviving passengers escaped through the L1 door, 34 through the R1 door and 27 through the overwing exit including 1 infant and 1 child in arms.

The air and ground movements controllers in the tower had seen the fire and smoke trailing behind the aircraft (Appendix 4) and had initiated 'full emergency' action. The air controller activated the alarm siren connected directly to the aerodrome fire service station (Manchester International Airport Fire Service - MIAFS), and gave brief details of the emergency to the MIAFS watchroom over the direct telephone link. The ground movements controller alerted the emergency telephone operator at the Manchester International Airport Exchange.

Members of the MIAFS who were on duty at the time, heard a bang and saw an aircraft decelerating on runway 24. Black smoke and flames were trailing from the left side of the aircraft and the firemen had already initiated their response when the crash alarm siren sounded.

Two Rapid Intervention Vehicles (RIVs) attended first, one arriving at the aircraft coincident with, the other just after the L1 door had opened and its slide deployed, as passengers were about to start to evacuate. About 30 to 40 seconds later, as two major foam tenders took up position, the R1 door was opened fully and its slide deployed.

The MIAFS vehicles were positioned in order to attempt to keep the escape routes clear of fire, and to attack the source of the fire.

A British Airways crew coach arrived at the accident site after about 4 minutes, carrying a Tristar cabin crew, who rendered first aid and comfort to the survivors and later to an injured fireman. They also led the survivors away from the aircraft and onto coaches for transportation to a suitable holding area, and then on to hospital. Other ramp and airport authority vehicles also attended.

A third foam tender arrived at the site, some 4 to 5 minutes after the aircraft had stopped, having been retrieved from the paintshop. On arrival the driver saw a hand move above a man trapped in the right overwing exit. He left his cab, climbed onto the wing, and pulled a young boy clear over the body of the man trapped in the exit. This boy, who was the last evacuee to survive the accident, was rescued some 50 minutes after the aircraft stopped.

Approximately 7 minutes after the aircraft stopped it became clear that no more passengers were likely to evacuate unaided and firemen equipped with breathing apparatus entered through the R1 door. However, an explosion occurred which blew one of the fireman out of the door and onto the tarmac. Following this, the officer in charge, who was becoming increasingly concerned about the limited amount of water remaining on the fire fighting vehicles, ordered that no further attempts to enter the cabin should be made until a reliable water supply was established. The crew of one of the foam tenders was directed to go to the nearest hydrant on the airfield to refill but this, and several others were tried and found to be dry. (After 10 minutes delay this vehicle returned empty and was redirected to the hydrant at the fire station.)

During the fire, the tail section and the fuselage aft of the wings collapsed onto the ground due to thermal weakening of the structure. Eye-witness accounts of the time at which this occurred varied considerably, from an estimated 35 seconds after the aircraft stopped by the crew of RIV 2 to many minutes later by other witnesses.

At 0621 hours the Greater Manchester Council (GMC) Fire Service arrived at the North rendezvous point (RVP) and, after having waited for an escort which had to be redirected from the West RVP, arrived at the site at 0626 hours, 13 minutes into the incident. Shortly after this a two man team with breathing apparatus entered the aircraft through the R1 door and reported a number of bodies. About 33 minutes after the aircraft stopped a male passenger was found still alive but unconscious, lying in the aisle near the front of the aircraft. He was the last person to be removed alive but died some 6 days later in hospital.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	2	53*	-
Serious	-	15	-
Minor/None	4	63	1 (fireman)

(* Including the man rescued after 33 minutes who died 6 days later in hospital.)

1.3 Damage to aircraft

The left engine combustion casing was split open, causing substantial secondary damage to the engine and nacelle, and the forward section of the No 9 combustor can had been ejected through the damaged engine casing. A fuel tank access panel on the lower surface of the left wing immediately outboard of the engine had been punctured, producing a large hole in the base of the main fuel tank. (Appendix 5 fig a) The left engine nacelle and adjacent areas of wing had been damaged by fire and the wing had suffered additional damage caused by an explosive over-pressure within the fuel tank. The right wing and engine were undamaged.

Parts of the rear fuselage left sidewall together with most of the cabin roof were burnt away, and the rear fuselage and tail section had collapsed to the ground. Most of the cabin interior was extensively burnt and the floor in the rear of the passenger cabin had collapsed down into the rear cargo hold.

Those areas of the cabin interior which had escaped direct damage by the fire were covered with a thick coating of viscous soot. (Appendix 3 photos e-f)

1.4 Other damage

There was some fire damage and fuel spillage on the runway and taxiway link Delta.

1.5 Personnel information

1.5.1

Commander	Male aged 39 years
Licence:	Airline Transport Pilot's Licence valid until 9 March 1986
Last medical examination:	Class 1 Medical Certificate valid until 30 September 1985 with no limitations
Part 1 Pilot-in command ratings:	PA 23, 30 and 39 Trident HS121, HS 748 Boeing 737 Series Certificate of Test: valid until 16 December 1985
Instrument rating:	Valid until 7 December 1985
Route check:	Valid until 29 November 1985
Emergency equipment and procedures check:	Valid until 18 January 1986
Flying experience:	Total all types: 8,441 hours Total Boeing 737: 1,276 hours Total last 28 days: 54 hours 25 minutes
Other ratings and approval:	Authorised by the Civil Aviation Authority (CAA) as a Type Rating Examiner, in respect of Boeing 737 aircraft. Also CAA approved as an Instrument Rating Examiner.
Duty time:	On the day before the accident the commander

was on duty for 4 hours 30 minutes, positioning by surface transport. Prior to this he had had the previous 2 days free of duty. Rest period before reporting for duty on 22 August 1985 was 15 hours 45 minutes.

1.5.2

Co-pilot: male aged 52 years

Licence:

Airline Transport Pilot

Last medical examination:

Class 1 Medical Certificate

30 September 1985, for distant vision and exercising the privilege

Part 1 Pilot-in-Command

PA 18, 22, 25, 28 and

ratings: Boeing 737-

Certificate of Test:

Valid until 30 November

Instrument Rating:

Valid until 25 March

Emergency equipment and procedures check:

Valid until 5 March 1985

Flying experience:

Total all types:

Total Boeing 737:

Total last 28 days:

Duty time:

The co-pilot had, on the day before the accident, flown a total of 5 hours 50 minutes within a flying duty period of 7 hours 09 minutes. The previous 2 days were free of duty, and his rest period before reporting for duty on 22 August 1985 was 17 hours 06 minutes.

1.5.3 Cabin crew:

1.5.3.1

Purser:

Male aged 39 years

Air steward 9 years.

Promoted Purser 5 May 1985.

Safety Equipment and Procedures (SEP)
refresher and check undertaken

3 and 4 January 1985.

Worked a duty period of

7 hours 39 minutes the previous day.

Duty time:

Rest period before reporting for the accident flight, 14 hours 36 minutes. The 3 days before the previous duty period were free of duty.

1.5.3.2

Forward Stewardess (No 4):

Aged 26 years

Employed on a seasonal contract from May 1984 until 31 October 1984. SEP certificate for Boeing 737 and L 1011 TriStar aircraft dated 1 June 1984. Re-employed April 1985,

SEP certificate Boeing 737 and L1011
TriStar

aircraft renewed 11 April 1985.

Subsequently employed on a permanent basis.

Duty time:

Duty and rest periods were as for the purser. The preceding 2 days were free of duty.

1.5.3.3

Rear stewardess (No 2):

Aged 23 years

Employed on a seasonal contract February 1985. Initial entry SEP certificate for Boeing 737 and L1011 TriStar aircraft dated 26 February 1985. Aircraft familiarisation for Boeing 737 and L1011 TriStar aircraft was completed on 15 and 16 March 1985 respectively. Previous experience was from May to August 1984 with an independent Boeing 747 operator.

Duty time: Duty and rest periods were as for the purser. The preceding 7 days were free of duty

1.5.3.4

Rear stewardess (No 3): Aged 27 years

Employed on a seasonal contract February 1985. Initial entry SEP certificate for Boeing and L1011 TriStar aircraft dated 26 February 1985. Aircraft familiarisation on Boeing 737 aircraft completed 2 March 1985. No recorded previous experience.

Duty time: Duty and rest periods were as for the purser. The preceding 3 days were free of duty.

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer: Boeing Commercial Airplane Company.

Type: Boeing 737-236 Series 1.

Engines: Two x Pratt & Whitney JT8D-15

Date of Manufacture: April 1981

Certificate of Airworthiness: UK Transport Category (passenger)

Valid to 2nd April 1986

Certificate of Maintenance

Valid to 26 November 1985

Review:

Total airframe hours: 12,977 hours

Total airframe landings: 5,907 landings

Weight and balance:

Maximum take-off weight 54,200 kg (119,511 lb)

Take-off weight (actual) 52,696 kg (116,195 lb)

Weight at time of accident 52,696 kg (116,195 lb)

Take-off fuel 12,370 kg (27,275 lb)

The weight and centre of gravity were well within the prescribed limits.

Fuel Jet A1

1.6.2 Engines

1.6.2.1 General

The Pratt and Whitney JT8D-15 is a two-shaft turbofan engine. The combustion section is can-annular and comprises 9 combustor cans enclosed by a Combustion Chamber Outer Case (CCOC) (Appendix 5 Fig b). Compressor delivery air enters the CCOC, where a small proportion is mixed with fuel in the combustor cans and ignited to produce the combustion flame. The remainder of the compressor air flows around the inner and outer walls of the cans to provide a cooling flow (note: the combustion temperatures are above the melting point of the can materials and thus the cooling flow is essential to maintain can integrity). Whilst the combustor cans contain the combustion process, the CCOC must withstand the compressor delivery pressure (in the order of 240 psi at take-off conditions) and it is therefore essentially a pressure vessel. It is basically a one-piece tube of AMS 5603 steel alloy with flanges fore and aft which attach to the engine casing by two rings of steel bolts.

The combustor cans themselves comprise a cast Stellite dome, or head, and 11 liners of Hastelloy X sheet material (Appendix 5 Fig c). The dome incorporates swirl vanes which direct the incoming compressor delivery airflow into the can prior to mixing with fuel from the fuel nozzle which is inserted into the centre of the dome. The fuel nozzle also provides radial location of the forward end of the can. Axial location is achieved via an integrallug on the dome which picks up on a mounting pin bolted to the diffuser case. The remainder of the can is constructed from 11 rings (liners) of sheet Hastelloy X material of varying diameters to achieve the desired profile of the can. Liner 3 incorporates the flame transfer ports to adjacent cans. The liners are resistance seam-welded to each other. The aft end of liner 11 is a sliding fit in the transition duct bulkhead, which provides radial support for the rear of the can but allows movement in an axial direction to accommodate thermal expansion and contraction. Can numbers 4 and 7 also have an igniter plug boss incorporated in Liner 2. All cans are fitted with an "air scoop" over the top of liner 2, as part of a programme to reduce the engine's smoke emission.

Cooling of the liners is achieved by directing the relatively cool compressor delivery air over the outside surfaces of the can and onto the inner surface through small film-cooling holes adjacent to each liner joint. Since there is a pressure differential of about +3% of compressor delivery pressure from outside to inside of the can, cooling air will flow inwards. Larger holes in the liner also allow larger volumes of air to flow in locally to cool and adjust the combustion gas flow pattern inside the can.

The combustor cans fitted to G-BGJL's engines were to Pratt and Whitney modification standard 5192, ie. the latest standard applicable to the JT8D-15 at the time of the accident. The modification was intended to overcome various problems encountered on the previous standard of can, including cracking of the seam weld between liner numbers 2 and 3. This was felt to be particularly undesirable because it occurred under the air scoop and could only be detected by radiographic techniques. It was stated by the manufacturer that this modification standard would provide a combustor can of "improved durability".

The combustion section is further enclosed by an aluminium alloy fan case which forms the by-pass duct and is the externally visible part of the engine casing in this area.

Each engine was fitted with a thrust reverser system typical of reverser systems fitted to this category of aircraft, comprising a pair of clam-shell doors which swung on linkages from their stowed position (around the exhaust duct) into a position aft of the engine, where they deflected the exhaust gases sideways and slightly forwards to provide reverse thrust (Appendix 6 Fig a).

Boeing 737 installations differed from the norm however, by having the 'split plane' of the reverser doors inclined at approximately 45° to the horizontal, with the lower door inclined outboard, so as to limit the ingestion of debris blown up by the reversed exhaust efflux. The thrust reverser door actuating system was inhibited below a critical engine oil pressure, nominally 35 psi.

1.6.2.2 History of the engines fitted to G-BGJL

(a) Engine serial number P702868 (Left)

This engine was delivered new to British Air Tours in April 1980 whilst fitted to aircraft G-BGJG. In the winter of 1983/1984, the engine was removed and stripped for a sample layout (see paragraph 1.17.2). At that time a Light Maintenance Inspection (LMI) was performed and the engine was re-assembled with repaired combustor cans from another engine, serial number P702946. This engine had been prematurely removed, having run 7482 hours/3371 cycles since new, in September 1983 due to a pilot report of high exhaust gas temperature and visible compressor damage. The engine was stripped and it was found that a failure of the 13th stage compressor outer shroud had caused damage to the 13th stage compressor blades. It was considered economically advantageous to perform an LMI at this shop visit, thus the combustor cans were inspected and repaired as necessary - this work being completed on 16 November 1983. Although the actual lengths of cracks found in the cans were not recorded, the Engine Strip Report for P702946 noted that "5 off combustion chambers (combustor cans) exhibited considerable burning and cracking to the 3rd liners adjacent to cross-overtubes". After the accident to G-BGJL, it was possible to determine the crack lengths from radiographic plates which had been retained. These radiographs had been taken to inspect for cracking in the 2/3 liner area (ie under the air scoop) but, fortuitously, the film also covered the area up to liner 5, specifically the 3/4 liner joint.

Examination of the radiographs showed that the can exhibiting the most cracking in the 3/4 liner joint was can No 9, serial number TS351 (installation position was the same on both engines). A circumferential crack 160 mm in length extended in the third liner from the male flame transfer tube around the outboard face of the can, in the area of the seam weld to the fourth liner. A second crack 25 mm in length, barely discernible from the radiograph, was seen about 50 mm further round from the main crack (Appendix 5 Fig d).

Can No 7 exhibited cracking in a similar area to the main crack in can No 9 but only some 75 mm in length. Can No 6 also had a crack of about 60 mm in this area. The remaining cans had either minor circumferential cracking of less than 50 mm in length or, in three cases, no discernible circumferential cracks.

It was also noted from detailed examination of the radiographs of the can set that can No 1 had a distinctive area of multiple "branchy" cracking in the 3rd liner area - some of the cracks having joined together and liberated a small triangular piece roughly 2.5 mm along each side. The length of the circumferential cracking was, however, only some 35 mm.

All the above mentioned cracks in the cans were addressed by direct fusion weld repairs during the LMI. Pre-weld Solution Heat Treatment (SHT) and post-weld stress relief (see paragraph 1.17.2) were not carried out.

The cans were installed in engine P 702868 which was fitted to G-BGJL on 2 February 1984 and ran a further 4,611 hours/2,036 cycles before the accident flight. The total hours/cycles run on the cans were thus 12,093/5,397, whilst the engine itself had run 14,503 hours/6,552 cycles.

(b) Engine serial number P 702841 (Right)

This engine was delivered new to British Airtours in January 1980 whilst fitted to aircraft G-BGDE. It had had three unscheduled removals in September 1982, August 1983 and October 1984. It was fitted to G-BGJL on 7 February 1985. At the time of the accident it had run 9,946 hours/7,172 cycles since new. There are no indications that the performance of this engine played any significant part in the sequence of events which led up to the accident.

1.6.2.3 Entries in the aircraft's technical log concerning performance of the left engine and associated rectification action

The aircraft's technical log and technical records were examined to determine the number and nature of crew-reported defects on the left engine since the installation of engine serial No P702868 in February 1984. Of particular interest were flight crew reports of slow acceleration, slow start and throttle stagger (see paragraph 1.17.2). A large number of these were found as detailed below:-

Throttle Stagger	Slow Acceleration	Slow Acceleration & Throttle Stagger	Slow Start
25.9.84	18.2.84	11.2.84	11.7.85
14.6.85	6.5.84	16.6.85	16.7.85
	6.5.84	20.8.85	
	6.11.84	21.8.85*	
	29.12.84		
	29.12.84		
	16.1.85*		
	17.1.85		
	25.1.85		
	29.7.85.		
	5.8.85		

Dates marked with an asterisk * indicate where the flight crew also commented on a low ground idle N2.

Slow acceleration is based on the time taken for the engine to reach the "stand up" setting of 1.4 EPR from ground idle. ("stand up" - both throttle levers moved to the vertical)

"Throttle stagger" refers to a mismatch in the position of the pilot's throttle levers when the EPR for both engines are matched. In all cases where throttle stagger was reported, the left engine lever was forward of the right engine lever to achieve the same EPR.

The three log entries for the month of August, 1985 are discussed in greater detail later in this section. The other 16 entries were dealt with in a variety of ways, including times when the crew were asked to accept the aircraft and to report further on the symptoms - on occasions no further crew comment was made. Where actual work was performed on the aircraft, it was always of a minor nature (eg checking the PS4 line for leaks and moisture contamination, checking engine bleed air for leaks). This rectification action appeared to cure the symptoms and, consequently, at no time was the engine combustion section checked for a disrupted gas path. Trim runs (see paragraph

1.17.2.3) were performed on 16 February 1984 and 18 June 1985 but the log merely records that they were carried out with no indication of any Fuel Control Unit (FCU) adjustment having been performed. Following the "slow acceleration" report on 17 January 85, the ground crew reported that they found the left engine ground idle N2 speed to be 1% low and adjusted the FCU accordingly.

The following is a verbatim extract from the Technical Log for the 5th, 20th and 21st August 1985 (Engine related reports only):-

Date	Defect	Action
5.8.85	No 1 (left) engine very slow to accelerate both forward and reverse	No 1 FCU damper versilubed (lubricated) PS4 line blown through
20.8.85	No 1 engine slow to spool up on take-off and about 1-2 inches throttle stagger at 1.4 EPR	PS4 pipes checked for leaks. Fuel system bled. Please give further report.
21.8.85	No 1 engine does not accelerate for 5 or 6 secs with thrust lever halfway up quadrant. Ground idle is very low: 28% N1 and 50% N2. Autothrottle drops out due to the amount of stagger at first. In the air, No 1 engine slower than No 2 as well.	ADD* raised for full trim run with test set to be carried out on No 1 engine. PS4 filter water drain trap removed - some water found. Ground idle adjusted 1 turn increase. Now matches No 2 engine but still seems slow to No 2 engine. Would crews please report further. (*Acceptable Deffered Defect)

The aircraft flew a further two sectors, a total sector time of 7 hours 14 minutes, arriving back at Manchester at 0431 hours on 22nd August 1985. No flight crew comment was made in the Aircraft Technical Log regarding the condition of either engine.

Statements made by the two technicians tasked with attending to the log entry on 21st August confirm the information contained in the "action" column above. Having consulted with British Air Tours Base Engineering at Gatwick, they elected to remove and replace the PS4 filter water-drain trap and adjust the ground idle trim screw by one turn in the 'increase RPM' direction. Both engines were then started normally and it was observed that both N2 gauges were reading 58%. The throttles were advanced to a point where the EPR gauges began to register a change. They reported that there was still about 0.5 inches of throttle stagger at the top of the levers when the EPR readings matched but were evidently satisfied that the acceleration times of both engines were similar and acceptable. Subsequent examination of the aircraft's Flight Data Recorder indicates that the left engine accelerated at about the same rate as the right but did not achieve the same levels of N2 and EPR during the ground run. This is consistent with the comments regarding throttle stagger and "still seems slow compared with No 2" (right) ie if both throttles were advanced together, then the right engine would achieve higher RPMs and EPRs than the left engine.

The ground crew also raised an ADD entry in the log to perform a trim run at the next visit to Gatwick (where a trim test-set was held). It would also appear that, had the flight crews remained dissatisfied with the performance of the engine, the aircraft would have been re-rostered into Gatwick on the 22nd August for this work to be performed.

1.6.3 Engine fire warning and suppression systems

The aircraft was fitted with separate FIRE and OVERHEAT detection systems designed to alert the crew to excessive temperatures within the engine nacelles. Flight deck indications were by means of warning captions and indicators, augmented in the case of a FIRE warning by an audio warning (bell sound). Built-in test equipment enabled serviceability checks to be carried out on both fire and overheat systems before each flight.

G-BGJL was typical of Boeing 737 (and other current commercial) aircraft in being equipped with a conventional "two shot" main engine fire suppression system.

1.6.4 Fuel system

Fuel was carried in three fuel tanks, all of which were integrally formed within the aircraft's wing structure. The two main tanks of 4,590 Kg capacity each were formed (one in each wing) by the main torsion box, and extended from the root rib outboard to a position close to the wing tip. The wing centre section formed the centre auxiliary tank, which had a capacity of 7,416 Kg.

Access to the interior of each main wing tank was provided by means of a total of 13 elliptically shaped removable access panels varying in size from approximately 18" by 10" inboard to 16" by 6" outboard, which were secured flush with the lower skin surface and sealed against fuel seepage by an 'O'ring gasket. The access panels were manufactured from a cast aluminium alloy material and had stiffening webs integrally formed on the upper (internal) surface. The panels were nominally non-stressed components so far as flight-loads on the wing were concerned; impact strength did not form a part of the design requirements for the wing lower skin, nor the access panel. The cast aluminium material had an impact strength approximately one quarter that of the lower wing skin, which formed the tank floor proper.

1.6.5 Air conditioning system

The aircraft had two air conditioning packs, each with a maximum delivery rate of 78 lb/min, which were supplied by the main engines or by the Auxiliary Power Unit (APU). The conditioned air was distributed throughout the cabin via a system of manifolds and ducts leading to the overhead nozzles and zone supply louvres. Exhaust (stale) air left the cabin via floor level louvres located in the cabin side-wall panels, and made its way into the cavities surrounding the cargo hold liners, i.e. the interspaces between the fuselage outer skin and the cargo hold side-lining, and the cargo hold roof-lining and the cabin floor (Appendix 6 Fig b). (The fibreglass wool insulation blankets, which fill the structural cavities between the cabin liners and the outer skin, were reduced in thickness around the hold areas to facilitate the passage of exhaust air). Approximately 56% of the total cabin exhaust air was routed via the floor louvres aft of the wing into the aft cargo hold cavity, from where it was dumped overboard via the main outflow valve situated in the rear fuselage underbelly. Approximately 36% was routed via floor level grills in the forward cabin, into the forward hold cavity, and thence into the electronic equipment bay where it was used to cool the equipment before being dumped overboard via the electronic equipment bay exhaust. The remainder of the exhaust air left the aircraft via various local vents and as a result of general leakage.

1.6.6 Cabin windows

Each cabin window comprised an assembly of three acrylic ("perspex") panels mounted into individual recessed forged aluminium frames (Appendix 6 Fig c). In order to improve their physical properties, the outer transparency panels, (the primary load-bearing panels), were stretched during manufacture whilst in a heated (soft) state, and allowed to cool and harden in the stretched condition. The centre panels, which were failsafe load-bearing panels designed to provide a back-up in case of a failure of the outer panel, were manufactured from cast acrylic. The inner transparencies were thin panels designed primarily to protect the load-bearing panels from damage.

