

No. 11

British Overseas Airways Corporation, Boeing 707-465, G-ARWE, accident  
at Heathrow Airport, London, England, on 8 April 1968. Report  
No. EW/C/0203 dated April 1969, released by the Board  
of Trade, United Kingdom as C.A.P. 324

1.- Investigation1.1 History of the flight

The aircraft was operating Flight BA. 712 from Heathrow Airport, London to Zurich with onward routing to Sydney, Australia. In addition to the normal crew complement, a check pilot was on the aircraft for the purpose of carrying out a route check on the pilot-in-command. The aircraft became airborne from Runway 28 Left at 1527 hours GMT and 20 seconds later, just before the time for the noise abatement power reduction, the flight crew felt and heard a combined shock and bang. The thrust lever for No. 2 engine "kicked" towards the closed position and at the same time the instruments showed that the engine was running down. The pilot-in-command ordered "Engine Failure Drill" and the flight engineer began the immediate actions of that drill. Because the undercarriage was retracted, the warning horn sounded when the flight engineer fully retarded the thrust lever; the check pilot and flight engineer simultaneously went for and pulled the horn cancel switch on the pedestal whilst the co-pilot, instinctively, but in error, pressed the fire bell cancel button in front of him. The flight engineer went for the engine fire shut-off handle but he did not pull it.

The lack of a flight deck voice recorder makes it impossible to establish a second by second timing of events, but at about this time the check pilot looked out of a flight deck window on the port side and reported a serious fire in No. 2 engine, adding words to the effect that a landing should be made at the earliest possible moment.

No member of the flight crew recalls hearing the fire warning bell. Nevertheless, the fire warning light in No. 2 fire shut-off handle was seen to be on and the pilot-in-command ordered an "Engine Fire Drill". The check pilot suggested, and the co-pilot with the pilot-in-command's approval broadcast, a "Mayday" call.

Having initially started an engine failure drill, the flight engineer changed directly to the engine fire drill. According to his evidence, having completed Phase I of the engine fire drill, which is required to be done by memory, he subsequently used his own copy of the check list to complete Phase II of the drill, including the operation of the fire extinguisher transfer switch and pushing the discharge button for the second shot thirty seconds after the first. When the co-pilot started to read the check list the flight engineer told him the check was already completed. During this period and subsequently, according to his evidence, the check pilot directed his attention to monitoring the state of the fire on the wing and to providing the pilot-in-command with comments intended to help him position the aircraft for the landing.

ATC originally offered the pilot-in-command a landing back on Runway 28L and alerted the fire services but after the "Mayday" call he was offered Runway 05 R which was

accepted as it would result in a shorter flight path. ATC ordered other landing aircraft to overshoot in order to ensure a clear approach to Runway 05 R and to clear Runway 28 R for the passage of the fire vehicles. The initial notification to the Airport Emergency Services of the expected landing on Runway 28 L was also revised.

About  $1\frac{1}{2}$  minutes after the start of the fire, No. 2 engine, together with part of its pylon, became detached and fell into a waterfilled gravel pit. This was unknown to the flight crew but because of the separation the light in the fire handle would have gone out. Nevertheless, they were aware that a serious fire continued to burn. At various places along the flight path a number of engine fragments and pieces of cowling had already fallen away, but these caused no injury to persons or damage to property.

At about the time the engine fell away the undercarriage was lowered and full flap selected. The undercarriage locked down normally but the hydraulic pressure and contents were seen to fall and the flaps stopped extending at  $47^\circ$ , that is  $3^\circ$  short of their full range.

The approach to Runway 05 R was made from a difficult position, the aircraft being close to the runway and having reached a height of about 3 000 ft and a speed of 225 kt. There is no glide slope guidance to this runway but the approach was well judged and touchdown was achieved approximately 400 yards beyond the threshold. To add to the pilot-in-command's difficulties, during the final approach the flight engineer informed him that the instruments of No. 1 engine indicated that it might fail, although it did not do so.