The two load-bearing panels in each aperture were located mainly by the recessed shape of the aperture housing, and were held into the aperture by a series of retention clips arranged around the periphery. The edges of the acrylic load-bearing panels were fitted with rubber gaskets to provide an air seal. The inner transparency panels were attached to, and effectively formed a part of, the decorative window reveal panels.

Acrylic is a thermoplastic material which starts to soften at temperatures of approximately 100°C.

1.6.7 Fuselage construction

The fuselage was of conventional construction utilising aluminium alloys for the main structural components and the external skin.

The fuselage cross-section was formed by a series of approximately circular ring frames spaced at regular intervals (typically 20 inches apart) along the length of the fuselage. Longitudinal stiffeners (typically of a 'top-hat' section) were spaced at intervals of approximately 10 inches around the circumference of the frames, and the whole structure was clad in skin panels which were riveted to the frames and longitudinal stiffeners. In the area of the rear cargo hold, the fuselage skin thickness was 0.036 inches.

At mid height on the fuselage (ie at cabin floor level) the longitudinal stiffeners extended the full width of the ring frame, and were known as "crease beams" (Appendix 6 Fig b). A series of floor beams, also fabricated from light alloy, were attached transversely to the frames at this same level, and these were connected fore-and-aft by further floor beams running longitudinally.

The cabin floor comprised a number of fibreglass/nomex honeycomb panels, which were attached to the floor beams. In the web sections of the crease beams there were a series of large holes to allow the passage of air conditioning exhaust air from the cabin section above the floor through to the cavity surrounding the cargo hold below.

The space below cabin floor level in the centre of the fuselage was occupied by the mainplane centre section carry-through structure, which also formed the centre fuel tank. The greater part of the remaining sub-floor space was occupied by the aft and forward cargo holds and the landing gear bays, except at the extreme forward and aft ends of the fuselage, which housed various system components. The cargo holds were accessed only via separate external cargo doors on the right side of the fuselage.

Within each cargo hold area, the internal space was lined by a thin, wear resistant fibreglass laminate, known as the cargo hold liner. The cavity formed between the cargo hold liner and the outer fuselage skins and between the liner and the cabin floor panels was used to provide an exit path for air conditioning exhaust air leaving the cabin interior.

1.6.8 Internal configuration - Approval and evacuation certification:

The aircraft was fitted with 130 passenger seats, two double and one single cabin crew seats. One of the double crew seats was forward of door L1 facing rearwards and the other double aft of door L2 facing forwards. In the forward passenger cabin a pair of full height galley bulkheads were positioned just aft of the two doors, L1 and R1. In the aft end of the cabin a full height stowage unit was located just forward of door R2 with a single crew seat mounted on the rear of it, facing aft. (Appendix 3 Figs a-b)

This configuration was in compliance with British Airways Configuration Modification No 25C211, Drawing No 1-54378 certified by the British Airways authorised engineer as being in compliance with the appropriate regulations on the 20 November 1981.

This drawing specifies a seating pitch of:

	Rows 1-9	Rows 9-10	Rows 10-22
Pitch	30 ins	31 ins	29 ins

In addition, this drawing specified that the outboard seats at row 10, ie 10A and 10F, should be of a type modified to prevent the seat-backs from hinging forward and row 9 seats should have no recline, in order that access to both overwing exits should not be impeded. The seat backs of row 9, in common with the majority of seats, could be folded forwards to create more room for the upper body of any person moving between rows 9 and 10 to the overwing exits. The Boeing 737 Type Certificate allowed the 737/200 model to be equipped with 130 passenger seats provided there was compliance with Federal Airworthiness Regulations (FAR) 25.2(b), (c) and (d). The Emergency Evacuation requirements for this Public Transport aircraft were in accordance with FAR 25.803 (Appendix 7).

United Kingdom evacuation certification of this aircraft type, with 130 passenger seats, was carried out at Luton Airport on the 26 November 1970 using a Britannia Airways Boeing 737-204 model. The 130 passengers and 5 crew were evacuated from the left exits (ie aft, overwing and forward) in 75 seconds.

1.6.9 Emergency equipment and exits

The aircraft was equipped with four main cabin doors ('Type 1') (para 1.17.6), two overwing emergency exits ('Type III') and two sliding-window emergency exits on the Flight Deck (Appendix 3 Fig a).

Each main door incorporated a slide pack which when used in the 'automatic' mode, ie with the slide 'girt-bar' pre-engaged in twin floor-mounted brackets, was designed to provide automatic inflation of the slide when the door was opened in an emergency. In addition, each slide included a 'manual' release handle which could be used to achieve inflation if it had not occurred automatically.

The overwing emergency exits were located at either side of row 10 and were intended for ground evacuation of centre cabin passengers, or as the primary exits for use after a sea-ditching (Appendix 3 Fig c). For the latter purpose, these exits were each equipped with a webbing-type escape rope/lifeline, anchored to the upper/forward corner of the aperture, with a snap-hook on the other end for attachment to a lug located on the upper surface of each wing near the trailing edge. These lifelines were some 17 feet in length and designed to provide evacuees with a means of stabilising themselves while on the wing upper surface prior to boarding the rafts. From the anchor point a single thickness of line ran along the top of the exit to a storage tube at the upper aft edge of the aperture. This portion of the line was designed to be held in position by retaining clips. The remaining line was stored in the tube attached to the structure with the exception of the snap hook

which was located in a pouch at the upper aft corner of the exit. For ground evacuation, arrows painted on the upper surface of each wing were intended to lead evacuees to the trailing edge and down the extended flaps.

On pulling the overwing exit hatch release handle the hatch, weighing 48 lbs, pivots inboard about its lower edge and requires lifting to remove it from the aperture to make the exit available.

The passenger flight safety card exercised a large amount of artistic licence in representing the area local to the overwing exit. (Appendix 3 Fig d) It indicated a large area in which to stand to remove the hatch and showed the hatch then being placed on the row 10 seats, the armrests raised. Even if this was achievable, bearing in mind the weight of the hatch and the fact that armrests are normally down, (always for take-off and landing), in this position it represents a further obstacle to anyone trying to reach the exit from the aisle. Furthermore the person opening the hatch was depicted in an all blue 'uniform' in the same way as were cabin crew in other sections of the safety card, possibly leading passengers to think that the hatch would be opened by a member of the crew.

The Flight Deck had two sliding-window emergency exits for use by the pilots, with two associated webbing-type escape ropes stored in the overhead above the windows.

The cabin crew stations at the forward and aft passenger doors (ie left) were each equipped with an interphone and passenger address microphone. The forward cabin crew were also provided with two 'Scott' smoke hoods, located in a cupboard stowage facing their bench-seat. One 1.5 Kg capacity Bromochlorodifluoromethane (BCF) fire extinguisher bottle (discharge duration 15 seconds) was also located in a stowage locker facing this seat. The other three smoke hoods, for use by the cabin crew, were stored in the overhead 'bin' at row 18 (right). One 1.5 lbs capacity water fire extinguisher was stored in this area of the cabin within the right overhead at row 20. A further two, 1.5 Kg BCF extinguishers were located on the aft wall of the rear right bulkhead. Two megaphones were available for cabin crew use, one stored in the forward left overhead bin at row 2 and the other in the aft right overhead at row 18.

Ten portable oxygen bottles were stored in the cabin overheads; two (for crew use) were located at row 2 right, two units either side of the aisle at row 10 (for passengers) and four units within the overhead at rows 20-21 right, of which three were designated for crew use.

1.7 Meteorological information

The accident happened during daylight.

The weather recorded at Manchester Airport at 0550 hrs was:-

Surface Wind:	270°/5 kt
Visibility:	25 km
Cloud:	1 okta at 1,400 feet
Temperature:	+ 13°C
QNH*:	1014 millibars

*(Corrected mean sea level pressure setting)

The weather recorded at 0620 hrs was:-

Surface Wind:	260°/6 kt
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Visibility:	1,000 metres in smoke
Cloud:	1 okta at 1,400 feet
Temperature:	+ 13°C
QNH:	1015 millibars

The Manchester Automatic Terminal Information Service (ATIS), information 'C' was received by the crew prior to starting engines. This gave the surface wind as 280°/6 kt, variable 240°-320°. When ATC cleared the aircraft for take-off, they passed a surface wind of 250° at 7 kt. The runway was dry.

1.8 Aids to navigation

Not applicable.

1.9 Communications

1.9.1 ATC

The RTF callsign of this flight was Beatours 28 Mike and Very High Frequency (VHF) communications were entirely normal.

Communications on the Ultra High Frequency (UHF) frequencies used by the fire service and ATC, together with those on the telephone links, were normal.

1.9.2 Aircraft public address (PA)

The aircraft's PA system allowed announcements to the passengers to be made from the flight deck, the forward galley area, and the rear galley area. The system had two gain (volume) levels, the lower for use before engine start, and the higher gain (by 6 decibels) selected automatically by the operation of the left engine oil pressure switch, for use after engine start and during flight. The failure of the left engine therefore caused the system gain to revert to the 'low' setting, significantly lowering the volume at the time the purser instructed the passengers to remain seated and the commander ordered the evacuation. A number of passengers did not hear these announcements, however, whether this was due to the lower volume or the effect of the noise level in the cabin could not be determined.

1.9.3 Interphone system

The aircraft's interphone system comprised a Service Interphone, allowing communication between the flight crew, cabin crew and ground engineers, and a Flight Interphone to permit communication between the flight crew and a ground crew member without interference from the Service Interphone.

It was possible to communicate with the flight deck from the forward and rear cabin crew stations using the Service Interphone, but its use was not encouraged during periods of high flight crew workload, such as take-off or landing, and it was not used following the 'thud'.

1.10 Aerodrome information

1.10.1 Manchester International Airport (Appendix 2)

Manchester International Airport, located 7.5 nm south west of Manchester was operated by Manchester International Airport Authority. The airport had a single runway 06/24, 3,048 metres in length by 46 metres wide with hard shoulders extending to 23 metres eachside, giving a total paved width of 92 metres. The take-off run available was 3,048 metres with a take-off distance available of 3,200 metres. The surface was concrete/asphalt.

The main terminal and manoeuvring areas were all on the northern side of the runway. The southern area was used almost exclusively for light aircraft and general aviation activities.

The scale of rescue and fire fighting (RFF) protection at Manchester International Airport met the requirements of CAP 168 for a Category 8 Aerodrome. Operation of a Boeing 737 only requires protection at Category 6 level at best.

1.10.2 Media requirements, media provision and discharge rates

Under clause 2 of the aerodrome licence, Manchester International Airport was required to provide the following minimum amount of fire fighting media appropriate to a category 8 airfield:-

Water for production of fluorochemical foam	= 18,200 litres
Fluorochemical foam concentrate	= 1,080 litres
Discharge rate water/foam	= 7,200 litres per minute

Complementary media requirement was:-

450 kgs of Dry Powder or 450 kgs Halon (BCF) or 900 kgs Carbon Dioxide or a combination of the above. 50% of the complementary media could be substituted by water for production of fluorochemical foam. In that event a substitution rate of 1 kg for 1 litre of water applied.

The following amounts of media were available for immediate response at the time of the accident:-

Water for production of fluorochemical foam	= 24,244 litres
Fluorochemical foam concentrate	= 2,850 litres
Maximum discharge rate water/foam	= 13,183 litres

1.10.3 Fire fighting and rescue equipment

On the day of the accident, Manchester Airport fire service had the following vehicles on immediate standby:-

Two rapid intervention vehicles (RIVs):

Each vehicle carried 50 kgs of Halon BCF, 817 litres of water, 73 litres of Aqueous Film Forming Foam (AFFF) concentrate and had a maximum (mixed) foam discharge rate of 908 litres/minute. These vehicles were based on modified Range Rover chassis and their purpose was to provide rapid access to the fire - to give 'first aid' fire protection pending the arrival of the major foam tenders.

One 'Protector' major foam tender, carrying:-

100 kgs of Halon BCF, 9,080 litres of water, 1,067 litres of AFFF concentrate and having a maximum foam discharge rate of 4,540 litres/minute,

One "Jumbo" major foam tender (J1), carrying:-

13,620 litres of water, 1,634 litres of AFFF concentrate and having a maximum foam discharge rate of 6,810 litres/minute.

Each of the major foam tenders carried sufficient foam concentrate for two full water tank loads, ie their water tanks could be replenished once before there was a need to re-charge with foam concentrate.

These appliances, together with a small ambulance, were on standby in the airport fire station located just north of the intersection between taxiways 2-North and 3, some 825 metres from the position where the aircraft stopped. A second fully equipped Jumbo foam tender (J2) was undergoing re-painting in hangar 3, some 550 metres from the fire station. Additionally, a Land Rover fire vehicle, which at the time of the incident was providing fire cover at the apron area, responded to the incident. This vehicle carried 50 kgs of Halon BCF and 100 kgs of Monnex powder (100 kgs of Monnex is deemed equivalent to 200 kgs of Halon BCF), but it had no foam capability. Even with the absence of J2, the fire cover available at the time of the accident exceeded the licencing requirements then applicable at Manchester.

1.10.4 Airport hydrants

Manchester Airport was equipped with a series of water hydrants spaced at intervals along the southern edge of the main runway, around the airfield western boundary, and at the fire station. Shortly after the accident, the water pressures at the hydrants in the area of link Delta were measured and found to be between 40 and 50 psi, giving flow rates of between 165 and 190 imperial gallons per minute.

At the time of the accident, the water hydrant system on the airfield was in the process of being modified by the installation of an additional water main, which was being laid alongside the existing main south of the runway to provide increased flow rates. This work had been in progress for some considerable time prior to the date of the accident. To facilitate the interconnection of the new and original pipework it had been necessary from time to time to isolate sections of the system.

Control over maintenance work at the airport was enforced by a system of work permits, issued solely on the authority of the Head of Engineering Services. Permits for work involving the isolation of hydrants carried several conditions, one of which was that the isolation was not to be carried out by the contractor's personnel. Furthermore, in the case of any work affecting the serviceability of hydrants, it was established practice for the Senior Fire Officer to be informed in advance and the information promulgated on the fire station notice board. At the time of the accident, no permit had been issued in respect of any work involving the serviceability of the hydrant system, nor had notification been given of any proposed work.

Investigation of the circumstances surrounding the hydrant failure has revealed that the system of work permits had not been adhered to; valves had been turned on and off by the contractor's personnel without any form of control and without the knowledge of the fire service. On the morning of the accident, contractors arriving for work observed firemen attempting to obtain water from the hydrants. Shortly after this, the water supplies were restored.

1.10.5 Emergency services liaison

The emergency orders in force at the time of the accident provided for the immediate notification of the Local Authority emergency services in the event of an aircraft accident. This notification was to be communicated by land line from the Airport Fire Service watch room.

For some considerable time prior to the accident it had been the practice of the external emergency services to respond to the West RVP, which is located near the airport fire station, where they met with a police escort vehicle. However, on the 25th July 1985, a meeting was held between the Head of Airport Services, the Airport Fire Officer and a Senior Fire Officer from the GMC. At that meeting, it was agreed that for all future incidents the RVP for external emergency services would be changed to the North RVP. The Police were not informed of the meeting and did not attend; they were not informed about the changes in procedure, nor were the changes promulgated. When the accident occurred, the external emergency services were told to report to the (new) North RVP, but this detail was not passed to the police, who dispatched their escort vehicle to the original West RVP. The fire service ambulance, departing from established procedure, acted as an escort vehicle but it too went to the old meeting point at the West RVP.

The delay in attendance by the GMC fire service, caused directly by the confusion over RVPs, was approximately 3 minutes, and occurred at a time when the effectiveness of the airport fire service was being limited by a shortage of water.

1.11 Flight recorders

1.11.1 Flight data recorder (FDR)

The aircraft was equipped with a Davall 1198 re-cycling wire, accident protected, digital FDR, this had a duration of 25 hours and was part of a Plessey PV1940 recording system. This system also incorporated a quick-access cassette which recorded essentially the same information as the accident protected recorder. A total of 27 analogue parameters plus 73 discrete parameters (events) were recorded.

The FDR was mounted overhead in the rear passenger cabin, just forward of the rear pressure bulkhead. It was recovered intact, the exterior being smoke blackened. The mechanism showed no sign of damage and no major problems were encountered during replay.

1.11.2 Cockpit voice recorder (CVR)

A Fairchild A100 CVR, an endless loop four track recorder with a duration of 30 minutes, was installed in the aircraft. The allocation of the four tracks was as follows:-

Track 1	P2 headset audio + 'live' microphone
Track 2 -	cockpit area microphone
Track 3 -	P3 headset audio + 'live' microphone
Track 4 -	P1 headset audio + 'live' microphone

The CVR was mounted in the aft end of the rear cargo hold. It was recovered slightly fire damaged and with some physical damage to the casing. The plastic based recording medium had not suffered any damage whatsoever and after removal a satisfactory replay was obtained.

1.11.3 Flight recorder analysis

There was an area of poor quality data during the ground roll, but this was partly recovered using manual bit shifting routines. Part of a second was, however, not recoverable. It is probable that the data had been corrupted due to electrical transients caused by the automatic bus bar switching which took place as a consequence of the engine failure.

A transcript of the CVR over the relevant period was produced and synchronised with the FDR data by comparing the recorded VHF key switch position with the ATC calls on the CVR.

The airspeed measuring system was of a type which did not record below 40 kt, and as such was not suitable for deriving the aircraft's position along the runway. This was derived by calculating the ground speed by means of an integration of the recorded longitudinal acceleration which had been corrected for datum error and pitch attitude changes. This was then used in conjunction with the recorded heading to calculate the aircraft's position, assuming that there had been no sideslip. The fixed datum position used was the known point at which the aircraft had come to rest.

It was known that the aircraft had executed a rolling take-off and from the calculations it would appear that the ground speed at power up was of the order of 5 kt. The airspeeds derived from the calculated ground speeds and reported wind speed agreed well with the recorded airspeeds. The points along the runway at which significant events occurred were thus deduced.

1.12 Wreckage and impact information

1.12.1 On site

1.12.1.1 Wreckage trail

The dome-shaped section of the left engine No 9 combustor can, sections of engine cowl, broken pieces of bypass duct, fragments of left wing tank access panel and other debris from the vicinity of the ruptured left engine combustor case were found on the runway between link 'C' and runway 06 fast turn-off.

A trail of fuel was identified from characteristic damage to the runway paved surface, caused in part by the solvent action of the fuel alone and in some areas by a combination of solvent and heat damage. The outline of this trail, which could be identified on airborne photographs taken by a Royal Air Force reconnaissance aircraft shortly after the accident, began in the same area of runway that the engine debris was found. Initially, the trail took the form of a series of increasingly large patches of unburnt fuel, which merged into a continuous but irregular trail approximately 1.5m wide running parallel with, and approximately 5m to the left of, the runway centre line. The width of the fuel trail remained irregular, but progressively widened until it appeared to stabilise in the region of runway 24 fast turn-off, where it was approximately 3.5m wide and was darker in colour with a sooty appearance, consistent with the fuel having been burning at that stage. This burnt fuel trail continued around into link Delta and up to the position where the aircraft came to rest, where, in the area around the left engine, it merged into a larger area of fuel and fire-stained tarmac.

It was not possible to directly determine the boundary of the pooled fuel fire because of the extent of general heating of the tarmac in the area of the wing puncture and the rear fuselage. However, a topographical survey carried out specifically to determine the ground slopes in the area where the aircraft stopped identified a general slope away from the area of the left engine into the region forward and to the left of the fuselage. This coincided with a spur of tarmac damage clearly caused by fuel and/or fire running diagonally forward from the area of the wing puncture (Appendix 8 fig g). The slope of the ground between the wing puncture and the rear fuselage was uphill, involving a rise of approximately 70 mm.

The aircraft came to rest on a heading of 315° true.

1.12.1.2 Examination of engines

The left hand engine, Serial No P702868, had suffered an explosive rupture of the CCOC. The case had split along an axial line adjacent to No 9 combustor can and had then 'petalled' apart from approximately the 11 o'clock to 5 o'clock position (viewed from the front), failing the attachment bolts on the front flange and the flange itself on the rear face. The upper section of the CCOC had blown upwards onto the underside of the engine pylon, striking the fire/overheat detection system electrical loom. The lower section had blown downwards and outwards. Witness marks on the exterior surface of the CCOC adjacent to the rupture showed that it had struck the inner surface of the fan case as the rupture occurred. (Appendix 5 Fig e)

The aluminium alloy fan case had shattered into several pieces in the region of the CCOC rupture. The remainder of the outboard half had suffered severely from the post-rupture fire.

The engine cowlings comprised two upper fixed sections and two lower hinged access doors. The outboard upper section had been broken into many fragments consistent with object(s) having passed through it. A section of the lower outboard door had blown off in a large, single piece, indicating that overpressure, rather than contact with other debris, was responsible for its detachment. In-fill panels on the engine pylon also showed evidence of overpressure damage. The remainder of the engine, its cowlings and thrust reverser, (which remained deployed) had suffered severe fire damage, particularly on the outboard face. Through the ruptured CCOC, it could be seen that only some 50% of the No 9 combustor can remained in the combustion section.

The aft portion of the can remained in the transition duct bulkhead in a crushed and burnt condition, and had rotated about 90° from its normal orientation. Hastelloy X metal spatter deposits could be seen on the adjacent cans 1 and 8, and more spatter was later found behind the can in the transition duct and on the first stage nozzle guide vanes. The dome recovered from the runway showed that separation had occurred around the 3rd/4th liner joint area- the aft portion of the can had then burnt and buckled in an irregular manner (Appendix 5 Fig f). A sizeable portion had broken off into the can and was found lodged against the nozzle guide vanes.

The dome portion, which embodied the majority of liner 3, had suffered comparatively little damage. Witness marks were found which matched those on the holed underwing fuel tank access panel, and a sizeable metal scrape deposit on the air scoop was later analysed and found to be of the same material as the access panel, proving conclusively that the dome had struck the panel. Two small indentation marks in the air scoop also showed that the can location pin retention bolts had contacted the scoop as the dome assembly was forced outwards, fracturing the pin with a single overload bending force. Some galling of the fuel nozzle shroud, associated with similar marks in the mating hole in the dome was also found, indicating movement of the dome relative to the nozzle. The dome itself, particularly the exposed fracture surface of liner 3, was noticeably free of burning or overheat damage although there had been some mechanical damage to the fracture surfaces. In addition to extensive cracking in the 3/4 liner joint area cans numbered 1 and 8 had clearly suffered extensive damage due to their proximity to the badly disrupted No 9 can, with material missing. The other six cans showed varying degrees of circumferential cracking in this area.

The right hand engine, Serial No P 702841 was undamaged with the thrust reverser stowed.

1.12.1.3 Airframe mechanical damage

The centre of a fuel tank access panel on the lower surface of the wing immediately outboard of the left engine was broken-out, producing an approximately elliptic hole, 8" by 7", directly into the central region of the main fuel tank. The panel exhibited signs of having been struck forcibly on its lower (outer) surface.

The upper skin on the left wing was torn upwards, the corresponding sections of lower skin were severely bulged downwards and the ribs inside the tank were buckled. All of the damage to the left wing structure, with the exception of the broken access panel, was consistent with a rapid over-pressure of the tank cavity resulting from the ignition of fuel vapour within the tank.

The rest of the airframe was free of mechanical damage, but had suffered extensive fire damage.

1.12.1.4 Airframe fire damage - general

The aircraft was extensively damaged by fire. Most of the light alloy components in the aft region of the left engine nacelle were melted or burnt away. The left wing lower aft surfaces, large sections of the trailing edge flaps inboard of the engine and the lower surfaces of the flaps outboard of the engine were melted, and the remaining regions of the left inner wing and the main landing gear bay were superficially fire-damaged. The lower skin of the left tailplane was burnt through over a region extending approximately 1 metre inboard from the tip.

The rear fuselage was extensively burnt between the wing trailing edge and the rear doors; a large part of the left fuselage side between frames 787 and 887 (approximately seat rows 17 to 21) was completely burnt away. (Appendix 8 Fig a) The whole of the fuselage aft of the rear cargo door and the tail section had collapsed onto the ground.

Most of the passenger cabin ceiling and crown skins were burnt away (Appendix 8 Figs a-b) and all of the overhead luggage bins were destroyed. The support beams which carried the cabin floor above the rear cargo hold were burnt away in the central aisle area and on the right side of the cabin (in the areas immediately forward of, and aft of, the rear cargo door), allowing most of the cabin floor above the hold to collapse down onto the baggage. Most of the cabin interior fittings and seats in this section of the cabin were destroyed completely or were very extensively damaged. The interior fittings in the centre and forward sections of the cabin were generally less severely affected by the fire. However, there was considerable local variability, particularly in the severity of seat damage. Notably, seats 8C and 9C (left aisle seats just forward of the overwing exits) were completely destroyed, whereas the adjoining seats were relatively intact. (Appendix 8 Fig c)

1.12.2 Subsequent detailed examination

1.12.2.1 Engines

Following removal of the left engine it was transported to an overhaul shop where it was stripped to its basic components. This showed that, apart from damage to the combustion section it appeared to be generally in good condition, although it was noted that some turbine blade rubbing had occurred, apparently due to engine case distortion after the CCOC rupture.

All components of the combustion section of the engine were subjected to detailed examination both at the manufacturer's premises and the Royal Aircraft Establishment, Farnborough under AAIB supervision. In addition to a bench test in the overhaul shop, the FCU was despatched back to its manufacturer for testing.

Only the dome portion of combustor can No 9 was subjected to detailed fractography, because the degree of burning and material loss on the aft portion of the can precluded examination of the 3rd/4th liner joint area. In the following description, positions of the can fracture surface are by reference to 'clock' positions, viewed from the front with 12 o'clock being the mounting lug.

From 10 o'clock to 2 o'clock, the fracture surface had suffered considerable rubbing and, in the vicinity of the cross-over tubes, severe burning prevented identification of the nature of the

original fracture mechanism. (Appendix 5 Fig g) Most of the fracture surface which had not suffered secondary damage was identified as being of a fatigue nature - a significant proportion exhibiting fatigue facets. Generally, the cracking appeared to originate on the inner wall of the can and the facets appeared to originate at a multiplicity of origins. These multiple origins led to the simultaneous growth of many cracks at different positions around the circumference of can No 9. Indeed, as noted in paragraph 1.6.2.2., this can had exhibited two separate cracks, centred on the 11 o'clock and 2 o'clock positions, prior to its last shop visit for repair. These had been repaired but cracks at similar radial positions re-grew in service and were joined by a third major crack centred on the 6 o'clock position. On a microscopic scale, these major cracks were faceted, formed by the joining of smaller cracks growing from separate origins. Patches of fatigue growth linking the major cracks were found, some exhibiting very clear fatigue striations. The nature of this striated fatigue damage was different from that observed in the faceted crack areas in that it appeared to propagate from but a small number of origins, indicating that the striated areas propagated after the major crack areas had developed - i.e. the previously weld-repaired areas and a third area at the 6 o'clock position had cracked first from multiple origins and were subsequently joined together by a further fatigue mechanism, resulting from an increased mechanical influence, which resulted in 360° separation of the can.

Although it has been established that the weld-repaired areas appeared to have been the first to re-crack in service, it was noted that the crack did not necessarily follow the original pre-repair crack path. Whilst the re-cracking did exploit the repair in some areas, in others it carved a new path adjacent to the weld.

The quality of the weld repair was checked by microscopic examination of the material structure. Voids, cracks and included matter were detected in the weld repairs. Although these features indicated deficiencies in the welding technique, it was felt that a better indication of the strength of the weld would be the path of re-cracking which occurred. As noted above, it did not necessarily follow the original crack path and it was felt that other factors, such as the build-up in material thickness after welding and the local temperature distribution in service, would be just as important in determining the re-cracking path as the quality of the weld per se.

The CCOC was examined metallurgically to confirm the nature of the rupture. It was obvious on a microscopic scale that a portion of the fracture surface in the region just aft of No 9 can dome had thinned to a 'knife edge' over a length of about 175 mm - the remainder exhibiting rapid tensile shear failure characteristics.

A plot of the material dimensions in the thinned area showed that an elliptical-shaped bulge in the CCOC had occurred prior to the rupture and the material had thinned to effectively zero thickness and a 175 mm slit had formed.

The engine manufacturer provided data gathered from previous CCOC failure incidents in which the length of pre-existing longitudinal cracks in the CCOC had been determined. Although these incidents resulted from primary fatigue cracks in the CCOC itself, it was felt that the situation was analogous to the loss of material properties resulting from softening/bulging. This data suggested that for the JT8D-15 engine, the nominal critical crack length would be 117 mm, beyond which explosive rupture would be likely to occur. It was therefore appreciated that CCOC overheating would not necessarily lead to explosive rupture if it occurred over a relatively small, discrete area, in which case burn-through or bulges might occur. In the case of the left engine of G-BGJL, the overheating had occurred over a length considerably exceeding the critical length and had resulted in catastrophic failure.

A check on the hardness of the CCOC in the vicinity of the bulged area suggested that temperatures of up to 930°C had been experienced by the casing, at which temperatures the material properties would have been significantly impaired.

The fuel nozzles from engine P 702868 were tested against the manufacturer's specifications for both the flow rate and flow pattern, which could affect the local heat distribution and thus the level of distress felt by the can. The conclusion of the tests was that they did not reveal any functional discrepancies compared with in-service standards.

The No 9 nozzle exhibited heavy wear of the outside diameter of the nozzle nut where it engages in the No 9 can, consistent with excessive movement of the can relative to the nozzle having occurred after the dome section had separated from the rest of the can.

The FCU was examined to check its serviceability and settings. Whilst the unit had suffered some fire damage, it was still possible to bench test it and to extract various parameters relevant to the accident. In particular, it was found that there was no evidence to support a lack of 'idle speed repeatability' - ie failure to maintain an idle speed setting. The condition of the unit was generally as might be expected from a unit with about 15,000 hours since last bench calibration. The idle trim screw was found about mid-way in its 22-turn range. It was concluded that the unit was capable of running a JT8D-15 engine throughout its operational range.

FDR evidence indicated that both the right and left reverser systems deployed normally, but that only the right reverser retracted again into the stowed position; the left reverser remained fully deployed.

The left reverser mechanism had suffered general fire damage, resulting in partial seizure of the feedback mechanism and stiffness of the lock mechanisms. The operating cable and interlock system mounted in the wing above the pylon were also affected by the fire. The retraction mechanism operated satisfactorily when the hydraulic system was pressurised by means of a hand pump, and the only evidence of abnormality was stiffness of the various linkages as a result of the fire.

Analysis of the flight recorder data from preceding flights showed that the left engine oil pressure typically decayed to 35 psi at an N2 of 26% (the oil pressure switch which inhibits the thrust reverser actuating system is set to trip at a nominal 35 psi). Recorder data for the accident flight indicates that the left engine oil pressure fell below this value 3 seconds after the reverser had deployed, but approximately 6.5 seconds before reverser thrust was de-selected (assuming right and left reverse were de-selected together), de-activating the operating system before reverse was cancelled.

1.12.2.2 Fire (Appendix 8 Figs a-b)

Fuselage

The whole of the rear fuselage aft of seat row 19 had collapsed onto the ground as a result of external fire attack on the fuselage lower skin and longerons between frames 867 and 907, and fire damage to the cabin floor structure which led to floor collapse over much of the area above the aft cargo hold. Aft of the wing trailing edge, between seat row 14 and the rear entrance vestibule, the fuselage was partially destroyed by a combination of external and internal fire. The greatest damage was concentrated on the left side in the vicinity of the aft baggage hold.

Empennage

The left tailplane lower skin panels were burnt through over a region extending from the tip inboard approximately 1m. The remaining lower skin panels over the outboard two thirds of the tailplane were burnt free of paint and buckled by heat, and the honeycomb panels and lower elevator structure had been partially destroyed. Inboard of this region, the damage tapered-off rapidly, leaving the innermost 50 cm almost undamaged and with little discolouration of the paint - comparable with the damage on the adjacent fuselage skin. The left tailplane upper surfaces exhibited little heat damage and were free of heavy sooting except for a small region approximately 2m wide at mid-span, extending from the leading edge back to approximately the half-chord position. The leading edge over this same region was heavily streaked with an oily -soot deposit running in streamlines back over the leading edge, consistent with the impingement of partially burnt fuel droplets whilst the aircraft was moving at speed. This contaminated section of the tailplane leading edge was approximately in line with the outer lip of the deployed inboard (upper) bucket on the left engine thrust reverser. The upper surface of the elevator horn balance was heavily sooted and had suffered moderate heat damage. The left side of the fin and rudder were undamaged, with bright and clean painted surfaces.

The right side of the fin and rudder, together with the upper surface of the right tailplane and adjacent fuselage, were sooty and had suffered moderately intense heating - sufficient to burn the paint from the skin panels between frames and stringers. The damage on the fin and rudder progressively tapered off towards the tip, where it was limited to sooting and blistering of some honeycomb panels. The upper surface of the right tailplane was similarly affected, with moderate heat damage tapering-off towards the tip, becoming negligible at about two thirds span.

The remainder of the tail section exhibited sooting, paint blistering and/or discolouration in varying degrees but without any evidence of intense heating.

Cabin interior (Appendix 3 Photos e-f)

The fire destroyed all of the overhead lockers except for a small section above seats 21B and 22B, which had remained in position but was badly charred. Remnants of overhead lockers were found randomly distributed throughout the cabin (there had been considerable disturbance by rescue personnel). The ceiling panels were all destroyed. The cabin side-liner panels were destroyed over most of the cabin aft of seat row 14, but forward of that location the panels had survived mostly intact below seat squab level; above squab level the aluminium backing panels had generally survived but the decorative plastic coating had mostly melted and peeled away in strips, or had been burnt off completely.

The carpet forward of seat row 14 was largely intact, except for some areas of localised burning from above, which matched damage on the adjoining seats. Aft of seat row 14, the carpet was burnt from below in the areas where the floor had collapsed, and from above where the floor panels had remained in position.

The seats on the right side of the rear cabin (seats 15 to 22D, E & F) were completely burnt away leaving only the steel subframe components. The corresponding seats on the left side (rows 14 to 20) were badly damaged but were still in position. Further isolated areas of badly damaged seats were located around the left overwing exit (rows 8 to 10), just forward of the floor collapse area on the right side (rows 13 and 14), and at the forward end of the cabin against the right sidewall (rows 1 to 5). Elsewhere, the seats were lightly or moderately damaged, but there was considerable variability and much of the damage appeared random. In particular, seats 8C and 9C were completely destroyed whereas the adjacent seats were either undamaged, or were much less severely damaged. Generally, the seat damage above and below squab level was similar, but there were

several small areas where the fire beneath these seats had been more severe than that above them. (Appendix 8 Figc).

The upper halves of the forward entrance vestibules were sooted and, above chest height, the plastic decorative surfaces had partially burnt away. In contrast, the lower halves were free of significant soot deposits and there were no indications of heat damage. The rear vestibule was more severely damaged, but the fire's attack was mainly evident above waist level and was more pronounced on the right side of the aircraft, adjacent to the door aperture: there was relatively little heat damage close to the floor.

The upper halves of each toilet compartment and the flight deck were heavily sooted and there were thick layers of oily soot on all horizontal surfaces, but each of these zones was free of heat damage.

There was no significant fire damage aft of the rear entrance vestibule nor below cabin floor level forward of the rear cargo hold.

The damage affecting the centre and forward sections of the cabin was consistent with a fire burning internally within the passenger compartment, whereas the damage to the aft fuselage was consistent with a combination of external and internal fire.

The fire damage to the cabin interior as a whole did not fall into any single overall pattern, but it did reflect the general severity of damage to the adjacent structure, upon which was superimposed additional damage produced by burning overhead debris falling down onto the seats. Pockets of severe, isolated damage were present at several locations, but there was no direct evidence as to their cause.

Window panels

All three panels were missing from most of the window apertures in the rear cabin; some panels had remained in position in the three apertures immediately forward of the L2 door and the partially burnt remains of all three panels were still present in the aperture immediately forward of the R2 door. In the centre and forward sections of the cabin most window apertures had one or more panels present. All of the surviving outer window panels aft of the overwing exits displayed a cubic cracking pattern on their outer surfaces consistent with heating of the panel from outside. Forward of the overwing exits, many of the outer panels displayed similar damage but with the cracking on the inner surfaces - consistent with heating from inside the cabin.

Examination of the window panels indicated that the following external fire penetration mechanism had occurred:-

a) outer panels - extreme local shrinkage of the outer (heated) surface producing a deep cubic cracking pattern of the affected surface together with overall shrinkage and thickening of the panel, causing it to pull out of the retaining clips and fallout of the aperture.

b) centre panels - softening and bulging of the panel. The loss of the outer panel removed clamping pressure from the centre panel, allowing the centre panel to come out of its securing clips and fall out of the aperture.

c) The inner (anti-scratch) panels melted down and burnt.

The window apertures in which there were no panels remaining displayed widely differing degrees of heat damage and sooting in the areas normally protected by the silicone rubber window seals, giving an indication of the stage in the fire when the window panels became detached. Generally, the

sooting and heating reflected the degree of fire damage evident in the adjoining area of cabin. However, in the apertures adjacent to seats 17A and 18A (in the left side burn-through zone) the paint was still present and relatively free of soot, although it had started to bubble due to heat - consistent with those panels and/or rubber seals having been in position until quite late in the overall fire sequence.

Cabin doors and overwing exits

All main cabin doors were found latched fully open. Both overwing exits had been opened and the hatches thrown to the ground. (There had been significant unrecorded disturbance of all cabin access points during the rescue.) Neither L1 nor R1 door had suffered significant damage during the fire, but sooting on the doors and apertures indicated that each had been open for most of the period of the fire. The fire damage on the doors and apertures at the rear of the aircraft was consistent with the R2 door having been open throughout the fire, and the L2 door having been closed throughout. The sooting pattern around the overwing exit hatches and hatch apertures indicated that the right exit had been opened during the fire, but the left exit had remained closed throughout.

1.12.2.3 Fire detection and suppression systems

The FDR indicates that the left engine fire detector triggered 9 seconds after the combustion case ruptured, but the overheat detector did not trigger at all. Examination of the fire detector system was limited to the left engine sub-system.

The fire and overheat detector control modules were undamaged by the fire and performed satisfactorily when bench checked in accordance with the approved test procedures. The upper detector module overheat element was badly kinked and crushed during the engine rupture; all other detector elements were undamaged. All detector elements were electrically checked in the cold state and under hot conditions using approved test equipment; all performed within specification.

The power supply cable feeding the left engine overheat detector elements was severed in the area of damaged firewall above the ruptured engine casing, disabling the whole of the left engine overheat detector system. The remaining overheat detector wiring and the whole of the fire detector system wiring was intact.

Both main engine fire extinguisher bottles had discharged fully. Examination of the discharge heads indicated that both bottles had been discharged into the left engine. Subsequently, the then empty number 1 bottle had been "discharged" into the right engine.

The enclosure formed by the left engine cowls, upon which the system relies to contain the extinguishing agent, was lost as a result of the heavy damage sustained when the combustion case burst.

The APU fire extinguisher bottle was completely discharged.

1.12.2.4 Fuel system

The fuel system was in its normal take-off configuration with all fuel pumps ON and the cross-feed OFF. At the time of examination, both Low Pressure (LP) shut-off valves were closed.

The right and centre tanks were completely undamaged. The left tank was not damaged by the fire but had suffered extensive mechanical damage. The access panel on the lower surface immediately outboard of the ruptured engine combustion case had been broken out in its centre, producing an

approximately 42 square inch hole directly into the tank interior (Appendix 9). Fragments of this access panel were recovered from the runway and one other fragment of the panel was recovered from inside the tank cavity. Reconstruction of the access panel fragments revealed witness marks and a pattern of distortion which matched exactly the shape of the No 9 combustor can dome and a fan case fragment.

Outboard of the engine, the skins forming the tank roof were torn upwards from the spars and the corresponding bottom skin, forming the tank floor, was severely bulged downwards. The tank ribs and internal structure were distorted in a manner compatible with chordwise tensile loading of the skins between the spars. With the exception of the damaged access panel, all damage to the left main fuel tank was consistent with a rapid overpressure of the tank cavity due to the ignition of fuel vapour in the outer section of the tank. The fracture surfaces at the upper skin/spar interface were relatively clean, whereas the adjoining skin surfaces were significantly sooted - indicating that the explosive overpressure occurred after the fire had been burning for some time.

At the start of the accident sequence the aircraft fuel load is estimated to have been:-

each wing tank	(full)	4,590 kg
centre tank		3,420 kg
total		12,600 kg

The fuel remaining in each tank could not be measured directly because of the practical difficulty of emptying each tank separately. However, a tide mark of soot was found on the internal rib and spar surfaces inside the left tank at a height which corresponded to the level of the damaged access panel, enabling the post-accident fuel contents of the left tank to be determined and hence the total fuel loss to be estimated.

The total quantity of fuel lost from the punctured left wing tank is estimated to have been 2,109 kg (689 US gals at specific gravity 0.808), based on the position of soot 'tide-lines' on vertical surfaces within the interior of the left wing tank and the tank initial contents and taxi fuel consumption data.

The leak rate was estimated by the manufacturers, based upon their knowledge of fuel flow rates through the various baffles and the internal structure of the wing. This data suggested that the leak rate would initially be very high, in the order of 16 US gals per second, but this would decay rapidly as the tank compartment immediately above the puncture emptied. After about 40 seconds, the leak rate would have decayed to approximately 2 US gals per second and would remain at approximately that level until approximately 200 seconds. Beyond that stage, the rate would taper off and the flow would cease after a total time of approximately 250 seconds. (Appendix 9)

As an independent check on the validity of the leak rate estimate, the theoretical leak rate was integrated with time and the resulting total compared with the leaked fuel estimate based on the residual fuel contents. These figures agreed within 5%.

1.12.2.5 Oxygen

The emergency oxygen distribution system mounted in the overhead units was destroyed in the fire, but because the system was isolated there was no discharge of oxygen. Both passenger and crew reservoirs were indicating full and the discharge discs were intact.

1.12.2.6 Doors and emergency equipment

Door slides

Inspection of the R1 door confirmed that the hinged lid of the slide container had fouled against the aft/lower radius of the aperture. A witness mark was present adjacent to the aft/lower corner of the lid which was consistent with contact between the lid and the door aperture. (Appendix 10 Photos a-c) The slide container lid is designed to be held closed by a latch mechanism, attached by a short length of cable to the 'girt-bar', which is manually engaged within two floor mounted brackets when the doors are 'selected to automatic' by the cabin crew as part of their pre take-off procedures. This latch will then automatically release the slide-box lid due to cable tension if the door is opened for emergency evacuation. The latch mechanism should not unlock until the door has cleared the aperture sufficiently to allow the slide to fall and deploy without any risk of fouling.

The R1 door slide was still inflated after the accident, as was that from the L1 door. The R2 slide had deployed fully, but had subsequently been partially burnt in the ground fire, causing deflation. The R2 girt-bar was still in position on the floor engagement brackets, with remnants of the slide 'apron' still attached and the manual inflation handle still fixed to its 'velcro' retainer.

Overwing exits

A male passenger had become lodged within the right overwing exit where he had ultimately died and the area adjacent to this exit was therefore examined in detail.

The seat next to this exit (ie seat 10F) was inspected in order to identify any means by which the man may have been trapped. It was noted that the existing gaps between the six coil springs, which support the vinyl-plastic seat-base to the seat-frame on either side, could trap only a small foot if the seat cushion became displaced from its "velcro" retention. (Appendix 11) The photographs taken of this area immediately after the accident show this cushion to have been displaced but this mechanism could not have trapped this particular individual.

In addition, this seat (and seat 10A adjacent the left overwing exit) was of a type with a 'baulk' fitted to the seat-back hinge, designed to prevent the seat-back hinging forward and restricting access to the overwing exit. However, inspection of the baulk on the 10F seat showed that it had failed as a result of pressure applied from behind the seat-back. In addition, the position of the baulk was consistent with the seat-back having been displaced almost fully forward, onto the seat cushion. The corresponding seat at 10A was inspected and the associated hinge-baulk was found still intact.

Two child's lap-belts were found still attached to the seat-belts associated with seats 10C and 10D.

In addition some survivors who had used this exit referred to a "white canvas strap" or "webbing" across the aperture. These descriptions were consistent with the ditching-strap/lifeline which is secured to the forward/upper corner of the overwing exit and is, in part, clipped along the upper width of the aperture. This strap had been consumed by the fire.

Seat pitches and aisle dimensions

Dimensional checks were carried out at the row 10 exit area and gave the following results:-

Access gap between front of row 10 seat cushions and back of row 9 seats: 10.5 inches

Distance from front of seat 10F cushion to projected forward outside edge of overwing aperture : 2 inches

Height of exit 'sill' above cabin floor: 14 inches.

Overwing exit aperture: 38.25 inches high x 20 inches wide.

Height of exit 'sill' above wing surface: 22-24 inches.

In addition, the cabin seat-pitch was measured:-

	Rows 1-9	Rows 9-10	Rows 10-22
Pitch	30 inches	31 inches	29 inches

Dimensional checks carried out with respect to cabin aisle width and also the width between the twin forward bulkheads gave the following results:-

Aisle width (measured at arm rest level): 15.5 -17.5 inches.

Forward cabin bulkhead gap width (constant width, floor to ceiling):-

22.5 inches. (Appendix 3 Fig b)

Cabin crew seats and equipment

The aft cabin-crew seats were inspected. The forward-facing twin bench seat located on the left side adjacent the L2 door was found with the seat folded up, enclosing both sets of lap straps, with the associated buckles undone. The surfaces enclosed by the folded seat had escaped the effects of fire, in contrast to the upper area of the back-rest and associated shoulder straps, indicating that the seat had been unoccupied and folded-up before the heat had become intense. The cabin crew torch was still in its holder above this seat and was badly fire-affected. The interphone and passenger address microphone were still in their stored positions on the intercom panel located outboard of the seat-back. Although blackened by smoke, these units were not badly fire-damaged and the associated coiled wiring was intact. The aft-facing single cabin crew seat located on the right/aft bulkhead showed similar evidence of the seat having been in the folded-up position during the fire, with harness undone and protected by the seat.