In order to bring the aircraft to a stop in the shortest possible distance after landing, in addition to the wheel brakes, reverse thrust from No. 1 and No. 4 engines was used down to a very low speed. The use of reverse thrust caused the flames to be deflected in towards the fuselage. The aircraft came to a stop just to the left of the runway centre line, about 1 800 yards from the threshold, on a heading of 0350M.

After the aircraft came to rest the flight engineer commenced the engine shut-down drill and closed the start levers. Almost simultaneously the pilot-in-command ordered fire drill on the remaining engines. Before this could be carried out there was an explosion from the port wing which increased the intensity of the fire and blew fragments of the wing over to the starboard side of the aircraft. The pilot-in-command then ordered immediate evacuation of the flight deck. The engine fire shut-off handles were not pulled and the fuel booster pumps and main electrical supply were not switched off. There were more explosions and fuel, which was released from the port tanks, spread underneath the aircraft and greatly enlarged the area of the fire.

The cabin crew had made preparations for an emergency landing and as the aircraft came to a stop opened the emergency exits and started rigging the escape chutes. The passengers commenced evacuation from the two starboard overwing exits and shortly afterwards, when the escape chutes had been inflated, from the rear starboard galley door and then the forward starboard galley door. However, because of the spread of the fire under the rear of the fuselage the escape chute at the rear galley door soon burst and, following the first explosion, the overwing escape route also became unusable. The great majority of the survivors left the aircraft via the forward galley door escape chute.

The co-pilot, who could not get into the galley to help with the evacuation, left the aircraft through the starboard flight deck window by use of the escape rope at that position. The Second Officer, who helped guide the passengers in the initial stages, followed, the pilot-in-command, having assisted the stewardess to inflate the port forward chute, also left by the flight deck window after seeing the evacuation was proceeding satisfactorily.

The flight engineer saw that the port forward chute had not inflated properly so he climbed down it to straighten it. However, immediately after it inflated it became unusable from heat and burst.

The evacuation of passengers had been largely completed by the time the airport fire and rescue services began to provide assistance. The fire services prevented the fuel in the starboard tanks from catching fire but the rear fuselage and port wing were burned out.

Four of the passengers and one stewardess were overcome by heat and smoke at the rear of the aircraft and did not escape, whilst thirty-eight passengers sustained injuries during the evacuation. Some hours after the accident it was not known how many had escaped alive or had been injured because some survivors were quickly removed to various treatment and rest centres whilst others left the vicinity of the airport without leaving their names.

#### 1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	1	4	
Non-fatal		38	
None	10	74	

#### 1.3 Damage to aircraft

The aircraft was destroyed.

#### 1.4 Other damage

None.

#### 1.5 Crew information

The pilot-in-command, aged 47, held an airline transport pilot's licence, endorsed for command of Boeing 707 aircraft. His last competency check was on 6 September 1967 and his last medical examination was on 20 October 1967. At the time of the accident his total flying experience was 14 878 hours, of which 1 555 were on Boeing 707 aircraft. He had flown 50 hours during the 30 days preceding the accident and had been free of duty for 18 days prior to the commencement of this flight.

The co-pilot, aged 32, held an airline transport pilot's licence, endorsed for command of Boeing 707 aircraft. His last competency check was on 4 August 1967 and his last medical examination was on 18 January 1968. At the time of the accident his total flying experience was 5 496 hours of which 2 829 were on Boeing 707 aircraft. He had flown 11 hours in 30 days preceding the accident and had been free of duty for 9 days prior to the commencement of this flight.

The second officer, aged 30, held an airline transport pilot's licence, endorsed for command of Boeing 707 aircraft. His last competency check was on 6 March 1968 and his last medical examination was on 4 December 1967. At the time of the accident his total flying experience was 4 120 hours of which 680 were on Boeing 707 aircraft. He had flown 5 hours during the 30 days preceding the accident and had been free of duty for 13 days prior to the commencement of this flight.