The forward cabin crew twin bench seat (aft-facing) located adjacent to the L1 door was undamaged by heat with both harnesses intact, and buckles undone. However, the torch located above the seat had partially melted.

The right escape 'rope' had been deployed from the right sliding-window on the flight deck.

Of the five cabin-crew 'Scott Aviation' smokehoods (15 minute endurance type), the three units which had been stored in the aft right overhead 'bin' at row 18 were found partially burnt and still in their respective cases. The two smokehoods for the forward cabin-crew were found undamaged and still in their bulkhead locker which faces the forward cabin-crew seat, together with the associated two pairs of asbestos gloves.

The forward 1.5 Kg BCF cabin fire extinguisher was in its storage locker and the two similar extinguishers on the rear right bulkhead (aft side) were still in their wall-mountings; all were fully charged. The single 1.5 lbs water-filled extinguisher from the aft/right overhead storage bin at row 20 had thermally ruptured.

The two megaphones, from the forward/left (row 2) overhead bin and aft/right (row 18) bin had been destroyed by the cabin fire.

Of the ten portable oxygen bottles (of 120 litre capacity), nine were found in the cabin. One of these had explosively ruptured, leaving the bottom 6 inches on the cabin floor in the region of seat 1D. The remaining eight cylinders had vented their contents, due to excessive temperature and pressure.

1.13 Medical and pathological information:

The pathological examination of the 54 people who died on board the aircraft was carried out by three teams of pathologists, each including one civilian pathologist and one aviation pathologist from the Institute of Pathology and Tropical Medicine (IPTM) at RAF Halton, Wendover. In addition, RAF odontologists assisted with the identification of the bodies. A special examination of the toxicology and histology aspects of the fatalities was carried out at the IPTM. (Appendix 12)

A marked deposition of carbon particles was found within the trachea of all victims, with some congestion of the mucosa (mucus lining) in 17 cases ("marked congestion" in the case of one passenger) with many instances of "excess mucus". The lungs of all fatalities showed marked general congestion and oedema (fluid), with carbon particles in the air passages, consistent with the inhalation of smoke. There was no evidence of organic disease which could have caused the death of any of the victims.

Blood samples were analysed to determine carboxyhaemoglobin and cyanide levels. In addition, hydrocarbon absorption was measured, including benzene and toluene, these two being the most prevalent volatiles found in all fatalities. Many other minor trace volatiles were found, including acetaldehyde.

Of the 54 occupants who expired on the aircraft, 43 (80%) had cyanide levels in excess of 135 micrograms/100 ml which would have led to incapacitation. Of these, 21 had levels above 270 micrograms/100 ml, the fatal threshold. Forty passengers (74%) had levels of carboxyhaemoglobin in excess of 30% saturation which would also be expected to cause incapacitation. Of these, 13 passengers had levels in excess of 50%, which is generally accepted as the fatal threshold. Only 6 passengers (from seats 21A, 21E, 20E, 17A or B, 17C or D, and 16C) had absorbed less than the incapacitating levels of carbon monoxide and hydrogen cyanide stated above, having died from direct thermal assault. The remaining 48 passengers who died on board did so as a result of smoke/toxic gas inhalation.

The passenger who survived for 6 days in hospital died because of severe pulmonary (lung) damage and associated pneumonia. He had suffered approximately 24% surface burns.

1.14 Fire fighting

The fire station crash alarm was initiated by ATC immediately the fire was observed from the tower. However, many fire crew personnel heard the bang, saw the fire and started to respond before the alarm had sounded. RIV2 and RIV1 rapidly departed and headed to where the aircraft could be seen entering link Delta, followed immediately by the Protector and J1 foam tenders. RIV2 routed via taxiway 2-North, RIV1 and the major tenders via taxiway 2. Other RFF personnel, on hearing the alarm, departed immediately to recover J2 from the hangar where it was undergoing re-painting.

The fire station ambulance, manned by RFF personnel, immediately departed for the West RVP to await the arrival of the GMC and Cheshire Fire Service appliances. The Airport Police also dispatched an escort vehicle to the West RVP. However, the GMC Fire Service had been alerted by the land line and told to report to the North RVP, which was in accordance with recently changed procedures.

RIV2 arrived at the scene approximately 25 seconds after the aircraft had stopped. It was positioned on the left side of the aircraft (Appendix 13 Figs a-d) and foam was applied initially onto the left side of the fuselage and then onto the left engine. RIV1 arrived shortly after RIV2, positioned off the nose slightly on the left side, and discharged the whole of its foam along the left side of the fuselage with the intention of protecting passengers, who by then were evacuating from the L1 chute, and cooling the left side of the fuselage. RIV2, having apparently knocked down the fire around the left engine, re-positioned to the rear on the left side, discharged its remaining foam into the rear fuselage, which by that time had collapsed to the ground, and was then re-positioned clear of the aircraft.

The Protector foam tender arrived at the aircraft approximately 30 to 40 seconds after the RIVs and positioned some distance off the nose, well on the right side. It then started to deliver foam into the area of the right overwing exit and the right rear fuselage, which appeared to be burning fiercely. Subsequently it was re-positioned twice, each time to bring it closer to the apparent seat of the fire on the right rear fuselage, before its water ran out. J1 arrived immediately behind the Protector, but was unable to position in the normally anticipated position on the nose of the aircraft because of the presence of RIV1. It was therefore positioned some 12 metres forward of the nose, slightly on the right side to the rear of RIV1, and foam was delivered down the length of the fuselage on the right side. This drove the flames rearwards, maintaining the forward and overwing exits clear of fire. Approximately 1 minute after commencing foaming, J1 was re-positioned onto the left side in order to attack more effectively the fire in the area of the left engine and rear fuselage.

J2 (the foam tender retrieved from the paint shop) arrived at the scene some 4 to 5 minutes after the aircraft stopped and positioned to the front of the aircraft in the area originally occupied by J1. Upon arrival, the driver of J2 saw an apparently lifeless body hanging out of the right overwing exit, and above this body a hand was moving. The driver immediately left his cab, climbed up onto the wing and pulled out a boy, who although unconscious was still alive and subsequently recovered. After this casualty had been handed down to officers on the ground, the fireman was forced off the wing by the smoke. Acting on the orders of the officer in charge, he then returned to J2 and applied foam along the top of the fuselage. Side lines were also deployed from J2 at this stage to cool a running fuel fire which was burning in the vicinity of the left engine. After some determined effort, this fire was eventually extinguished using two 50 kg units of Halon (BCF).

Approximately 7 minutes into the incident, after it became clear that no more passengers were likely to emerge unaided, a team with breathing apparatus made an entry via the R1 door. Conditions inside the cabin at that time were very bad, with thick smoke and a serious fire in progress at the rear of the cabin. Shortly after entering, an explosion occurred which blew one of the firemen out of the door onto the tarmac. The officer in charge was by that time becoming increasingly concerned about the reducing water supplies, especially with regard to the potential loss of water supplying sidelines deployed within the cabin, and directed that there would be no more attempts to gain entry until there was a reliable supply of water. In the interim, sidelines were used on the exterior only. At about this time a fire was seen to flash briefly along the cabin.

About 8 minutes into the incident the GMC appliances, carrying a total of 1,600 gallons (7,272 litres) of water, arrived at the North RVP but there was no police escort there to meet them. Some 3 minutes later, the GMC appliances were still without an escort and a radio call was made to GMC fire control advising them of the situation. Shortly after this transmission, a police escort arrived and the convoy set off for the scene.

By approximately 11 minutes into the incident, the internal fire appeared to have spread forward throughout the cabin, where breaches in the roof could be seen. J1 was dispatched to replenish

with water from the hydrant system: the vehicle was positioned at three hydrants in succession, but no water could be obtained from any of them. This resulted in a delay of about 10 minutes, after which J1 returned to the scene empty. It was then dispatched to the hydrant behind the fire station, where replenishment was successful. However, the hydrant discharge rate was such that this took between 15 and 18 minutes and the vehicle returned to the scene too late to play any further active role. The Protector foam tender was also dispatched to the fire station to replenish with water.

The GMC fire appliances arrived at the aircraft approximately 13 minutes into the incident. Initially, the Station Officer (SO) in charge experienced some difficulty in identifying the officer commanding the airport fire service, resulting in some delay before the water requirements were identified and the transfer of the 1600 gallons of water from the GMC appliances to J2 could begin. Using a sideline from the newly replenished J2 tender, a two-man team with breathing apparatus was then able to make an entry via the R1 door using a short ladder, and, for the first time, were in a position to begin addressing the internal fire.

At approximately 21 minutes into the incident, a Divisional Officer (DO) from the GMC arrived and, in accordance with procedure, took command of the emergency services. At +29 minutes, unaware of the earlier problems with the hydrants, he ordered a hose relay to be set up and this was done, using one of the RIVs to carry hose across to hydrant 130. On this occasion the hydrant supplied water. Shortly afterwards, the GMC DO and SO each donned breathing apparatus and entered the cabin via the R1 door. Conditions inside at this time were poor, with very limited visibility. Two bodies were visible and the DO left the aircraft to transmit a message advising that there were fatalities. Upon re-entering the aircraft, the smoke had cleared somewhat and further casualties could be seen at the rear of the aircraft.

At approximately +33 minutes a male survivor was found near the front of the aircraft. Regrettably this casualty, who was the last person to be found alive, died some time later in hospital.

1.15 Survival aspects

From the statements of the survivors, it is evident that the effects of the fire on the left side of the aircraft rapidly instilled fear and alarm in many passengers, particularly those in the aft/left cabin - ie row 14 aft. These effects appear to have been marked heat radiation through the windows together with "cracking, melting and smoking" of the window transparency panels, which motivated some passengers from the aft cabin to enter the aisle and move forward before the purser's 'sit down' announcement on the PA, and therefore before the evacuation call 14 seconds prior to the aircraft stopping.

The opening of the R2 door by one of the rear cabin crew, with slide deployment approximately 6 seconds before the aircraft stopped may have been a rapid reaction to the evacuation call or a direct response to the worsening situation within the aft cabin. However, as the aircraft came to a halt this exit was rapidly engulfed in thick black smoke and no one escaped via this route.

As the aircraft stopped, the aft cabin was suddenly filled with thick black smoke which induced panic amongst passengers in that area, with a consequent rapid forward movement down the aisle. Many passengers stumbled and collapsed in the aisle, forcing others to go over the seat-backs towards the centre cabin area, which was clear up until the time the right overwing exit was opened. A passenger from the front row of seats looked back as he waited to exit the aircraft, and was aware of a mass of people tangled together and struggling in the centre section, apparently incapable of moving forward, he stated "people were howling and screaming".

Many survivors from the front six rows of seats described a rollof thick black smoke clinging to the ceiling and moving rapidly forwards along the cabin. On reaching the forward bulkheads it curled down, began moving aft, lowering and filling the cabin. Some of these passengers became engulfed in the smoke despite their close proximity to the forward exits. All described a single breath as burning and painful, immediately causing choking. Some used clothing or hands over their mouths in an attempt to filter the smoke; others attempted to hold their breath. They experienced drowsiness and disorientation, and were forced to feel their way along the seat rows towards the exits, whilst being jostled and pushed. Many, even in the forward cabin, resorted to going over the seat backs in order to avoid the congested aisle. This was reported by passengers in seats 7A, 6B, 5D, 3E, 3F and 2F, in addition to statements from passengers who confirmed that they had gone forwards over the seats. Some stated that "the smoke generated an immediate sense of panic".

At the start of evacuation from the L1 door, the stewardess stated that passengers seemed to be jammed in the cabin aisle and entranced to the galley (ie between the twin forward bulkheads). She cleared the jam by pulling one young passenger forwards and the flow then started. Later she saw a young girl lying on the floor of the forward aisle. She pushed another youth back, pulled the girl forward by her collar and pushed her down the slide. As the passengers came forward through the bulkhead aperture so the smoke built up in the forward galley area. She recalled feeling a body slump against her legs, bent down and, due to improved visibility near the floor, saw that it was another girl passenger. Her face was black with soot, eyes fixed and dilated with no signs of breathing. The stewardess considered giving her the kiss of life when a fireman down below shouted for her to throw the girl down to him. With great difficulty she lifted her by the waist and threw her onto the chute. After being forced down by the smoke onto her hands and knees, the stewardess felt around for other passengers back as far as the galley cabin entrance. She was considering getting her smoke hood when a fireman shouted at her to jump, concerned that she would perish if she delayed. Having been unable to locate any further passengers, she went down the slide.

The Purser stated that, after getting the R1 door open at his second attempt and initiating evacuation from this exit, the smoke began entering the galley area. He stood with his back to the galley bulkhead with the door on his right, pushing passengers past towards the chute. He stated that passengers were not carrying any "noticeable or unacceptable hand baggage". The density of the smoke increased very rapidly, and became very acrid. It became so bad that he could not see across the galley, and then could not see his slide as the visibility went down to inches. Smoke was by this time pouring out of the door. He inhaled some smoke and felt that if he inhaled any more, he would not survive. A number of people came out of the cabin and he followed them onto the slide.

The aisle aperture between the twin forward bulkheads in this configuration was 22 inches wide, effectively restricting passengers approaching along the aisle and over the seat backs to a single-line exit flow in spite of both forward doors being open from approximately 1 minute 10 seconds after the aircraft stopped. Many passengers, in addition to the two females assisted by the stewardess, collapsed in this area but survived. Unfortunately one of these passengers, (from seat 8B) who was found some 33 minutes after the aircraft stopped, died some 6 days later due to lung damage and associated pneumonia. Four bodies were eventually recovered from the area of the forward aisle.

The 18 passengers from the front 3 rows of seats appear to have escaped from the forward exits before being affected by the smoke. In addition 3 passengers from row 13 and 2 passengers from row 14 were also unaffected. Thus, of the 17 passengers who escaped from the L1 exit and 34 passengers who escaped from the R1 exit, some 23 (45%) escaped before the thick smoke had reached them.

The decision to open the right overwing exit was taken by passengers themselves, motivated by the fact that the forward aisle was by this stage blocked with passengers waiting to exit through the forward galley area, with others already making their way over the seats. The female passenger in seat 10F adjacent to the right overwing hatch, upon being exhorted by passengers behind to open the door, undid her seat belt and turned in her seat to face the hatch. She saw the 'Emergency Pull' instruction at the top of the hatch, but pulled at the armrest which was fixed to the lower area of the hatch. She was not familiar with the door opening procedure and unaware if the door was hinged at the top, bottom, left or right, or if it would come straight off. Her female friend in seat 10E stood up and pulled at the release handle adjacent to the instruction. The hatch, which weighed 48 lbs, fell inboard across the chest of the passenger in 10F, trapping her in her seat. She managed to get out from under the door and a male passenger sitting behind her assisted by lifting the hatch over the back of row 10, depositing it on the vacant seat 11D. This exit was seen to be open by about 45 seconds after the aircraft stopped. The two female passengers escaped onto the right wing and both jumped down from the leading edge, the passenger from seat 10E twisting her ankle. At that stage, there was no foam on that side of the aircraft. A number of other passengers quickly followed them out including the occupants of 10C and 10D carrying their children.

The girl from seat 10E stated that there had not been enough room between the seats at row 10. A further passenger from 15D also commented on the lack of space at the overwing exit and more generally about "Far too little space to evacuate the plane in a panic situation, 2-3 exits not enough".

Shortly after the right overwing exit was opened, it was obscured by dense black smoke which came forward from the aft cabin. The smoke poured out of the overwing exit, which was on the downwind side of the fuselage. The smoke was consistently described as heavy, thick, black, acidic, toxic and very hot. As observed by the forward cabin passengers the effects of this smoke on the respiratory system was rapid and for some catastrophic. Within one or two breaths of the dense atmosphere survivors recall burning acidic attack on their throats, immediate and severe breathing problems, weakness in their knees, debilitation and in some instances, collapse. A male passenger from seat 15C recalled taking one breath which immediately produced "tremendous pain" in his lungs and a feeling that they had "solidified".

Very rapidly the area around the overwing exit became a mass of bodies pushing forward to the exit. People all around were falling and collapsing to the floor. Many passengers who ultimately got out of the right overwing exit, nevertheless collapsed temporarily within, or adjacent to it. The exit was blocked with "people's bodies lying half-in and half-out of the aircraft". A male passenger, from 16C, died after becoming lodged in this right overwing exit. A young boy, from 12D, was pulled out over this man's body by a fireman about 5 minutes after the aircraft stopped. It is notable that some passengers managed to escape forward from the worst area of the rear cabin only to succumb within the central area. Several of the survivors who used the overwing exit were impeded by becoming entangled in the ditching strap. However, one passenger recalled catching hold of it as she collapsed, to recover consciousness with her head outside the exit.

Of the 24 passengers who escaped from the right overwing (not including the 2 young children and the young boy pulled clear) some 11 passengers (46%) went over the seats as opposed to using the congested aisle to get there. Only two of the 24 reported seeing fire in the aft cabin. More observations of fire in the aft/centre cabin were reported by passengers before they evacuated from the forward exits. A passenger from 8D recalled looking around after the aircraft had stopped and seeing huge tongues of flames shooting into the cabin through the windows of the fuselage on the left side. He stated that flames commenced at the first window past the central emergency hatch with six or seven windows behind thus affected. The flames were lapping up to the ceiling. Several people who were in seats nearest these windows were seen engulfed in flames.

A passenger from seat 6A saw a sheet of flame inside the cabin. It seemed to be near the centre of the aircraft and separated the front half from the back. Another passenger from 6B, after seeing foam being sprayed over the fire on the left side of the aircraft, tried to move into the aisle but it was jammed with people and it was difficult to move. On turning he saw flames shooting in through the side windows and up through the floor area. The flames were several feet in length and continual.

The fireman who, after rescuing the young boy, attempted to rescue the man jammed in the overwing exit, reported feeling "dizzy" from the effects of the fumes and smoke. Comments on the effects of the smoke outside the aircraft were made by many of those assisting, who complained of its effects on their throats and breathing.

A British Airways coach had collected the crew of a Tristar aircraft with the intention of taking them to their flight office after clearing Customs. When the driver saw the aircraft on fire he informed his passengers that he was taking the coach to assist at the accident. Upon arrival (at approximately 4 minutes after the aircraft stopped) the cabin crew immediately went to the assistance of the survivors, many of whom ran towards the coach. The first evacuees were in a state of shock, but dry, whereas those following them were blackened with smoke and wet with foam. Several stewardesses assisted a woman who was lying approximately 100 yards forward of the aircraft and appeared unconscious. She was being given cardiac massage by a fireman. After resuscitation with oxygen, this passenger began to recover and a deep wound was found on the back of her head. She was taken to an ambulance. A young girl of approximately 17 years, was also found in the grass forward and to the left of the aircraft. Her face was black, hair wet, and her eyes "frosted over" with a white deposit. She had no signs of burning on her clothes.

The crew members also assisted a young man of about 24 years, he was crouched on the grass and covered in soot. He was having difficulty in breathing and thick mucus was pouring from his nose and mouth. A stewardess hit him in the back, the practised method of causing a cough reflex. As she did this, he started to cough and his breathing became easier.

The TriStar crew members met both surviving cabin crew and assisted them away from the aircraft. The British Airways coach was joined by another three coaches from the Manchester Airport Authority.

After some 40 survivors had been led aboard the British Airways coach, it left the scene at approximately 0725 hours for Pier B, gate number 1 departure lounge where approximately 15 British Airways cabin crew had set up chairs, blankets etc to receive the passengers. The young boy pulled from the overwing exit was given some treatment here for the burns to his hands, using a first aid box from an adjacent aircraft. Another passenger who was having difficulty breathing was given oxygen to ease her respiration. It was, however, quickly decided that this area was not suitable for the condition of the survivors who were in a state of shock, and they were then taken on by the British Airways coach to Wythenshawe Hospital at 0745 hours, where staff were ready to receive them.

The young boy, whose condition was deteriorating, was not taken directly to the hospital, but was taken to the Fire Station in a catering van by a British Airways stewardess, where he was reunited with his father. The remaining survivors had been taken to the fire station crew room by the Manchester Airport coaches. These survivors were later taken to Wythenshawe Hospital. Many British Airways cabin crew staff stayed at Wythenshawe Hospital to console the survivors and also to take names and addresses for dissemination to relatives.

A cabin seating plan showing which passengers used each exit and the seat location of those who died is at Appendix 14.

1.16 Test and research

1.16.1 Engines

A general feature of most, if not all combustor designs is that uneven temperature distributions can occur, producing areas of locally relatively high temperatures. The combustor cans from the left engine of G-BGJL and others from the same operator showed evidence of localised 'hot-spots' i.e. areas of the can liner material exhibiting excessive overheat blistering and/or multiple cracking. Such local effects can also be produced by different causes, such as a distorted fuel nozzle flow pattern, distortion of the dimensions of the can or cooling airflow disturbance caused by repairs or faulty design/manufacture.

In order to measure the temperature of these hot-spots and the general temperature distribution and gradients around the can, a series of tests was undertaken using a JT8D-15 engine loaned by the operator and using the operator's facilities. The engine was assembled with part-run cans which had been painted internally and externally with temperature sensitive paint. The engine was then run through a typical British Airways cold day take-off and pull back sequence, returned to idle for a short time and shut down. The cans were removed and the paint examined. A suitable can was then selected to be instrumented for a further test. For this test, seven thermocouples were attached onto the outside of the can at various locations including on and around a hot spot in the 3rd/4th liner joint area identified from the heat-sensitive paint. An eighth thermocouple was used to record combustor inlet air temperature (T4). All the cans were re-coated with heat sensitive paint and then re-assembled into the engine.

The procedure for the first run was repeated, using chart recording of the thermocouple measurements but, in addition, the throttles were advanced for a few seconds above the maximum rated power. This was to simulate a rated power take-off on a hot day, since the tests were performed in ambient temperatures of around 5°C or less. It is estimated that the degree of 'throttle push' employed was equivalent to:-

- a) Exhaust Gas Temperature (T7) changes approximately equivalent to a 15°C increase in ambient temperatures.
- b) T4 changes approximately equivalent to a 12°C increase in ambient temperatures.

NB These effects still fall short of simulating a 30°C ambient day take-off, as may commonly have been encountered on the routes flown by G-BGJL.

Examination of the paint and thermocouple results after the second test showed eight cans with hot-spot temperatures of 825-950°C on the third liners and two cans with spots in excess of 1,025°C. The distribution of temperatures was generally similar on all nine cans and the instrumented can did not appear to be the hottest. The thermocouple traces showed that maximum material temperatures occurred at highest power rather than associated with any transient condition, such as throttle retardation effect.

It was noted that the temperature of the hot spot rose dramatically as peak power was approached i.e. at a greater rate than simple theory would have predicted. It is hypothesised that a concentration of combustible reactants in the wall cooling layers became rich enough for combustion to begin next to the wall itself, elevating the liner temperature disproportionately.

The results of these tests were used to estimate the stress levels generated by thermal cycles and a simplified mathematical model used to calculate the stress/cycle relationship for Hastelloy X material. The tests showed that temperature gradients of at least 150°C and possibly 200°C over 2-3

mm can be anticipated at peak power, and the calculation showed that thermal stresses in the order of 29,000 psi would therefore be generated in the liner material. Tests on sample Hastelloy X material at elevated temperatures showed that, at this stress level, the fatigue life of the material would vary between 100 cycles at 980°C to 1,000,000 at 815°C. These results serve to emphasise the very damaging effects of high temperatures and it can therefore be argued that hot spots in the can will suffer rapid localised cracking within, say, 1,000 flights from new or repair whilst the cooler regions would have a vastly greater life. The fatigue life of the can is thus essentially limited by the performance of the cooler, longer-life regions, rather than the performance of localised hot spots.

1.16.2 Search of existing data on Aircraft Fires

1.16.2.1 Emissions from burning aircraft cabin materials

Much attention has been paid to the emissions from the synthetic foams used in cabin-seat cushions. Thermal decomposition of such foams in air produces a complex mixture of smoke and gases, which not only varies with the type of foam (eg polyurethane, polyetherurethane etc) and whether it has added constituents (eg flame-retardants), but is also dependent upon combustion conditions - eg flaming or non-flaming (eg smouldering) conditions. However, the other cabin materials such as wall panels, windows/surrounds, overhead passenger service unit panels, overhead baggage compartments, ceiling panels, sealing strips, curtains etc. also produce toxic, irritant gases and smoke when burnt.

Comprehensive data on the gases emitted from the combustion of seat-foams and other cabin materials is contained in a Federal Aviation Administration (FAA) report 1 (Appendix 15a). These data indicate that the well known problems associated with the foams used in cabin seat-cushions represent only one part of the general problem concerning the products of combustion of aircraft cabin materials.

Polyvinylchloride (PVC) material from cabin panels produces almost as much carbon monoxide as does polyurethane foam, for the same weight burnt, but also produces almost six times the concentration of the acidic gas hydrogen chloride.

Polyurethane foam produces less hydrogen cyanide than modacrylic material, which can be used for curtains, carpets etc. Relatively small weights of any such materials can produce substantial concentrations of toxic/irritant gases and smoke when burnt within an aircraft cabin volume.

eg. The burning of only some 5.7 lbs of modacrylic curtain material in a cabin volume of about 6,000 cubic feet, will produce a critical concentration of 200 parts per million (ppm) of hydrogen cyanide - sufficient to induce rapid incapacitation and death.

Wool is often preferred to modalcrylics for curtains, carpets etc (as was the case on G-BGJL), but also produces hydrogen cyanide, although in reduced quantities.

Fluorinated materials which are frequently applied in the form of decorative films to cabin wall panels (eg 'Tedlar' Polyvinyl fluoride finish on the wall panels of G-BGJL at Manchester) emit the intensely irritant hydrogen fluoride acidic gas when burnt.

Fibreglass materials generally exhibit much lower toxic/irritant gas emissions, dependent upon the resin used - eg phenolic fibreglass is superior in this regard to epoxy fibreglass. Such materials can still, however, emit large concentrations of particulate - ie 'smoke'.

The cabin materials fitted in G-BGJL are listed at Appendix 15b

1.16.2.2 Toxicological effects of combustion gases (Appendix 15 Table c)

The effects of those gases which are generally recognised as the important toxic/irritant components of such combustion atmospheres are listed below:

Carbon Monoxide (CO):

Carbon monoxide is produced when any combustible cabin material burns incompletely, or in reduced oxygen conditions. It is always present, often in high concentrations, in large uncontrolled fires. It is the agent that is generally accepted as being most responsible for deaths due to smoke inhalation. In large fires involving kerosene fuel, large concentrations of carbon monoxide can be expected. (eg the tests at Teesside, where carbon monoxide concentrations of several thousand ppm were measured inside a Trident fuselage during a large-scale test demonstrating water spray systems)

When carbon monoxide is inhaled, it is absorbed by the blood from the lungs and combines with haemoglobin to form carboxyhaemoglobin. This reaction inhibits the absorption and therefore the transport of oxygen to the body tissue. 10-20% carboxyhaemoglobin in the blood can be tolerated generally with only a slight headache, but concentrations of 30-40% may induce a severe headache, weakness, dizziness, dimness of vision, nausea, vomiting and collapse. Concentrations above 50% can lead to collapse and death. Recovery can be effected from lower concentrations, since the reaction is reversible with the administration of oxygen to the victim.

The effects of a given concentration of carboxyhaemoglobin are influenced by physical activity.

Hydrogen Cyanide (HCN)

This gas is produced from the combustion of wool, modacrylics, nylon and leather and stimulates breathing, thereby accelerating the rate of absorption. Cyanide affects the body by direct absorption into the tissues, affecting certain enzymes such as cytochrome oxidase which blocks the uptake of oxygen by cell tissue from the blood. A concentration of only approximately 200 ppm of hydrogen cyanide in the atmosphere will induce rapid collapse and death.

Nitrogen Dioxide (NO₂)

This gas often occurs with other nitrogen oxides, such as nitric oxide (NO), in fires and is often denoted as NO_x, for this reason. Nitrogen oxides combine with moisture to form nitric and nitrous acids. These can be absorbed directly, or with the carbon particles of smoke which have 'adsorbed' these acids. The acids attack the throat, trachea and lung tissues and are highly irritant. Some of the acid may also be neutralised by an alkaline reaction within the tissues producing nitrate of sodium. Nitrate absorption causes arterial dilation, hypo-tension, headache, vertigo and the formation of methaemoglobin.

High concentrations cause pulmonary oedema which, even after a successful evacuation, may cause death some hours later.

Hydrogen Fluoride (HF)

Hydrogen fluoride, produced from fluorinated polymers such as polyvinyl fluoride, combines with moisture to produce hydrofluoric acid, one of the most powerful acids. Pathologically, this acid is much more active than hydrochloric acid and causes major oedema within the respiratory tracts. It is also a protoplasmic poison.

Burns produced by hydrofluoric acid produce throbbing pain and progressive destruction of tissues with decalcification and necrosis of bone. Combustion of fluorinated polymers may also produce saturated and unsaturated fluorinated hydrocarbons of low molecular weight, which are also extremely toxic.

Hydrogen Chloride (HCl)

Combustion of PVC and many fire-retardant materials produces hydrogen chloride. Hydrogen chloride combines with water to form hydrochloric acid which has a highly irritant effect on the throat and respiratory tracts, causing destructive damage to the mucous membranes and pulmonary oedema. It is an intense irritant to the eyes, throat and respiratory tracts, causing destructive damage to the mucous membranes and pulmonary oedema.

Sulphur Dioxide (SO₂)

This gas is produced on combustion of both natural and synthetic rubbers and other compounds containing sulphur. It combines with moisture to produce sulphurous acid which is highly irritant to tissue, including the eyes. It attacks the mucous membranes of the respiratory tract, causing uncontrollable coughing. Very high concentrations can induce respiratory paralysis.

Ammonia (NH₃)

This gas is produced upon combustion of polyurethane, polyamides, polyacrylonitrile, silk and wood. It is a highly irritant caustic and has a violent effect upon the respiratory tract and eyes. It inhibits respiration and in high concentrations may cause cardiac arrest via the respiratory reflexes. It produces bronchial constriction and pulmonary oedema.

Acrolein (CH₂ CH CHO)

Acrolein is one of the most irritant of the aldehydes produced by the combustion of cabin materials. It is also produced in small amounts from burning kerosene and from the combustion of natural materials such as wood and cotton. It is an intense eye irritant and in concentrations as low as 5.5 ppm has been shown by Deichmann and Gerarde² to cause irritation of the upper respiratory tract. At higher concentrations, pulmonary oedema occurs, with death after a few minutes at only 10 ppm.

Aromatic hydrocarbons (eg Benzene, Toluene, Styrene etc)

A whole range of aromatic compounds are produced by the thermal degradation of synthetic (and natural) materials. They produce varying degrees of narcosis. Several of these aromatics such as benzene (from PVC) are not only absorbed due to inhalation, but can also be absorbed directly through the skin. Concentrations of 100 ppm are considered injurious to health. Toluene is less toxic than benzene but, conversely, represents a greater danger in chronic exposure.

Styrene is considered safe at concentrations less than 100 ppm, but above this is highly irritant to the mucous membranes, causing symptoms of toxicity with impairment of the neurological functions. In concentrations of approximately 800 ppm, it causes 'styrene disease', characterised by nausea, vomiting and total weakness.

Aliphatic hydrocarbons

Thermal degradation of all organic materials produces a variety of aliphatic compounds. Some of these compounds with the lower molecular weights can produce narcosis. Unsaturated

hydrocarbons generally have a greater toxic effect than saturated compounds. Acids, alcohols and aldehydes may be present with their respective toxic effects.

Acetaldehyde

This is produced from the thermal degradation of a wide range of synthetic (and natural) materials. It is an irritant gas which can induce central nervous system suppression, producing headaches, stupor and eventually coma and death. Even amongst those who recover, pulmonary oedema usually develops within 2 hours of exposure.

1.16.2.3 Full scale fire tests

Whilst there has been research carried out over the years into the atmospheres associated with aircraft fires, and much valuable work has been done particularly by the FAA Technical Centre at Atlantic City, the tests in general have been rather limited in terms of the fire-model used. There is a lack of information concerning the atmospheres generated in differing types of fire, covering a wide cross-section of situations. This has led to the 'read-across' of such results from rather specific test scenarios to general aircraft fire accidents.

The FAA Technical Centre has, for many years, carried out full size fire tests on a Lockheed C133 fuselage, extensively thermally insulated to withstand repeated fire tests. The test set-up was intended to simulate a pooled-fuel ground fire attack on the cabin interior via a door aperture (76" x 42") representing a breach in the fuselage. An 8 ft x 10 ft 'tray' of kerosene was ignited immediately outside the aperture and the resultant thermal radiation of 1.5 BTU/sq ft/second initiates an internal fire amongst the cabin furnishings. A second single door was used to exhaust the combustion products from the cabin.

This test series³ has demonstrated one phenomenon repeatedly -ie that of 'flashover' (Appendix 16 a). Flashover occurred at about 2½ minutes after the tray-fire had been initiated. At this point the cabin temperatures soared to approximately 1,700/1,800°F at ceiling level near the fire aperture plane. In addition the oxygen level, which remained at the normal 21% prior to flashover, reduced to approximately 12% after 3 minutes 10 seconds (measured at a datum 40 feet from the fire aperture towards the 'exhaust' door). (Appendix 16 Fig-b-c)

Three points are notable from these results:

1. Before flashover, only hydrogen chloride and hydrogen fluoride are shown as being emitted in significant concentrations, rising to some 830 ppm and 840 ppm respectively.
2. The carbon monoxide concentration appears negligible (approximately 100 ppm) before flashover.
3. Very little hydrogen cyanide is produced, even after flashover, with a maximum of around 20 ppm.

This latter finding is somewhat surprising, since real survivable aircraft accidents with fire-related fatalities have shown significant cyanide absorption by the victims.

The limiting incapacitation time based on calculations from this type of data and applicable to three heights within the cabin - ie at the 5ft 6 inch, 3 ft 6 inch and 1ft 6 inch levels, gives respectively a time to theoretical incapacitation of 2 minutes 39 seconds, 3 minutes 13 seconds and 3 minutes 22 seconds (Appendix 16 Fig d). It is notable that for these tests the thermal part of the total

incapacitation threat, even after flashover, was very small when compared to that due to the effects of hydrogen chloride, hydrogen fluoride, carbon monoxide and hydrogen cyanide.

Thus, even given this extreme situation of flashover within 2 minutes of the cabin interior being exposed to the heat flux from a large pooled-fuel fire, it would appear that incapacitation may be delayed beyond flashover in parts of the cabin away from the fire, until some 2 minutes 39 - 3 minutes 22 seconds. Furthermore, experience from real aircraft fires indicates that this situation is not always encountered - ie flashover is either significantly delayed or may not occur generally at all in the cabin.

In this context it is notable that the authors of this work, have stated:-

"uncontrolled post-crash fires in an intact fuselage will produce a flashover condition, which will be followed by a loss in survivability throughout the cabin."

In addition it is the case, from pathological examination, that the majority (c.80%) of fire fatalities occur not due to direct and excessive thermal assault, but due to smoke/gas incapacitation⁴.

Tests have also been carried out at the FAA Technical Centre on the effectiveness of seat cushion 'fire-blocking' coverings. Polyurethane foam cushions covered with materials such as 'Vonar' have been tested against unprotected foam cushions, both in simulated ground fire situations and also internal cabin fires with air-conditioning air-flow, to simulate in-flight fires. These tests indicated an increase in the time to incapacitation of about 60 seconds as a result of reduced cabin temperatures (Appendix 16 Fig e). It should be noted, however, that fire-blocking layers merely delay the onset of combustion of these cushions in a full-scale ground fire situation.

One aspect of the 'in-flight' tests is of interest. Flashover did not occur during the time that 'air-conditioning' air-flow was being used, but when it was shut-off at approximately 3 minutes, flashover occurred very quickly thereafter, within 30 seconds. It is also notable that well before this time, and indeed from the start of the fire, the concentrations of hydrogen fluoride and hydrogen chloride became critical, in spite of the air-flow operating. However, during this period the oxygen concentration remained at 21%.

The final fire test of the C133 series was carried out on the 30 July 1987 and produced some interesting new data. In this test some 105 seats were installed in the cabin. All seats were of the new 'fire-blocked' type. The fire, which in earlier tests was extinguished after some 5 minutes, was allowed to continue for some 15 minutes. The hydrogen cyanide sampling was located at a higher level in the cabin than in all previous tests - ie at a height of 5 feet above the floor. For the first time, some 200 ppm of hydrogen cyanide was detected in the time before flashover occurred (latter took place 4 minutes from the initiation of the fire). In addition, some 700 ppm of hydrogen bromide was also detected before flashover. This emission was attributed to the epoxy-fibreglass material of the wall, overhead stowage 'bins' and ceiling panels. Hydrogen fluoride and hydrogen chloride were also detected before flashover, as in previous tests.

1.16.2.4 The materials fire hardening strategy

It is notable that the current regulatory standard for cabin material certification, FAR 25.853, was adopted in May 1972 and specifies that all large usage material must be self-extinguishing in a vertical orientation when subjected to a 'Bunsen-burner' flame. Whilst such a test may be useful for demonstrating protection against a small flame in a cabin, it clearly does not indicate the results of exposure to a large external (eg pooled-fuel) fire.

As a result of their awareness of the clear deficiency of this certification test and the effects of toxic gas and smoke on survivability, the FAA proposed two important changes in 1974/75:-

Advance Notice of Proposed Rule-Making (ANPRM) No 74-38 was issued on 30 December 1974. This notice invited 'public' participation in developing standards governing the toxic gas emission characteristics of compartment interior materials when subjected to fire.

Also, Notice of Proposed Rule-Making (NPRM) No 75-3 was issued on 12 February 1975. This notice invited comments on proposed amendments to FAR parts 25 and 121 concerning the introduction of limitations on smoke emission characteristics of compartment interior materials when subjected to fire.

The industry responded, citing inadequate test methodology and questionable safety benefit. The FAA withdrew both proposals.

The FAA then set up the SAFER (Special Aviation Fire and Explosion Reduction) Committee in June 1978 to: "Examine the factors affecting the ability of the aircraft cabin occupant to survive in the post-crash environment and the range of solutions available."

After its investigations into cabin materials technology, this committee issued recommendations concerning further research and development of materials, investigation of the problems of smoke and toxic gas emissions and the evaluation/implementation of a "radiant-heat" test method for cabin materials certification.

The previously described C133 fire-test programme originated from such recommendations. The flashover phenomenon, which was apparent during these tests, sustained the flammability approach to materials certification, but it appears to have done so at the expense of any serious consideration of smoke and toxic/irritant gas emissions. The associated justification for this was that:-

"(1) There is a correlation between flammability characteristics and toxic emissions.

(2) The severe hazard from toxic emissions occurs as a result of flashover in fires involving interior materials. The level of toxic gases measured before flashover or when flashover did not occur, were below levels estimated to prevent occupant survival."

Both of these conclusions are severely undermined by the last C133 fire test on 30 July 1987, when some 200 ppm of hydrogen cyanide was detected in the time before flashover.

As a result of that approach, the Ohio State University (OSU) radiant heat test apparatus, modified to measure heat release, was adopted. This test used a radiant heat flux of 3.5 watts/sqcm.

The current regulatory response to this problem has thus been to continue to approach it solely through material flammability criteria, excluding any certification requirements for smoke or toxic/irritant gas emissions.

In this context, a discussion document issued by the FAA in July 1986 requesting further comments on their 'Improved Flammability Standards for Materials Used in Interiors of Transport Category Airplane Cabins' is of interest. In response to requests from two commenters from the materials industry for assurance that no rule-making with respect to smoke and toxicity was anticipated in the foreseeable future, the FAA replied; "Based on the information currently available, the FAA has no plans to establish standards for either smoke or toxicity; however this does not preclude taking such action in the future if, as noted above, further research shows such

standards are warranted and human tolerance levels can be adequately defined." The FAA thus amended FAR parts 25 and 121 to include the OSU test, on 20 August 1986.

Airworthiness Notice No 61, 'Improved Flammability Test Standards for Cabin Interior Materials' issued by the CAA on 16 March 1987 and applicable from 20 August 1988 is in compliance with this approach, and does not include any criteria for smoke and gas emissions.

This regulatory approach has already led to the use of flame-retardant materials developed by the chlorination of earlier materials. However, when burnt in a real fire, many such materials were found to generate even more smoke and gas (eg hydrogen chloride) than previously.

Research work⁵ completed as early as 1973 into smoke emission from aircraft interior materials indicated that:-

"To date the major concern of those engaged in the development of fire-retardant materials has been the reduction of the ignition tendency and flame propagation. Thus, it has been possible to meet code and regulatory requirements regarding flame-spread but in the opinion of the author the total hazard resulting from incomplete combustion has been increased".

This report also included the standard disclaimer used by the American Society for Testing Materials:-

"No direct co-relation between these tests and service performance should be given or implied".

Whilst the regulatory authorities have not yet introduced requirements for materials certification to take account of smoke and toxic/irritant gas emissions, many aircraft manufacturers already stipulate associated limitations for their materials. For example, in 1977 Boeing established goals/guidelines (the so-called "Withington" guidelines) covering smoke emission (more stringent than the limits in NPRM 75-3), toxic gas emission (hydrogen cyanide, carbon monoxide, hydrogen chloride, hydrogen fluoride, sulphur dioxide + hydrogen sulphide, nitrogen oxides), and flame spread index (ASTM E162). In 1978 Airbus Industrie released ATS 1000.001 covering smoke emission (using the limits in NPRM 75-3) and toxic gas emission (using the limits in Boeing's Withington guidelines). ATS 1000.001 has subsequently also been used by Fokker and British Aerospace. McDonnell Douglas has similar criteria on smoke and toxic gas emission.

Whilst this type of testing represents a considerable improvement in materials certification, the radiant heat flux used to combust the material sample is still low (2.5 watts/sq cm) compared with the radiant heat from a real pooled fuel fire which can rise to 14-20 watts/sq cm.⁶

1.16.2.5 Visibility and escape path low level lighting

In addition to the toxic effects of gases, such as hydrogen cyanide and carbon monoxide etc, the 'acid' gases such as hydrogen chloride, hydrogen fluoride, sulphur dioxide etc. attack the eyes, causing intense irritation and lachrimation (discharge of tears). Considerable research has been carried out into the effects on vision of smoke emissions from burning cabin materials⁷, revealing that:-

"The predominant factor affecting visibility is not the obscuration of vision by particles of smoke, but the irritating effects of combustion gases, predominantly hydrogen chloride and sulphur dioxide. These gases in combination with the moisture in the eyes, tend to cause great discomfort and irritation".

"The dominating factor on human critical visibility is strongly related to the irritating effects of combustion gases generated from flaming materials in a crash-fire situation".

Further research work carried out in Japan⁸ also highlighted the marked effects of irritating gases on vision:-

"In thick irritant smoke, the subjects could not keep their eyes open for a long time, and tears ran so heavily that they could not see the words on the signs".

"In irritant smoke, the subjects could no longer walk straight and began to 'zig-zag' or walk along a wall".

Walking speed slowed down in smoke by more than 50% and was further reduced in irritant smoke.

Notwithstanding such research evidence, the regulatory authorities had for some time been progressing towards a requirement for low level lighting within aircraft cabins with the intention that evacuating passengers would be able to follow the lights to escape more quickly in conditions of thick smoke and reduced visibility.

1.16.2.6 Passenger smokehoods:

As a result of several accidents in the United States, and particularly the short landing/fire accident to a Boeing 727 aircraft at Salt Lakes City on the 11 November 1965 where 43 passengers died, 35 of whom had carboxyhaemoglobin levels of 13-82% ($A_v = 36.9\%$), the FAA Civil Aero Medical Institute (CAMI) at Oklahoma initiated research into passenger smoke protection.

A simple hood was developed made from 'Kapton' polyimide, a high-temperature resistant translucent material which could protect the head against temperatures of 800°C. This simple device had no air supply, filter or carbon dioxide absorbent and merely provided a reservoir of air within the hood sufficient for some 1-2 minutes breathing under heat/exercise conditions.

The first model, which featured a 'draw-string' neck seal, was quickly superseded by a hood with a much improved elasticated 'septal' neck seal. This hood was known as the Schjeldahl 'S'hood and subsequent variants were partly metalised to reflect radiant heat. In the following 4 years, considerable testing was carried out on these hoods⁹ and included:-

neck seal leakage evaluation (including exposure to carbon monoxide and smoke);

breathing capacity and carbon dioxide build-up under exercise conditions;

visibility measurements;

acoustic measurements;

effects of variations in safety briefings on use of hoods by naive subjects;

evacuation tests using naive subjects in dense non-toxic smoke conditions.

In assessing the evacuation tests this report concluded that the use of hoods had no significant effect on evacuation rates, the main factor affecting evacuation rates being the presence of smoke.

In 1967, aircraft belonging to the FAA were equipped with Schjeldahl smokehoods for their occupants.

On February 27/28th 1968, more extensive evacuation tests were carried out at the Aeronautical Centre, Oklahoma. An FAA Boeing 720 aircraft was fitted with a passenger seating capacity of 124 with 4 stewardesses supplied by Braniff. A total of six evacuation tests were carried out, both with and without smoke. The associated report concluded:-

"There are indications that the use of smoke hoods during an emergency evacuation of a typical air carrier jet aircraft causes a small increase (approximately 8%) in the overall time required for naive passengers to evacuate".

The results of this test and the other research were judged satisfactory by the FAA and on the 11th January 1969 NPRM 69-2 was published in the Federal Register, with the intention of amending FAR part 121 to require that protective smoke hoods be carried for all occupants on aircraft operating under these regulations:-

"These hoods would be available for use by their occupants to facilitate airplane evacuation when fire or smoke is present after a crash-landing or other emergency".

Whilst there was much support for this proposed change, some sections of the aviation community were unconvinced. On the 11th August 1970, NPRM 69-2 was withdrawn by the FAA, with the principal reason given that the hood might cause a delay in evacuation.

In late 1971 a comprehensive report on smoke hoods was reviewed by the US National Research Council. They rejected the viewpoint that carbon dioxide accumulation in the hood and the accompanying hyperventilation would cause passengers to remove the hood, but suggested the addition of a carbon dioxide absorber and oxygen supply to the hood to extend usage. The feasibility of using a small chemical oxygen source was investigated.