The flight engineer, aged 35, held a flight engineer's licence, endorsed for Boeing 707 aircraft. His last competency check was on 27 December 1967 and his last medical examination was on 4 December 1967. At the time of the accident his total flying experience was 6 436 hours of which 191 were on Boeing 707 aircraft. He had flown 52 hours during the 30 days preceding the accident and had been free of duty for 22 days prior to the commencement of this flight.

The check pilot, aged 50, held an airline transport pilot's licence, endorsed for command of Boeing 707 aircraft. His last competency check was on 6 November 1967 and his last medical examination was on 6 December 1967. At the time of the accident his total flying experience was 12 957 hours of which 3 185 were on Boeing 707 aircraft. He had flown 56 hours during the 30 days preceding the accident and had been free of duty for 9 days prior to the commencement of this flight. He had been a check pilot on 707 aircraft since 1963.

All members of the flight crew and the cabin crew had received emergency procedure training within the prescribed period.

#### 1.6 Aircraft information

##### (a) General

G-ARWE was built in 1962 and went into service with BOAC the same year. It had been regularly serviced in accordance with an approved maintenance schedule. At the time of the accident it had flown a total of 20 870 hours.

On 21 November 1967 it was involved in an accident at Honolulu, when a turbine in No. 4 engine failed during the take-off run: flying debris punctured a fuel tank and released fuel which ignited and the take-off was abandoned. The fire was subsequently extinguished by the airport fire services. The aircraft was repaired and all the engines were changed.

##### (b) No. 2 engine

This engine was constructed in 1961 and the records show that it was completely overhauled in March 1965. In May 1965 it was removed from service because of reported vibration. Investigation revealed a Stage 8 high pressure (HP) compressor blade failure due to fatigue. The engine was repaired and returned to service. In October 1967 the engine was removed because of flame tube deterioration and forwarded to the BOAC engine overhaul base for repair. During this repair, in which the engine was only partially stripped, the (HP) compressor was not disturbed but the low pressure (LP) compressor, of which the No. 5 wheel was an original component, was completely stripped and overhauled. No crack detection procedure was required or carried out during this repair. After the repair the engine was bench tested on 22 November 1967. During this test, after several runs and vibration surveys, the engine was rejected for excessive vibration at the No. 3 pick-up close to the HP compressor. The location of this pick-up position and these



particular vibration limits were instituted by BOAC as aids to maintenance and were additional to those laid down in the overhaul schedule by the engine manufacturer. The manufacturer's limits were not exceeded at any time. After considering the record of the tests a company concession was issued and the engine accepted. It was installed in another Boeing 707 and after running 1 415 hours it was removed for a modification concerning the turbine seals. On 5 April 1968 it was installed in the No. 2 position in G-ARWE.

At the time of the accident this engine had run a total of 14 917 hours since new including 4 346 hours since its last complete overhaul, and 1 416 hours since its last repair in 1967. The Conway series 508 normally has a period of 5 500 hours running time between complete overhauls.

(c) Aircraft fuel system

The aircraft fuel tanks are an integral part of the wing structure with the front wing spar forming the forward face of each fuel tank. Just behind the front spar and just inboard of the centreline of each engine pylon, is a fuel-free area known as the dry bay, housing the electrically operated fuel shut-off valve. The shut-off valve can be operated either by an individual gated switch on the flight engineer's fuel panel on the flight deck or by the appropriate engine fire shut-off handle on the glare shield between the two pilots. All fuel to an engine must pass through the shut-off valve in the dry bay and thence through the front spar and down the centreline of the pylon. The fuel is fed down through a 1½ inch steel pipeline inside the pylon fairing to a high pressure backing pump and to a high pressure fuel valve on the engine; this high pressure valve is operated mechanically by the engine start lever on the flight deck pedestal.