In June 1980, the FAA Technical Centre at Atlantic City requested CAMI to re-examine passenger smoke hood protection, stating:

"Survival and escape of passengers in a transport cabin fire may be impaired or prevented by smoke and toxic gases. Advancements in protective breathing devices and limited progress in the minimization of cabin fire hazards prompted the SAFER (Special Aviation Fire and Explosion Reduction) Committee Technical Group on Compartment Interior Materials to recommend a re-assessment of protective breathing devices for usage by passengers aboard Part 25 Aircraft".

This led CAMI to evaluate, in the period 1981-1985, the possibility of using a 'rebreather bag' attachment to the standard passenger oxygen-mask ('yellow-cup'). This system had a number of deficiencies in supporting respiration and failed to protect the eyes or address the evacuation case.

In 1983, as a result of their investigation into the in-flight fire and emergency landing accident to an Air Canada DC9 at Cincinnati on the 2 June, in which 23 of the 41 passengers died before they could evacuate the cabin (and survivors breathed through hand towels), the National Transportation Safety Board (NTSB) issued Safety Recommendation A-83-76 on the 31 October 1983. This recommended that the FAA:-

"Expedite the research at the Civil Aero Medical Institute necessary to develop the technology, equipment standards, and procedures to provide passengers with respiratory protection from toxic atmospheres during in-flight emergencies aboard transport category airplanes".

It is also noteworthy that in July 1982 a very comprehensive report, sponsored by the FAA, was issued on the problems of aircraft fire. This report included a very detailed cost/benefit analysis of a wide variety of different approaches to combat fire on aircraft. It concluded that smoke hoods

were by far the most cost-beneficial approach for survivability and would achieve the highest survivability factor, with the lowest cost per death prevented. (Appendix 17)

1.16.3 AAIB passenger smokehood test programme

During a visit to CAMI by AAIB investigators on the 17/18th March 1986, it was confirmed that the 'rebreather-bag' approach was unlikely to prove satisfactory for passenger smoke protection. It was also established that CAMI had not, at that stage, carried out any assessment of modern breathable-gas or filter type hoods.

It was therefore confirmed that the AAIB would continue to fund and direct a research/test programme to explore the potential of breathable gas and filter hoods. Work on this programme had begun in January 1986.

1.16.3.1 Breathable gas smokehoods

The tests on the breathable gas hoods were carried out in two stages. Initially, four different types of passenger hood and one French cabin crew hood were tested at the RAF Institute of Aviation Medicine, Farnborough, to establish the breathing capacity/duration, carbon dioxide build-up and temperature rise within the hoods at various work rates, using human subjects. Additional tests were also carried out at the Chemical Defence Establishment, Porton Down, to establish the ability of the neck seals to prevent the external atmosphere entering the masks.

Using test protocol 1 (Appendix 18 a), it was found that none of the 5 hoods achieved a fully satisfactory standard, with three of the hoods requiring an increased oxygen capacity and at least one other hood needing improved carbon dioxide absorption. These results were not altogether surprising since each of the hoods tested had been developed prior to the CAA draft specification, which was used as the basis for these tests.

In the spring of 1987, 2 of the latest standard of passenger type hoods were tested, together with a cabin crew hood of the same type used in the earlier tests to provide comparative data. These tests were carried out in the laboratories of the Scientific Division of British Coal at Edinburgh, using an 'Auer' lung simulator. (Appendix 18 b)

Three test protocols were devised for these tests (Appendix 18a), designed to cover broadly the performance envelopes required for the emergency evacuation case; a 15 minute test to allow comparison with the cabin crew hood (rated for 15 minutes duration); and testing to the CAA Draft 'Type 1' test performance requirement.

In the first two protocols, both passenger hoods substantially outperformed the cabin crew hood which weighed 3 lbs, compared to the 1 lb weight of each passenger hood.

The first passenger smokehood surpassed the CAA Draft Specification 20 minutes endurance with ease, achieving 28 minutes (with the final 10 minutes at the highest workload of 100 watts/minute) before the inhaled carbon dioxide concentration exceeded the 5% limit. Indeed when the CAA required 15 minute sedentary period was extended to 25 minutes in a later test this type of hood achieved an endurance of 31 minutes before the inhaled carbon dioxide concentration exceeded 5%.

The second passenger hood achieved the 20 minutes endurance required by the CAA draft Type 1 specification, although it exceeded slightly the carbon dioxide level (7.75%). (Appendix 18 c)

The tests at Porton Down indicated that elasticated septal neckseals alone were capable of providing adequate sealing against the external atmosphere. It was considered that the addition of an ori-nasal mask would further enhance sealing effectiveness.

1.16.3.2 Filter smokehoods

The problem of testing filter hoods was the more difficult. Indeed, the initial question confronted was whether filter-protection could be regarded as a viable approach to survival in aircraft fires, since there was a widespread belief that there is insufficient oxygen in fire atmospheres. However, the young boy and man survived the fire at Manchester, others have survived for protracted times in other aircraft ground fires and there have been many instances of passengers surviving in-flight fire/smoke situations - eg the Canadian DC9 at Cincinnati in June 1983 (para. 1.17.7), where most survivors breathed through wet hand-towels issued by a stewardess.

In addition, the large amount of data from the C133 Fire Test Programme at the FAA Technical Centre, Atlantic City, indicated that the available oxygen concentration in the cabin did not reduce appreciably until temperatures exceeded human tolerance levels. Similar evidence was apparent from the earlier NAFEC cabin fire tests carried out in 1965. Thus, whilst this vital question is still open to the consideration of further data, based on this assessment carried out early in 1986 there appeared reasonable grounds to proceed with a scientific evaluation of filter-protection in order that the other important questions of particulate-induced blockage, toxic/irritant gas protection etc, could be addressed.

The next question concerned how a meaningful test could be devised, since aircraft fires are infinitely variable. The key to this question, which began to emerge as the research data was examined, appeared to be that although fires are variable, the prime reasons for incapacitation, which appeared generally accepted, were those associated with hydrogen cyanide and carbon monoxide toxic gas absorption and the related problems of attack by irritant gases such as hydrogen chloride, hydrogen fluoride, nitrogen oxides, sulphur dioxide and acrolein.

With regard to carbon monoxide, there is a body of opinion that this particular gas is slow to reach incapacitating concentrations in fires and that much of the pathological evidence of high carboxyhaemoglobin levels in fire-fatalities derives from post-incapacitation absorption, before respiration ultimately ceases. It is contended that hydrogen cyanide, which can cause rapid incapacitation at very low concentrations of approximately 200 ppm, is the more potent toxic gas. This was an important consideration, since although carbon monoxide can be countered by catalysts such as Hopcalite*, this requirement increases the weight and depth of any filter.

Since however, the aim of the AAIB tests was to evaluate the best protection that filters could provide, a firm decision was made that any filters to be tested within the AAIB smokehood test programme would be required to combat carbon monoxide.

Following a search of available data the following Challenge Atmosphere and acceptable filter breakthrough levels were arrived at:-

Gas	Challenge concentration	Filter Break-through (After 5 minutes)
Carbon Monoxide	10,000 ppm (1%)	400 ml (max cumulative total)
Hydrogen Cyanide	400 ppm	20 ppm

Hydrogen Chloride	1000 ppm	10 ppm
Nitric Oxides	200 ppm	10 ppm
Sulphur Dioxide	100 ppm	10 ppm
Acrolein	20 ppm	1 ppm
*Hydrogen Fluoride	500 ppm	10 ppm

* Separate single gas challenge requirement.

The above definition of the challenge atmosphere was included in Passenger Smokehood Acceptance Criteria, issued by the AAIB on 5th March 1986 to interested manufacturers within the UK and abroad, which included requirements for the following parameters:-

filter performance, including carbon dioxide limitations (5%);

inhaled gas temperature limitations (45°C, wet);

flame and molten drop resistance;

robustness;

weight (1 lb);

compactness;

donning time target (8 seconds) for both breathable gas and filter-type hoods.

Challenge atmosphere generation and analysis

A major question was whether such an atmosphere could be modelled, particularly since the aim was to attempt generation by burning a wide cross-section of cabin materials and kerosene in order to derive a representative complex atmosphere.

This task was given to the Rubber and Plastics Research Association (RAPRA) at Shawbury on the 19 February 1986. By the end of May, they had achieved significant success with generation of the atmosphere in a large 34 cubic metre chamber, lined with polypropylene. By June of 1986 the atmosphere could be generated on an acceptably repeatable basis, using a derived weight and 'mix' of cabin materials. An effective degree of control for such gases as carbon monoxide, carbon dioxide, oxygen, hydrogen cyanide, nitrous oxides, and sulphur dioxide was achieved, although hydrogen chloride levels were still variable.

The range of cabin materials used to generate the atmosphere were as follows:

Material	Source
Wool	Curtains, carpets, seat-covers
Polyurethane Foam	Seat cushions
GRP (Polyester)	Ceiling panels
Epoxy Honeycomb	Overhead bins
PVC (rigid and plasticized)	Carpet strips, seat backs/mouldings, life-

	jacket holders
PVC/Polyester	Seat cushion support
Polyester Fibre	Lap belts
Polycarbonate	Window surround
Nylon	Mouldings - eg hinges
Acrylonitrile-Butadiene-Styrene (ABS)	Seat leg mouldings
Chlorosulphonate Polyethylene	Cable insulation
Polyethylene Foam	Seat padding
Polysulphide	Sealants
Kerosene	Aircraft fuel

Note: Fluorinated compounds (such as the 'Tedlar'/Polyvinylfluoride film used to cover aluminium alloy side panels on the Boeing 737) were not included within the above list of materials due to current health concerns regarding the combustion of fluorinated compounds. Separate tests were conducted later at the Scientific Division of British Coal at Edinburgh using hydrogen fluoride gas atmospheres.

The equipment used to analyse the challenge combustion atmosphere permitted continuous monitoring of carbon monoxide, carbon dioxide, residual oxygen, nitrogen oxides, chamber temperature, and time-weighted averages of hydrogen cyanide, hydrogen chloride, sulphur dioxide, acrolein and particulate.

A full Gas Chromatography Mass Spectrographic (GCMS) analysis of the complex organic compounds in each of the atmospheres was also carried out.

In addition to the required levels of the challenge atmosphere, RAPRA were asked to monitor for other gases, including ammonia, hydrogen sulphide and phosgene. This testing indicated the presence of up to 850 ppm of ammonia within these atmospheres, acrolein levels up to 40 ppm and in addition particulate densities up to 5 milligrammes/litre.

The only gas which was difficult to generate to the required levels via natural combustion of the materials was nitrogen dioxide and because of this, cylinders of this gas were used to boost the atmosphere to the required levels artificially. In retrospect, some boosting of the hydrogen chloride levels would also have been advantageous, although supplementary tests were carried out where high hydrogen chloride levels had not been achieved in earlier test-runs.

Lung simulation and filter breakthrough analysis

The second major task was to devise truly representative lung simulation (with carbon dioxide and humidity insertion, to simulate human respiration) associated with a dummy head in the test-chamber. For this part of the exercise the AAIB obtained the committed assistance of the Scientific Division of British Coal at Edinburgh.

An extensively modified 'Auer' lung simulator was used so that human breathing could be fully simulated. In addition, a system was devised so that the inspired gases entrained through a filter during each inhalation could be sampled, so that accurate analysis was achieved. The lung was

set to inhale 30 litres/minute at a breathing frequency of 20 cycles/minute, with the exhalate fully saturated with water vapour at 37°C and containing 4.5% carbon dioxide.

Carbon monoxide, carbon dioxide, oxygen, nitrogen oxides, inhaled gas temperature and filter resistance were monitored continuously, whereas hydrogen cyanide, hydrogen chloride, sulphur dioxide, acrolein etc were absorbed in impinger-solutions so that their associated average concentrations could be measured over the test duration of 5 minutes.

In addition, a GCMS analysis was carried out on the filtered atmosphere.

Filter tests

Testing began at the end of July, 1986. Although the intended approach was to test in the region of 40°C and 100°C, this was in fact quickly modified. High temperature runs were directed towards a 5 minute test averaging approximately 100°C. Medium temperature runs were initiated later in the natural temperature decay and averaged approximately 65°C for 5 minutes. Runs were also carried out to check carbon monoxide penetration at low challenge levels around 0.25%, where carbon monoxide 'slippage' (filter penetration) can occur, and were achieved using a partial 'purging' of the smoke chamber, the temperature averaging approximately 65°C during these runs.

Filter performance tests were conducted against the Challenge Atmosphere to establish:

gas and particulate filtering efficiency;

limitation of inhaled carbon dioxide concentration;

breathing resistance characteristics against time;

limitation of inhaled gas temperature;

% moisture in the inhaled gas.

These tests were primarily directed towards a 5 minute test duration, but many tests were extended beyond this time scale, up to 30 minutes endurance.

A total of 5 weeks intensive testing of six different filter types was carried out, before the facility was closed down on the 16 October 1986. Seventy test-runs had been completed, using a total of approximately 7 ton of materials.

In addition, at the laboratory of the Scientific Division of British Coal at Edinburgh, testing was carried out to check the performance of filters against hydrogen fluoride atmospheres to assess the 'sorption' capacity, followed by testing against 1% carbon monoxide to check for any deterioration in carbon monoxide catalyst efficiency resulting from hydrogen fluoride exposure. Tests were also conducted against an hydrogen fluoride/carbon monoxide mixture, followed by carbon monoxide exposure.

Results summary:

The filter test programme demonstrated that filters based on the 'Hopcalite' catalyst can provide the necessary protection against carbon monoxide, hydrogen cyanide, hydrogen chloride, hydrogen fluoride, nitrogen oxides, sulphur dioxide, ammonia, acrolein, benzene, toluene, styrene, acrylonitrile and other toxic/irritant gases, including the associated particulate, provided there is sufficient oxygen in the fire atmosphere to sustain life and that the concentration of carbon dioxide is not such as to induce severe debilitation. The C133 test results indicated that, prior to

flashover, oxygen levels were maintained at the normal level of 21% by volume and the carbon dioxide concentration was negligible.

The inhalation resistance of filters increased, as expected, with time of exposure to such atmospheres. However, except for a number of high temperature fires (approximately 140°C) the inhalation resistances measured would be reasonably acceptable to most healthy people in an escape situation, for periods of 5-10 minutes.

While certain designs of filter can maintain the inhaled gas temperature just within acceptable limits even when exposed to atmospheres at 100°C, it was demonstrated that the inclusion of a simple metal heat exchanger behind the filter can satisfactorily reduce inhaled gas temperatures. (Appendix 18 d)

1.16.3.3 Summary of additional tests carried out at RAPRA on filter and breathable gas hoods

1 Smokehood light transmission measurements before and after exposure to the challenge atmosphere, with further light transmission measurements after a simple 'wiping' of the hood transparency.

2. Monitoring of any detrimental effects on the hood materials as a result of exposure to the challenge atmosphere.

3. Flame tests on all hoods using the British Standards Institute Flame Test Rig with a modified protocol.

4. Molten drip tests on all hoods.

It was found that smokehoods lost some 40-50% of their light transmission capability by the end of their exposure to the challenge atmosphere, as a result of smoke particulate deposition on their transparencies. With the exception of one hood, all had their light transmission characteristics restored to within 10% of their 'as-received' values after simple 'finger-wiping'. The one exception was a hood made from pure 'Kapton' material which was affected by the challenge atmosphere, creating a 'tacky' surface on the exterior. This could not be restored by wiping, and left the hood with a reduction in light transmission of some 30-35%. PFA*-coated Kapton was not affected in this way and performed satisfactorily. No other detrimental effects were found due to exposure to the atmospheres.

Flame testing demonstrated that hood materials are available which can successfully resist an impinging flame of 915-920°C maximum temperature for some 6 seconds. In addition smokehood materials can satisfactorily resist the effects of flaming droplets of nylon.

A full report on the AAIB Passenger Smokehood trials is available as a separate publication.

1.16.4 Internal water spray systems

The potential for water to extinguish many types of fire has long been appreciated. However, although fire authorities have known for some time that the way in which water is applied is of importance it is commonly believed that relatively large volumes of water are required and that its use on certain fires, involving fuel oils for example, is undesirable if not counter productive.

Water typically extinguishes a fire by absorbing the heat generated and depriving the fire of oxygen. The heat absorption rate is largely governed by the surface area of water exposed to the fire environment and therefore the larger the surface area of the water the greater the effect. The exposed area is increased by reducing the droplet size in a spray application but below a certain

mass the droplets lack sufficient momentum to penetrate the turbulent gases to reach the seat of the fire. There is, therefore, an optimum droplet size to meet the compromise between maximum exposed surface area and minimum droplet mass.

Consideration of the use of water spray systems in aircraft is not new and was the subject of an evaluation by the FAA in the early 1980's. Such systems appeared at that time to have significant potential but the cost of installation and the weight of onboard water necessary to effectively supply the spray nozzles were issues which, it was felt, required further research and development to reduce the operational penalties.

For some years before the accident to G-BGJL water spray nozzles had been developed for use on manifold systems distributed about large earth moving vehicles, which had proved prone to fire and difficult to evacuate. An installation had then been developed for road transport passenger vehicles and thought given to developing the system for aircraft passenger cabin protection. The Manchester accident accelerated this development and a number of trials were conducted with systems installed in a VC 10 passenger cabin furnished with limited seat rows and cabin materials. Two separate but complimentary philosophies have been demonstrated:-

1) an 'onboard' system, primarily intended to protect the cabin and passengers until the first fire appliance arrives, comprising a single line of misting nozzles down the centre line of the cabin roof. These were to be fed from an onboard water supply at a total flow rate of approximately 13 gallons/minute into a cabin 15 ft diameter by 60 ft long. This water could be drawn from the aircraft's domestic system or from a dedicated supply - about 30-40 gallons being required in a Boeing 737 sized aircraft to give 2-3 minutes application. It was intended that the system would only operate with the aircraft on the ground and be activated as soon as there was risk of fire starting in, or penetrating the fuselage.

2) a 'tender' system having an array of sprays inside the cabin and other critical zones to be supplied with water from a fire appliance alongside the aircraft. (In the case of an airfield accident the first fire appliance should arrive in not more than 3 minutes and could then start pumping water into the system, at 150 gallons/minute in the case of a Boeing 737 sized aircraft.)

Tests were carried out using fires initiated directly within the passenger cabin, using trays of kerosene producing fire transfer to rows of seats, and fires initiated with trays of kerosene outside of a door sized aperture igniting seat rows adjacent to the door by radiant heat transfer.

The 'onboard' system at a flow rate of 13 gallons/minute prevented the external fuel fire transferring into the cabin and prevented a large fuel fire within the cabin from developing to involve significantly the seats.

The 'tender' system extinguished the cabin fires in approximately 3 seconds, dramatically dropping the cabin temperature and improving visibility by 'washing' much of the particulate out of the atmosphere.

Further trials are planned to demonstrate the systems within a fully furnished aircraft. Although the tests carried out to date have not explored the issues of installation, reliability and system integration, they have nevertheless demonstrated that the concept has great potential both to limit fire development before the first fire appliance arrives, and then to allow firefighting personnel to tackle internal cabin fire directly - something which airfield fire services are currently denied during the period of passenger evacuation.

In further, separate, developments in this area, nozzle designs used within the petro-chemical industry have been adapted to produce very small droplets, with attendant increase in surface

area, which are transported to the seat of the fire on their own column of moving air. This nozzle has, to date, only been tested on hose-end applications but has shown great potential when used to extinguish pans of burning crude oil. In controlled tests this nozzle significantly out-performed more conventional fire hose nozzles on a 'standard building fire'. A major advantage, in addition to the extinguishing potential is the relatively low pressures of water required to achieve a 'throw' comparable with conventional hoses, resulting in greatly reduced hose-end reaction forces. It is hoped that future tests will explore the application of this nozzle and delivery system to cabin spray distribution systems.

1.17 Additional information

1.17.1 Pratt and Whitney JT8D relevant history

The JT8D first entered service in 1964, since when it has become the most widely used jet engine in the world. It has undergone many developments to increase its performance, resulting in a range of engines with differing rated thrusts. Information provided by the manufacturer shows that the JT8D-15 engine, as fitted to G-BGJL, exhibits the highest combustor can metal temperatures of the entire engine model range.

There had been twelve reported cases of CCOC explosive rupture prior to the G-BGJL accident of which seven were attributed to a primary defect in the CCOC itself. Two cases were attributed to problems with the fuel nozzle and/or support, while the remaining three cases resulted from combustor can problems. These engines were fitted to Boeing 727 aircraft and involved two JT8D-15 and one JT8D-9 model. In at least two of these cases, parts of the can responsible for the rupture had been expelled, causing some minor airframe damage, but there was no resultant fire.

In addition to those instances when explosive rupture of the CCOC actually occurred, it must be recognised that 'burn-throughs' of the CCOC (ie penetration by the combustion flame but not resulting in explosive casing rupture) represent a different outcome from a similar initiating failure mechanism and should be included for consideration. There were 16 recorded cases of burn-through of the CCOC prior to the accident to G-BGJL, of which 4 were attributed to combustor can failure, 5 were due to can shift (locating pin failure) and the remainder due to fuel nozzle or fuel system failure.

1.17.1.1 Pratt and Whitney letters and telexes to operators relating to combustor can/CCOC failures

Regarding the three cases of CCOC explosive rupture due to can failure which occurred in 1979, 1984 and 1985, Pratt and Whitney advised all JT8D operators of the 1979 incident in a letter, dated 31 January 1980. This letter described the circumstances of the incident to a JT8D-9A:-

"In July 1979, the combustion case of a JT8D-9A engine ruptured during climb out after take-off. The case rupture initiated at the 8 o'clock position and the resultant blowout pressure caused the edges to peel back in both the clockwise and counterclockwise directions resulting in a hole which extended circumferentially from 5 o'clock to 11 o'clock. The fan case and engine nacelle were also ruptured along this same plane. A 1 inch by 2 inch hole was found in the aircraft vertical fin, evidently caused by debris liberated from the case rupture. The No 7 combustion chamber was expelled through the hole in the combustion case. Although the chamber was not recovered, our investigation into this incident has led us to conclude the incident was initiated by the complete fracture of one of the chamber seam welds joining two liner sections. Resultant misalignment of the chamber segments caused combustion within the chamber to impinge on the combustion case wall, softening the case to the point of rupture." (ie a very similar mechanism to

that known to have occurred on G-BGJL, albeit where the 360° fracture occurred in the No 3 liner material, not in the seam weld itself).

The letter further documents numerous cases of 360° cracking reported to Pratt and Whitney:-

"2-3 Liner Seam Weld Cracking: This condition was first observed after introduction of reduced smoke combustion chambers and is peculiar to that configuration. It has occurred in all JT8D models. There have been 9 reported instances of 360° cracks in the 2-3 liner seam weld with part times ranging from 1,810 hrs to 7,510 hrs. Twenty additional instances of 360° cracking have also been reported. Part times for these cases could not be determined. Because of the 'piloting' effect of the air scoop and crossover tubes, 360° cracking in 2-3 liner seam weld is usually seen only at engine disassembly. However, if allowed to continue in service for a sufficient period of time in the 360° cracked condition, vibration and gas loads could cause the chamber to separate, sag and allow fuel spray deflection."

"3-4, 4-5 and 5-6 Liner Seam Weld Cracking: Circumferential cracks in these liner seam welds have been reported in reduced smoke liners in all JT8D engine models. These cracks typically vary from 1 inch to 6 inches in length and are normally detected during hot section inspections. This condition has been repaired in the shop by fusion welding the cracked areas or by replacing the entire liner. Recently, however, we have received several reports documenting 360° cracking of the 4-5 or 5-6 liner seam welds. Although part times were not available, times since last shop visit ranged from 3,200 hrs to 7,000 hrs. Chamber separation in these seam welds is potentially more serious than in the 2-3 liner area because these liners do not have the benefit of the piloting features of the air scoop and crossover tubes. Once the crack has progressed 360°, combustion chamber sag within a short period of time is possible. One of these incidents caused softening and bulging of the outer combustion chamber case due to resultant fuel spray deflection."

"Liner separation in some cases, is evidenced by slow spool-up from light off to idle or by slow acceleration above idle."

The letter then described a "development programme to better understand the liner cracking and to identify improved repair and management procedures" recently initiated by Pratt and Whitney. The programme was to include the following elements:-

- (a) Investigation of improved techniques for detection of cracks in the shop (maintenance workshop).
- (b) Investigation of high time combustion chambers for possible degradation of material properties such as hardness and fatigue life.
- (c) Evaluation of fusion weld overlay to strengthen the 3-4, 4-5 and 5-6 liner seam welds.
- (d) Evaluation of the effectiveness of SHT of the combustion chamber liner assembly for restoration of fatigue life.
- (e) Determination of the number of cycles to crack initiation and for 360° progression.
- (f) Evaluation of alternate methods for production welding of combustion chamber liners for improved weld life.
- (g) Re-examination of Engine Manual limits and procedures for combustion chamber repairs.

The target date for the completion of the above programme was July 1980, at which time Pratt and Whitney expected to provide additional information directed towards controlling liner seam weld

cracking. The letter concluded; "Pending completion of the programme, we recommend that the following currently available shop maintenance procedures be utilised to reduce the potential for combustion chamber liner separation due to circumferential seam weld cracks."

A Solution heat treat the combustion chamber liner assemblies prior to weld repair. Refer to the Engine Manual, Section 72-42-1, Repair for the SHT procedure. SHT is beneficial in fatigue life restoration of the Hastelloy X material, and has the additional advantage of cleaning the part prior to welding if done in an inert atmosphere.

B Pay particular attention to detection of circumferential seam weld cracks. Completely rout out cracks prior to weld repair to ensure weld integrity.

C Replace bulged and oxidised liners and replace liners which have been extensively weld repaired.

D Incorporate a 2-3 liner fusion weld overlay per Engine Manual, Section 72-42-1, Inspection.

A further letter was despatched to operators dated 5 December 1980. This letter stated that the cause of the circumferential cracking was identified as thermal fatigue and that the 360° circumferential progression generally occurred in weld-repaired liners which have "lower fatigue strength than non-weld-repaired liners". The letter further stated that tests had shown the value of fusion weld overlay and SHT on fatigue life and that rig tests were being undertaken on weld-repaired cans in order to develop an improved technique. Four recommendations were made:-

(a) To conduct a periodic inspection of combustion cans for seam weld cracks.

(Recognising the difference in operating patterns, maintenance procedures and part times Pratt and Whitney could only recommend that each individual operator establish his own inspection frequency, but quoted one operator who had successfully overcome a can separation problem by inspecting his combustion section at 6,000 hours time since last workshop visit.)

(b) To undertake SHT prior to welding repairs.

(c) To rout out cracks prior to weld repair.

(d) To replace bulged and oxidised liners and liners which have been extensively weld repaired.

A further letter dated 13 May 1983, addressed primarily to overhaul agencies, recalled the circumstances of the 1979 CCOC rupture following a can separation and introduced the process known as braze reinforcement repair, which was claimed to provide a "two-times" improvement in can seam-weld fatigue life. (After the accident to G-BGJL, this process was withdrawn by Pratt and Whitney in November 1985 as being counter-productive.)

Finally, a telegraphic 'All Operators Wire' dated 7 February 1985 was despatched from Pratt and Whitney "to inform (operators) of two recent incidents involving the Combustion Chamber Outer Case". The first incident described a JT8D-15 engine which experienced a CCOC rupture during the take-off roll. The take-off was abandoned without further problems. The telex went on to describe how the No 7 can was considered to have cracked sufficiently to allow combustion gases to impinge on the inner face of the CCOC and recommended "strict adherence to engine manual repairs and close monitoring of engine response especially during transient conditions". Specifically, "reports of slow starting or acceleration should be suspected as a potential cause of severely distressed or misaligned combustion chambers". The second incident described a primary failure of the CCOC on a JT8D-9A engine.

1.17.1.2 Pratt and Whitney operators conferences

Pratt and Whitney JT8D Operators Conferences, held in 1980 and 1985 addressed the can cracking problem and the notes prepared for these generally reflected the situation described in the letters issued in those years. It was noted that the 1980 conference depicted the type of cracking which could lead to 360° can separation in the area of the No 2 through No 9 liner seam welds. The cracks observed on the No 9 can of G-BGJL were not in the seam weld but adjacent to it.

The 1985 conference also gave much information on cracking in the seam weld location and said "most reports of problems related to chambers concern high time parts which have been weld repaired many times and probably never metallurgically refurbished".

1.17.1.3 Pratt and Whitney Service Bulletins

In November 1980, Pratt and Whitney issued Service Bulletin 5192 which introduced a re-designed combustion can for the JT8D-11, -15, -17 and -17R engines. This new can incorporated several improvements (including fusion weld overlay reinforcement of the 2/3 liner seam weld). It also addressed igniter guide wear and buckling of the number 11 liner. The Bulletin stated that these modifications would provide a can with "improved durability" although it was aimed primarily at the problem of seam weld cracking of the 2/3 liner joint which, because it occurs under the air-scoop, requires radiographic inspection to detect. British Airways JT8D-15 engines were all delivered with this modification incorporated during engine build.

A further Service Bulletin, No 5461 was issued in April 1983 and was applicable to all JT8D-15/15A engines fitted with SB 5192 standard combustor cans. This SB introduced a modification to these cans whereby a ceramic coating could be applied to the interior to provide an insulation barrier and reduce metal temperatures by 50°F-100°F. The compliance category was 8 - "Accomplish based upon experience with prior configuration". Although it appears the modification was not widely adopted, it was noted that it did provide the information that "burning and cracking has been observed in some combustion chambers at the 2nd to 5th liners after 3,000 to 5,000 hours of operation". Pratt and Whitney do not apply this modification to new cans leaving their factory.

1.17.2 Engine maintenance requirements

1.17.2.1 General engine maintenance and repair

There is no laid-down time specified by Pratt and Whitney for strip inspection and overhaul of the engine as a whole. Whilst hard-lived items on the engine may require engine strip to replace them (at which time, of course, the particular module would be inspected/overhauled as necessary) the operator is expected to arrange a maintenance programme with the relevant Airworthiness Authority.

The "Pratt and Whitney Maintenance Planning Guidelines" booklet was produced to assist operators utilising any of the principal maintenance processes (hard-time engine overhaul, modular overhaul, condition monitoring and on-condition maintenance) and provided suggested initial inspection intervals for each, dependant on the particular operator's experience.

Following negotiations with the CAA, British Airways embarked on an engine sampling programme in which engines were removed and strip-inspected at various times to monitor deterioration - the aim being to establish fixed overhaul lives for the major parts of the engine. Commencing at 5,000 hours Time Since New (TSN) various engines were sample inspected, following which it was agreed that each engine would run between 10,000 - 12,000 hours TSN before an LMI was carried out - this would include a full combustion section overhaul. A Heavy Maintenance Inspection (HMI) was to be performed at 16,000 hours since last HMI or TSN. The LMI would be repeated at 10,000 hours since last HMI.

It can be seen, therefore, that the combustion section of engine P702868 would have been overhauled for the second time at 16,000 hours on this maintenance schedule, although British Airways target was to establish a 20,000 hours/13,000 cycles HMI interval, subject to a satisfactory 16,000 hour sample. The HMI would also include a combustion section overhaul.

The Pratt and Whitney Maintenance Planning Guidelines provided the following recommendations when inspecting the combustor cans:-

"Visually inspect and x-ray combustion chambers. Repair combustion chamber distress to Engine Manual specifications, as required, paying particular attention to liner cracking, hole pattern/wall distortion, worn locator lugs and worn crossover tubes."

This appeared in the British Airways Approved "Light and Heavy Maintenance Inspection Schedule" as:-

"Fully inspect combustion chambers in accordance with Overhaul Manual (including x-ray of No 3 Liner seam weld)"

-note this refers to the 2/3 liner weld under the air-scoop and was not to address a known problem with the 3/4 liner joint.

1.17.2.2 Information contained in the engine technical manuals

In the Pratt and Whitney Engine Manual, inspection and fusion weld repair of combustion cans are covered in sections headed:-

"Inspection 01"

"Inspection 02"

"Repair 06"

Extracts from the Engine Manual relevant to the G-BGJL accident are given below:-

Inspection 01 1B General

"(1) Cracks in combustion chamber surfaces are usually of a stress relieving nature and, as such, are not serious in that the rate of growth decreases as the crack lengthens."

Inspection 01 Subtask 72-41-22-044

"(1) Any circumferential and axial crack, except in No 1 liner and nozzle stator, not exceeding 0.030 inch wide may be weld repaired."

Inspection 01 Subtask 72-41-14-046

"(g) Severe local distortion and/or oxidation of liners is not acceptable and is not weld repairable. See figure 807. Replace liner if condition exists. (Appendix 5 h)

Inspection 02 Subtask 72-41-26-000

"(1) (e) Examine developed film for circumferential cracking in area of 3rd liner cooling holes. For crack limits see paragraph (2). For crack repair see Task 72-41-14-30-046 (Repair -06)".

Inspection 02 Subtask 72-41-26-000, paragraph (2)

"(2) Any circumferential or axial crack not exceeding 0.030inch wide may be weld repaired. See Fig 803. Cracks in excess of this limit will necessitate replacement of liner assembly. For combustion chambers with cracks more than 2.500 inches in length stress-relief is recommended after welding. See Task 72-41-14-30-046(Repair 06)".

Repair 06 Task 72-41-14-30-046-001: Liner Crack Repair (FusionWeld Method). Subtask 72-41-14-37-005

"(2) Before welding solution heat treat @ 1,875° - 1,925°F".

Subtask 72-41-14-37-022-002

"(6) For combustion chambers with cracks in excess of 2.500inches in length, stress relief is recommended but optional based on operator's experience".

It should be noted that the term 'Overhaul Manual' is used in this report, as distinct from 'Engine Manual' as used by Pratt and Whitney, to reflect the fact that the two are not necessarily the same. Under the terms of the approval granted to British Airways/British Airways Engine Overhaul Ltd (BEOL) by the CAA, they may vary the content of their manual with respect to the manufacturer's document.

Such variations are submitted to, and approved by, the CAA. This occurred with the requirement to SHT the material prior to welding. BEOL had difficulties with implementing the process and it was deleted from their Overhaul Manual for some years before being re-instated in early 1985.

1.17.2.3 Trouble-shooting and trim runs

Information on day-to-day engine fault diagnosis is contained in the trouble-shooting sections of the Pratt and Whitney Maintenance Manual. At the request of British Airways, the section was also reprinted in the Boeing Maintenance Manual. The section covering 'slow acceleration' as it existed at the time of the accident is reprinted below:-

J. Slow Acceleration

Possible Cause	Test Procedure	Corrective Action
(1) Defective Fuel Control Schedule	Check Ps4 sense line for leaks	Retorque or replace line as necessary; if no leaks, replace fuel control
(2) Bleed Valves Off-Schedule	Check bleed valve operation per <u>Adjustment/Test</u>	
(3) Combustion Chambers Shifted Rearward	Perform hot section inspection (Chapter/Section 72-40, <u>Removal/Installation</u>)	Replace chambers as necessary (chambers incorporating SB 4190-and/or 4421 feature greater wear resistance in mounting lug area)

(4) Defective Start Bleed Control Valve Check bleed valve operation
(see Adjustment/Test)

It should be noted that cause (3) is not directly related to the problem of combustion can cracking, but refers to an earlier problem experienced with wear/failure of the can mounting pin. All British Airways engines were equipped with cans featuring SB 5192 with greater wear resistance in the mounting lug area.

No mention of combustor can defects was made in the 'Thrust Lever Misalignment' (throttle stager) section of the Boeing Maintenance Manual and there was no trouble shooting guidance given for low ground idle symptoms, nor was any mention made of possible inter-relationships between some of the symptoms.

The Boeing Maintenance Manual describes the procedure to be adopted for performing a Part-Power Trim Run. It is essentially to ground run the engine with a test-set of reference instruments connected and to record the various engine parameters for checking against data tables in the manual. Adjustments are then made to the fuel control unit as required so that the engine performance corresponds with these data tables.

The first step is to check N2 idle speed and adjust as necessary (it is recommended that the ground idle be adjusted to the upper limit of the tolerance band). A part-power trim stop is engaged on the engine and the pilot's throttle levers advanced until the thrust lever on the FCU contacts the stop. This provides both a datum against which to judge the engine's performance, and also the means to check for incorrect rigging of the throttle lever cables (one possible cause of throttle stager).

Since adjustment of the 'Idle' trim screw has some effect on the engine at higher settings, a second adjustment, referred to as the 'Mil' trim screw is used to adjust the fuel flow at the part-power setting. Having checked the parameters against the manual figures, the engine is returned to idle for 5 minutes, when the idle N2 is checked again.

The manual procedure then continues:-

"Idle adjustment of as much as 0.5% N2 (8 clicks) is permitted after final setting of part-power trim without a recheck of part-power trim provided final adjustment is made in the increase RPM direction".

Both Boeing and Pratt and Whitney have stated that they do not sanction adjustment of the fuel control unit outside of a part power trim run.

British Airways routinely performed trim runs when installing a replacement engine or FCU. They did them on some occasions when low ground idle, slow acceleration or throttle stager were reported by flight crews. It is known that some airlines regarded routine trim runs as unnecessary if the replacement engine or FCU had been calibrated on the test bench and would rely on the first flight to verify performance. Equally so, minor idle speed adjustments would also be carried out without a trim run. Questioned by an operator at the 1984 Hamilton-Standard Operators Conference on their opinion regarding the latter practice, Pratt and Whitney accepted that it was widely done. They added that the part-power trim procedure was largely intended to correct throttle stager snags and that, where the airline is satisfied with the initial engine output following a trim run and satisfactory experience, they could see no objection to minor adjustments being made as long as they are logged and monitored. Pratt and Whitney demonstrated, however, that their customer training courses, which were attended by a large number of British Airways technicians and engineers, emphasised the importance of correct engine trim in accordance with the manual.

1.17.2.4 Post accident regulatory action

The basic mechanism and sequence of failure of the No 9 can was appreciated at an early stage after the accident. Accordingly, the CAA, in consultation with Pratt and Whitney, the FAA, British Airways and other UK and foreign operators of the JT8D, issued an emergency Airworthiness Directive (AD) No 011-08-85 on 27 August 1985. This called for an isotope (radiographic) inspection of JT8D engines, or disassembly, to permit visual examination of the combustion section to detect and measure the extent of combustor can cracking.

The AD has undergone several subsequent revisions to both the approved inspection methods and the initial and repeat inspection intervals in response to operator feedback. A broadly similar FAA AD has also been issued along with an Alert Service Bulletin from Pratt and Whitney, No 5639.

These mandatory documents were drawn-up from a considerable mass of data and information by the Airworthiness Authorities and it is to be hoped that they will prevent a similar accident occurring to a JT8D engine. It is also understood that the CAA have re-examined similar British engine designs to see whether the same problem could arise.

1.17.3 Malfunctions during take-off

The operator's Operations Manual - Flying, in use at the time of the accident, contained the following instructions and advice on the actions to be taken in the event of a malfunction before V1.

"Reject the take-off for engine failure, fire, take-off configuration warning or if the Captain calls Stop. Upon recognition of failure or warning, either pilot may call "Stop". The handling pilot should maintain directional control and apply MAXIMUM wheel braking consistent with the airplane's position on the runway (overriding Autobrake on Series 2 Aircraft). The non-handling pilot should immediately disconnect autothrottle, select idle thrust, lift the reverse thrust levers (to activate the automatic speed brake facility) and apply GA (Go Around) reverse thrust. He should then check/select the speed brakes fully up. Whilst the handling pilot brings the airplane to a stop (taxiing clear of the runway if conditions permit), the non-handling pilot must monitor the engine instruments and observe the GA thrust limitations. If a fire exists, consideration should be given to turning the aircraft into wind before bringing it to a complete stop. Once the airplane has stopped, the first officer should carry out any emergency procedure as instructed by the Captain. (This applies regardless of who was handling the airplane prior to the "Stop" call).

If the first officer was handling the controls at the time "Stop" was called, the Captain may elect to take control once the vital actions are complete and the airplane is decelerating. In this event, the Captain should call "I have control" and the first officer should take the reverse thrust levers, monitoring/adjusting the power as required".

(This section has subsequently been amended so that the handling pilot brings the aircraft to a stop on the runway and the revised evacuation drill is commenced when the aircraft has slowed to a taxi speed in anticipation of a possible evacuation. The captain's option of taking control from the first officer after the vital actions are completed is retained.)

The Abnormal Procedures section of the Flight Crew Orders advised that:-

"When bringing the aircraft to a stop following an engine fire, consideration should be given to wind direction".

The Boeing recommended rejected take-off procedure differed from the operator's in use at the time of the accident in that it called for the pilot to stop the aircraft on the runway and evaluate the problem, before deciding whether conditions permitted taxiing clear of the runway.

1.17.4 Passenger evacuation checklists

The Passenger Evacuation (Land) checklist contained in the Operations Manual and the Quick Reference Handbook in use at the time was based on the aircraft manufacturer's suggested format with detailed differences, and was designed specifically to cover all areas of ground operation from start up and push back, as well as take-off and landing incidents. The non-memory evacuation drill consisted of 15 items, of which item 14 (item 13 on Boeing drill) was the initiation of the evacuation. The crew reported that they found such a lengthy drill inappropriate to this emergency.

As a result of this accident a simplified memory evacuation checklist has been produced and adopted.

1.17.5 Cabin crew composition, disposition, training and duties

1.17.5.1 Composition of cabin crew complement

The requirement for cabin attendants is contained in Article 17 paragraph 7 of the Air Navigation Order (ANO). Sub paragraph (a) refers. (Cabin attendants referred to in the ANO are synonymous with cabin crew.)

"When an aircraft registered in the United Kingdom carries 20 or more passengers on a flight for the purposes of public transport, the crew of the aircraft shall include cabin attendants carried for the purposes of performing in the interest of safety of passengers duties to be assigned by the operator or the person in command of the aircraft but who shall not act as members of the flight crew".

Sub paragraph (7) (c) of Article 17 relates to aircraft with a seating capacity of not more than 200 passengers and the number of cabin attendants required.

"In the case of an aircraft with a total seating capacity of not more than 200, the number of cabin attendants carried on such a flight as is mentioned in sub-paragraph (a) of this Article, shall be not less than 1 cabin attendant for every 50, or fraction of 50, passengers carried".

1.17.5.2 Disposition of cabin crew

The Boeing 737 Air Cabin Crew Safety Equipment and Procedure Manual recovered from the aircraft contained a diagram which illustrated the cabin crew seating positions. The Senior Cabin Crew Member (SCCM) occupies the forward inboard, No 1, crew seat. The forward outboard seat is designated No 4, and the rear inboard and outboard seats Nos 2 and 3 respectively. (Appendix 3 Fig a) The cabin crew are often referred to using the number of the station they were allocated for the flight. The next most senior or experienced member of the cabin crew was usually given the choice of which crew station they would like to occupy. For a variety of reasons, the number 4 position in the forward cabin appears to have been a popular choice. All cabin crew are trained in emergency procedures to the approved standard for each cabin crew station. Other operators have indicated that the SCCM, and the next most senior or experienced crew member would be positioned at either end of the cabin for take-off and landing.

The door opening responsibilities assumed that the minimum complement of two cabin crew would be carried, and they were responsible for opening the left main doors initially. When four cabin crew were carried, it involved the individuals crossing over to get to their individual doors.

An amendment issued in December 1985 resolved the anomaly, and Nos 1 and 2 open the right main doors, and Nos 3 and 4 the left main doors.

1.17.5.3 Cabin crew training

The issue of an Air Operators Certificate by the CAA to an operator engaged in public transport activities requires that the operator arranges a suitable course of training for newly employed cabin crew. A very large proportion of such a course will consist mainly of Safety Equipment and Procedures (SEP). The individual is then required to undergo a refresher check at suitable intervals, normally once a year.

The cabin crew on G-BGJL had all undergone a course of lectures and practical demonstrations upon their initial entry to the company. The certificates of competency for the purser and the No 4 stewardess, who were occupying the forward end of the aircraft, were renewed by undergoing a 2 day refresher course and both certificates were valid for Boeing 737 and Tristar aircraft. The certificates of competency raised for the Nos 2 and 3 stewardesses, who were occupying the rear cabin, were issued after they had both completed the same initial entry course on 1 March 1985. These were also valid for Boeing 737 and Tristar aircraft. The Nos 2 and 3 stewardesses underwent assessment flights under the supervision of a purser on 21 August, and 8 July 1985 respectively. The assessments in both cases were "above-standard to excellent", the SEP knowledge being graded as "above-standard".

The smoke hoods contained in the cabin were originally envisaged as being for use in dealing with cabin fires; three were positioned in the racks above row 18, and two stowed in the forward vestibule. Cabin crew were trained in their use, but not in removal from their container. During tests carried out after the accident, the fastest removal and donning of a smoke hood was 40 seconds by a steward, and 1 minute 40 seconds by a stewardess.

1.17.5.4 Safety Equipment Manual - Cabin Crew Procedures:-

The British Airways Air Cabin Crew Manual 'Safety Equipment and Procedures' for the Boeing 737 included direction in numerous areas associated with the initiation and control of an emergency evacuation.

Part 1 of this SEP Manual, under 'Aircraft Hazards', stated:-

"Cabin crew should always bear in mind that an aircraft emergency can occur without the flight crew being immediately aware of the situation, eg auxiliary power unit fire, refuelling truck fire, cabin fire, engine fire, smoke in the cabin, noise and vibration. In any emergency situation, cabin crew should start an emergency procedure only after an order from the captain. However, in cases which are clearly catastrophic, individual crew members should be prepared to act immediately on their own initiative.

Any cabin crew receiving an emergency instruction from the flight deck shall repeat back the instruction".

In Part 3, the Manual further stated:-

"The captain or, in his absence, the next most senior crew member, will order an evacuation indicating, if conditions so require, the exits that should be used. Only in cases which are clearly catastrophic should individual crew members be prepared to act immediately on their own initiative".

On page 6 of part 7 under 'Emergency Opening of Doors' the manual stated:-

"In the event of an emergency evacuation the doors are operated in the following manner:

- 1 Check girt-bar engaged (not ditching).
- 2 Check for outside hazards.
- 3 Operate door handle in normal manner.
- 4 Push door outwards to eject slide which will inflate automatically.

To deploy escape slide the door must be opened in one continuous movement without hesitation, to its fullest extent. A greater force is required to open the doors in these circumstances - so swing out and push hard. Automatic deployment of the slide occurs during door opening.

- 5 If a slide fails to inflate pull the manual inflation handle completely clear of the slide pack.

When the slide is ejected from its container the manual inflation handle marked 'Pull' will become visible".

Part 10 dealt with 'Cabin Smoke/Fire'. This section described the cabin crew procedures relating to fire within the cabin, toilets or galleys. It included the instruction:-

"Smokehood - if dense smoke is being generated, fit a smokehood before entering the fire area. Portable oxygen bottles must not be used as breathing apparatus when fire fighting."

This manual did not include any instruction to cabin crew concerning the use of their smokehoods in a ground fire evacuation.

1.17.6 Minimum exits

The aircraft was equipped with exits in accordance with FAR Part 25 which, in section 25.807 'Passenger Emergency Exits' specified, for a passenger seating capacity of 130, that the aircraft should have two 'Type I' and one 'Type III' emergency exits on each side of the fuselage.

A 'Type I' exit is defined as having "a rectangular opening of not less than 24 inches wide x 48 inches high, with corner radii not greater than one-third the width of the exit. Type I exits must be floor level exits."

A 'Type III' exit "must have a rectangular opening of not less than 20 inches wide x 36 inches high, with corner radii not greater than one-third the width of the exit, located over the wing, with a step-up inside the airplane of not more than 20 inches and a step-down outside the airplane of not more than 27 inches".

Section 25.809 (c) states "the means of opening emergency exits must be simple and obvious and may not require exceptional effort".

FAR Part 25 does not specify any minimum access widths to overwing exits. British Civil Airworthiness Requirements, Chapter D 4-3 'Compartment Design and Safety Provisions' states in paragraph 4.2.5 'Access', "Easy means of access to the exits shall be provided to facilitate use at all times, including darkness; exceptional agility shall not be required of persons using the exits. To this end the following shall be complied with:-

(a) Passage ways between individual compartments of the passenger area and passage ways leading from each aisle to each Type I and Type II emergency exit shall be provided and shall be unobstructed and not less than 20 inches (508 mm) wide.

(b) The main passenger aisle at any point between the seats will not be less than, for aeroplanes having a maximum seating capacity of more than 19 persons, 15 inches (381 mm) wide up to a height above the floor of 25 inches (635 mm) and 20 inches (508 mm) wide above that height".

There is no specified minimum access width to Type III overwing exits, which are covered by the following:-

(d) Access shall be provided from the main aisle to all Type III and Type IV exits and such exits shall not be obstructed by seats, berths or other protrusions to an extent which would reduce the effectiveness of the exit, and

(i) For aeroplanes that have a passenger seating of 20 or more the projected opening of the exit provided shall not be obstructed by seats, berths or other protrusions (including seat backs in any position) for a distance from the exit not less than the width of the narrowest passenger seat installed in the aeroplane".

1.17.7 Appraisal of other survivable aircraft fire accidents

An assessment of previous, fire-related, major aircraft accidents was carried out in order to compare findings with this accident and also to examine associated evidence from in-flight cabin-fire situations.

1.17.7.1 Respiratory effects on passengers

a) AN FAA report¹² refers to the effects of smoke on the evacuation of the United Airlines DC-8 at Stapleton Field, Denver on the 11 July 1961 stating the following:-

"During evacuation, the principal environmental hazard was smoke. When the aft galley door (ie aft/right) was opened, a 'chimney-effect' developed, drawing outside 'kerosene' smoke into the right window (ie overwing) exits, down through the aft section of the cabin and out of the open door. For this reason, the concentration of smoke was heaviest in the aft cabin.

Although occasional tongues of flame were blown in through the right window exits, destructive invasion of the cabin by fire occurred only after 98 passengers had escaped and 16 others had been incapacitated by smoke.

Just prior to opening of the galley door, the passengers had promptly left their seats and began to queue-up in the aisle. From all accounts, this was done in an orderly and relatively calm manner; little shoving or shouting occurred and many persons took time to collect their personal belongings. As this line was forming, dense black smoke began filtering into the cabin, making breathing difficult and obscuring vision. Judging from their statements, many passengers - who up to then had reacted calmly - became frightened for the first time."

"Most witnesses estimated that the evacuation was completed within 3-5 minutes after the aircraft came to a halt".

b) The same report refers to the accident to the United Airlines Boeing 727 which landed short of runway 34L at Salt Lake City Airport on 11 November 1965, initiating a localised fuel-fed fire within the aft/underside of the fuselage as the aircraft slid down the runway after both main undercarriage legs had sheared:-

"Apparently, one of the early effects of the dense, acrid smoke that rapidly filled the cabin was to cut short any attempt to vocalise and many passengers stated that after a breath or two they could no longer breathe or utter any sound. One man, a registered pharmacist and the only survivor reporting with any medical knowledge, described the sudden effect of smoke upon himself as causing a "massive bronchospasm".

Other passengers recalled that after a few initial shouts and cries the cabin suddenly became quiet with the only sounds coming from the flames and the muffled efforts of passengers struggling towards the exits. This silence seemed especially eerie, some recalled, because they had always previously imagined such scenes of human panic to be accompanied by screaming".

c) On the 11 July 1973, a Varig Boeing 707 Registration PP-VJZ was at FL 80 some 22 nm from Orly Airport, Paris after a flight from Rio De Janeiro with some 17 crew and 117 passengers, when the cabin crew reported smoke issuing from the area of the aft left toilet. After alerting ATC the pilot reported, whilst still some 10 nm from Orly, that the passengers were being asphyxiated by thick smoke in the cabin and that smoke could be smelt on the flight-deck. By the time the aircraft had descended to 2,000 ft on approach, the flight-deck crew had donned their oxygen masks, but the visibility was so reduced by the smoke density on the flight-deck that they could not see their instruments. A forced-landing was carried out 5 kilometers short of the runway. No significant fuselage damage was sustained and there was no evidence of external fire.

Only ten escaped, all crew members. No external fire was evident at this time other than smoke issuing from the right side of the fin root.

By the time the fire crew arrived, 6 minutes after the forced-landing, the fire had burnt through the aft upper fuselage. Four unconscious passengers were removed by the firemen, but only one survived. Subsequent pathological examination found that all passengers had died due to asphyxiation. The flight engineer died due to impact injuries. Seventy-eight per cent of the 122 fatalities had levels in excess of 66% carboxyhaemoglobin, 9% had 50-60% and some 13% had less than 5%.

d) On the 19 August 1980 a Saudi Arabian Airlines Lockheed L1011 aircraft, registration HZ-AHK, had departed Riyadh Airport for a continuation flight to Jeddah with 14 crew and 287 passengers. Seven minutes after take-off the crew were alerted, by an audio warning and visually by smoke entering the aft cabin, that they had a fire in the aft cargo compartment.

Seven minutes later, the flight engineer informed the commander that the passengers were in a state of panic at the rear of the cabin. Some 4 minutes later the flight engineer reported to the commander that fire was penetrating the cabin and a cabin crew member reported "that passengers were fighting in the aisles", indicative of the extreme effects of such atmospheres.

e) The NTSB produced a report¹³ on the accident which occurred to an Air Canada DC-9-32, registration C-FTLU, on 2 June 1983 which suffered a fire behind an aft toilet partition whilst en-route from Dallas to Montreal. The aircraft was diverted into Greater Cincinnati International Airport. The aircraft landed 17 minutes after the smoke was first noticed issuing from the toilet. Of the 5 crew and 41 passengers, 23 failed to evacuate. This report stated:-

"During descent, the cabin filled with black, acrid smoke from the ceiling down to about knee level. Passenger and flight attendant testimony and statements indicated that all of the surviving passengers had covered their faces with either wet towels distributed by the flight attendants or articles of clothing. They all attempted to breathe as shallowly as possible, and all reported that the smoke hurt their noses, throats, and chests and caused their "eyes to water". By the time the airplane landed,

they could not see their hands in front of their faces whilst seated or standing. One passenger was experiencing severe distress trying to breathe. He was brought forward and seated on the forward flight attendant's 'jump-seat', and the flight attendant in charge administered oxygen to him from the portable bottle."

"The smoke in the cabin was reportedly so thick that most of the passengers had to get to the exits by using the seat back to feel their way along the aisle. None of the passengers noticed if the emergency lights were illuminated. Several passengers said that when they either bent forward or got on their hands and knees, they were able to breathe and see a little better, but it was not much of an improvement. One of the passengers who used an overwing emergency window exit said that she was able to locate it when she saw a very dim glow of light coming through the aperture. Another stated that she was able to locate the overwing emergency exit window when she felt a slight draught on the back of her knees".

Of the 23 passengers who failed to evacuate it was reported that 10 were found still in their seats. Toxicological examination found levels of 20-63% carboxyhaemoglobin and 80 - 512 micrograms/100ml of cyanide in the victims.

1.17.7.2 Hair-ignition

The aft stewardess on the aircraft in the Salt Lake City accident had been seated at her station in the aft 'jump-seat', 3 seat-rows aft of the area where the fire suddenly penetrated the cabin - ie under seat 18E, as the aircraft slid down the runway. She stated:-

"When the plane came to a stop all lights went out. The back of the plane was filled with smoke and fire. I got out of my seat. It took a few extra seconds to get my shoulder straps off. I opened the aft pressure door. Immediately two men ran through the door onto the stairs. At this time my hair caught fire. I put it out with my hand and my hat fell off."

This stewardess and the two men sheltered in the ventral area of the tail section until rescued 25 minutes later by firemen. During this time the stewardess breathed through her jacket. They were assisted by some air entering the partially open stairwell external door.

This evidence on hair-ignition appears similar to observations from the male survivor from seat 8D at Manchester who has referred to a lady passenger in the aisle whose hair suddenly ignited.

1.17.7.3 Effects of reducing/shutting-off air conditioning air-flow

The effect of reduced air-flow through the cabin during an in-flight emergency smoke situation are apparent from the following extract from the NTSB DC-9 Report 12:-

"Once the passengers had been repositioned (ie forward of row 13) and the cabin air vents opened and directed aft, the smoke appeared to lessen, but shortly thereafter the smoke began to increase rapidly. Several passengers stated that the cessation of air-flow from the vents coincided with the increase in the smoke. Other passengers stated that it occurred at the beginning of the descent or sometime shortly after the airplane began descending".

The evidence relating to the events following the landing of the Lockheed L1011 at Riyadh are also of interest in this context.

The aircraft landed on runway 01 at 1836.24 hrs - ie 21 minutes after the first indication of a fire/smoke problem associated with the 'C3' aft cargo compartment. It was turned off the runway and

eventually stopped at 1839.03 hrs. No external evidence of fire was seen by the following fire vehicles at this time.

At 1839.06 hrs, SV163 informed ATC that they were going to shut the engines down and evacuate. At 1840.33 hrs, after SV163 was told that their "tail was on fire", they replied "affirmative, we are trying to evacuate now". This was the last RT transmission from the crew.

The engines shut down at 1842.18 hrs - ie some 3 minutes 15 seconds after the aircraft had stopped (5 minutes 54 seconds after touchdown or approximately 27 minutes after the fire was detected).

External witnesses stated that just after the engines shut down, a large puff of white and black smoke was discharged from the underside of the aircraft, just forward of the wings. Also within 1 minute, smoke issued from the top of the fuselage just forward of the number 2 (centre) engine followed by flames. The report concluded that a flash-fire had occurred in the cabin shortly after the engines had been shut down and the associated air conditioning air-flow ceased. All 301 occupants perished due to fire and smoke inhalation effects but there is insufficient pathological data to identify the exact cause of death.

1.17.8 Aerosol cans

In recent years the aerosol industry has moved away from the use of the non-flammable gas Freon as a propellant in aerosol cans, and has adopted hydrocarbons instead, notably butane, which is widely used as a fuel for camping gas stoves and lamps. Certain products, such as 'dry air fresheners', contain almost pure butane with only a very small amount of an aromatic agent. Many other products such as hair sprays, which are perhaps the most likely to be carried in hand baggage, use butane as the propellant.

Research into the hazards posed by aerosols has shown that such cans invariably rupture (as a result of gas overpressure) if the temperature of the can and its contents exceeds approximately 70°C, releasing the gas in a minor explosion. The extreme turbulence associated with this explosive release of the butane propellant promotes very efficient mixing of the gas with the air. If this turbulent, rapidly expanding gas mixture ignites, which would inevitably occur in a cabin fire environment, the flame front will propagate extremely rapidly, producing a very sharp fronted, but relatively sustained pressure rise. (During a test detonation of an aerosol can located in an aircraft forward toilet, the overpressure was sufficient to blow out the toilet door, allowing the compartment pressure to vent into the cabin. Despite the cabin itself being vented by open rear doors and overwing exits, the resulting overpressure in the main cabin blew the flight deck door out of its aperture and forward several feet into the flight deck, where it jammed between floor and ceiling.)

A total of 27 aerosol cans were recovered from the cabin debris. Fifteen of these had ruptured as a result of temperature overpressure, and of these 3 showed signs of having been propelled at high speed into the aircraft structure or furnishings.

2. ANALYSIS

2.1 Introduction

Many of the factors which affected this accident should have biased events towards a favourable outcome. The cabin was initially intact, the aircraft remained mobile and controllable and no one had been injured during the abandoned take-off. The volume of fuel involved, although capable of producing an extremely serious fire, was relatively small compared with the volume typically carried at take-off, the accident occurred on a well equipped major airport with fire cover

considerably in excess of that required for the size of aircraft and the fire service was in attendance within 30 seconds of the aircraft stopping. However, 55 lives were lost.

The investigation has identified the cause of the engine failure. The sequence of events which followed, relating to the development of the fire and the evacuation, were extremely complex, involving numerous interlocking factors, many of which critically affected survival.

Although much evidence was destroyed in the fire and other evidence, especially that from survivors and rescue personnel required careful interpretation, particularly concerning their assessment of timescale, it has been possible to construct a reasonably consistent picture of the fire in all its aspects. Statements from the survivors were highly descriptive and provided a rare insight into the evacuation problems encountered. For the most part, conclusions derived from an analysis of the wreckage accorded well with those arrived at via witness testimony and from other sources.

2.2 General circumstances

The explosive failure of the CCOC and the damage to the adjoining tank access panel were clearly related events. Witness marks on the access panel fragments exactly matched the shape of the domed head of the separated No 9 combustor can and the fan case fragment, and a smear of panel material was identified on the dome indicating beyond all doubt that it was this which struck and shattered the panel. It is clearly evident that the dome was ejected through the disrupted engine casing as a result of the extremely rapid escape of high pressure combustion air through the ruptured CCOC. The release of fuel from the damaged wing tank directly into combustion gases from the ruptured combustion chamber, and its inevitable ignition, changed the nature of the event from a purely engine related incident into a catastrophic accident.

2.3 Crew performance

2.3.1 Flight deck crew.

The flight deck crew were properly licenced, trained, experienced and rested to undertake the flight. They were aware of the technical log entries for the left engine and had monitored its performance during start-up, taxi, and the initial part of the take-off run. Throughout this period the engine appeared normal and, by the time the event occurred, it had been dismissed from their minds. The commander's assessment of the 'thud' as a tyre burst or fuselage bird strike was therefore quite reasonable; he responded to the cues which were available to him, which at that time consisted solely of the noise, a 'thud'. His response was rapid and decisive ordering "stop" in less than 1 second and he and the co-pilot speedily implemented the abandoned take-off drill. Although it might be argued that the falling left engine parameters should have provided additional cues which might have altered their perception of the event, any such indications would have been masked by the falling parameters on both engines accompanying the abandoned take-off. During reverse thrust application, there would have been some indications of thrust imbalance, but the level of reverse thrust used was minimal and applied for a very short time, during which neither crew member would have had cause to monitor the instruments closely.

In the light of his assessment that the problem might have been a tyre burst, and the fact that a timely initiation of the abandoned take-off had left plenty of runway available, the commander directed the co-pilot not to employ unnecessarily harsh braking, so as to avoid possible wheel damage. The co-pilot responded by modulating the braking effort.

For the first 9 seconds after the 'thud', events proceeded as expected, reinforcing in the commander's mind his assessment of the problem, and he had every expectation that they would be able to

complete the abandoned take-off and turn off without difficulty. When he had satisfied himself that the immediate problems associated with the abandoned take-off were contained, with the aircraft decelerating through 85 kt ground speed, he transmitted his abandon call to ATC. As he began this transmission the number 1 engine fire warning occurred and he modified his call adding, "it looks as though we've got a fire on number 1." This fire warning was somewhat fortuitous, the system having been designed to respond to fires contained within, not external to, the engine cowlings, large pieces of which separated as the engine failure occurred.

This was the first indication to the flight deck crew that the problem could be other than a tyre burst or bird strike. It is evident that this new and conflicting information could not easily have been reconciled with either, except perhaps as a result of secondary damage, and the crew's ability to analyse its impact was clearly limited by their already high workload. As a result, they proceeded with the existing abandoned take-off plan whilst they considered how to deal with the new information. While the fire bell was still ringing on the flight deck, as the aircraft decelerated through 50 kt ground speed ATC transmitted, "right there's a lot of fire, they're on their way now." The commander responded quickly seeking guidance from the tower controller on the need for passenger evacuation.

During this period, the actual handling of the aircraft was being carried out by the co-pilot following the original abandoned take-off plan, whilst the commander was dealing with the significant management task. However, with a nose wheel steering tiller on the commander's side only, it was necessary for him to take control of the aircraft at some stage if he intended to turn off. It is quite apparent that by the time the briefing and other tasks were completed and he was in a position to re-assess the actual abandon take-off process, the commander was already committed to turning off.

All these events took place rapidly; the replay of the CVR provided a striking indication of the commander's workload during that period of almost continuous communication, not only with the tower but with briefing the cabin crew and responding to their confirmation request. (Appendix 1)

The key element in understanding why the crew did not continue a maximum braked abandon take-off, which would have resulted in an earlier stop, was the lack of any flight deck indication when the engine failed that an aircraft or engine malfunction had occurred, in particular the absence of a fire warning. Thus the decision to abandon the take-off and the subsequent chain of actions was largely determined by the initiating event; the apparent tyre burst or bird strike.

Had maximum braking been applied after recognition of the fire warning, or at least after the ATC transmission about "a lot of fire", a number of seconds might have been saved. However, any change in the outcome due to this alone remains entirely speculative. Nevertheless, it is clear, that as the aircraft was turning, the need to stop at the earliest opportunity introduced by the fire was recognised, because the aircraft was brought to a halt still partially on the runway.

With the benefit of hindsight, the decision to turn to the right off the runway can be seen to have had a severely adverse effect on the fire. The operator's Operations Manual-Flying, referring to engine malfunctions during take-off, advised taxiing clear of the runway if conditions permitted and added that, if a fire existed, consideration should be given to turning into wind before stopping. However, as already explained, the way that the limited information became available to the crew, who were already engaged in a high speed abandoned take-off with concomitant very high workload, left no capacity for analysing the true nature of the emergency. Furthermore the wind, which earlier had been variable in direction and on take off was quoted as 250°/7 kt, would have been of little, if any, operational significance as far as aircraft handling was concerned. There is no doubt that this crew, and indeed the aviation community at large, were quite unaware of the critical influence of light winds on a fire, and they did as most other crews would have done faced with a similar

predicament. The crew would have been conditioned to clear the single runway to the right at the usual turn off at Manchester, where only light aircraft were permitted to use the area to their left.

The commander wanted to alert the cabin crew to the need for a passenger evacuation as soon as the aircraft had stopped, so he broadcast over the PA "Evacuate on the starboard side please", 14 seconds before, and in anticipation of, the aircraft stopping. This call was acted upon by the purser, who obtained confirmation from the commander 8 seconds before the aircraft stopped and then made a number of evacuation calls himself over the PA.

It should be noted that if an evacuation instruction is made before the aircraft stops it could precipitate an evacuation, with cabin doors being opened, before the aircraft comes to a halt. At speed this could result in slides being damaged and, in any event could lead to inappropriate doors being opened. Unless there are overriding reasons to the contrary doors should not be opened until the aircraft has stopped.

The fire drill was carried out for the left engine immediately the aircraft stopped and the right engine shut down, because evacuation was to take place on that side. The crew then started on the non-memory 'Passenger Evacuation (Land) Drill' which proved unrealistically long for such an emergency, calling for 'passenger evacuation' as item fourteen.

The drill carried an introductory note which read:-

"Shutdown engines as soon as possible to reduce possibility of slide damage or personnel injury. Do not delay evacuation if any possibility of smoke or fire exists".

Clearly in this case it was necessary to shutdown the remaining engine and smoke/fire did exist, leaving the crew without an appropriate effective drill. Some items were actioned but the crew decided to evacuate via the right side sliding window as burning fuel flowed forward on the left of the aircraft. The operator's procedure required the flight deck crew to leave the aircraft promptly and supervise the evacuation from outside. The operator considered it undesirable to use the flight deck crew as integral members of the internal passenger evacuation team, as on some occasions they may be unavailable, having been incapacitated. However, the aircraft manufacturer's recommended procedure is for the flight deck crew to enter the passenger cabin after completing the cockpit drills and render all possible assistance to the evacuation from inside. Indeed this is the practice adopted, apparently successfully, during the evacuation certification tests.

The flight deck crew responded to the 'thud' in a prompt manner in accordance with their experience and training. Their initial assessment of the problem and their subsequent actions were entirely reasonable based on the cues available to them. The decision to turn off was a critical factor in the destructive power of the fire. However, in the context of the knowledge, training and operating practices current at the time of the accident, it is considered that this decision should not be criticised.

It is vital that in future operators and ATC services recognise that all abandoned take-offs and emergency landings should end with a full stop on the runway. Only then can a full evaluation of the situation be undertaken by the crew with the assistance of ATC and the airfield fire service as necessary. ATC will have to be prepared to accept any resulting disturbance to aircraft movements, particularly at single runway airfields. Similarly all operators must recognise the potential of even light winds to enhance the destructive power of a fire, and modify their procedures and training to ensure that aircraft are not stopped with a fire upwind of the fuselage, if at all practicable.

2.3.2 Cabin crew

Those areas of the cabin interior which had escaped direct damage by the fire were covered with a thick coating of viscous soot. (Appendix 3 photos e-f)

1.4 Other damage

There was some fire damage and fuel spillage on the runway and taxiway link Delta.

1.5 Personnel information

1.5.1

Commander	Male aged 39 years
Licence:	Airline Transport Pilot's Licence valid until 9 March 1986
Last medical examination:	Class 1 Medical Certificate valid until 30 September 1985 with no limitations
Part 1 Pilot-in command ratings:	PA 23, 30 and 39 Trident HS121, HS 748 Boeing 737 Series Certificate of Test: valid until 16 December 1985
Instrument rating:	Valid until 7 December 1985
Route check:	Valid until 29 November 1985
Emergency equipment and procedures check:	Valid until 18 January 1986
Flying experience:	Total all types: 8,441 hours Total Boeing 737: 1,276 hours Total last 28 days: 54 hours 25 minutes
Other ratings and approval:	Authorised by the Civil Aviation Authority (CAA) as a Type Rating Examiner, in respect of Boeing 737 aircraft. Also CAA approved as an Instrument Rating Examiner.
Duty time:	On the day before the accident the commander