When the fuel shut-off valve in a dry bay is closed, there can be no fuel supply to the appropriate engine regardless of the settings of any other switch or fuel valve, except for such fuel already contained in the length of the 1½ inch pipe from the shut-off valve down to the engine itself. It is estimated that this would not be sufficient to sustain an in-flight fire for more than a few seconds after closure of the shut-off valve.

(d) Engine fire extinguisher system

In this aircraft, means are provided for smothering an engine fire by flooding the engine cowling space with an inert gas. The system for each engine is controlled through its fire shut-off handle and appropriate switches, located on the pilot's glare shield.

In the event of an engine fire a red warning light will illuminate in the appropriate fire shut-off handle and the fire warning bell will ring. Pulling the fire shut-off handle will cause a number of vital actions to take place including the following:

- (i) To arm electrically the fire extinguisher discharge switch.
- (ii) To cause the fuel shut-off valve in the dry bay to close electrically within one second and, at the same time (in the case of engines Nos. 2 and 3) shut-off the supply of hydraulic oil to the engine driven hydraulic pumps.
- (iii) To trip the generator control relay after 5-10 seconds.

The fire shut-off handle has a positive pull out: stay out action requiring a force of approximately 12 lb to operate or re-set. When pulled it protrudes about  $\frac{1}{2}$  inch from the adjacent handles. Only after the fire shut-off handle has been pulled can fire extinguisher bottles be discharged. If the fire continues to burn despite the first discharge, the appropriate transfer switch should be moved to "transfer" when, by pressing the same fire extinguisher button again, the extinguishant from the bottles for the adjacent engine can be used.

#### 1.7 Meteorological information

The only relevant weather information is that for the immediate area of Heathrow Airport, London. At the time of the accident it was a clear, sunny afternoon. The 1515 hrs observation was as follows:

Surface wind 210°/1 kt; visibility 12 km; Cloud 1/8 cumulus  
at 4 000 ft; QNH 1030.7 mb; Temperature 10°C; Dew point -3°C

A special report made at 1531 hours following the accident, gave the surface wind as 160°/3 kt; there was no other significant change from the 1515 hours report. The stable weather conditions, particularly the good visibility and the light surface wind, permitted the return approach and landing to be made without the complications of tail or crosswind or other weather factors.

#### 1.8 Aids to navigation

The aircraft remained in visual contact in the immediate vicinity of the airport in good visibility.

#### 1.9 Communications

After using various ground control frequencies for start-up and taxiing, the aircraft changed to VHF frequency 118.2 Mc/s before commencing the take-off and remained in good contact with the tower throughout the remainder of the accident flight. This frequency was in use for all landing and departing traffic at the time of the accident, but in view of the urgency of the situation and the limited time available the tower controller decided that it would be inadvisable to transfer either G-ARWE or the other aircraft to an alternative frequency. Good R/T discipline was maintained throughout by all concerned and it is not considered that the other R/T traffic on this frequency in any way handicapped communication between G-ARWE and the tower.

#### 1.10 Aerodrome and ground facilities

The airport fire fighting and rescue services, assisted by the London Fire Brigade, were heavily engaged in this accident and their participation has been examined in detail by a special group, whose report is attached at Annex 1.\*

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#### \* Note from the Secretariat:

Reports of working groups are not normally reproduced in the Aircraft Accident Digest. However, in the present case it is reproduced as an example of the benefits which can be gained by pursuing the investigation beyond pure causal factors of the accident.

The salient points brought to light by this investigation are:

- (1) That the number of appliances, the amount of fire extinguishing media and the staff available to the airport fire service were in excess of those required by the terms of the aerodrome licence.
- (2) That appliances converged upon the crash scene from the two fire stations.

The first unit, from the central area sub-station, arrived at the aircraft within 30 seconds of its coming to rest; the remainder from the main station on the north side of Runway 28 R arriving two minutes later, having been held up for about three-quarters of a minute before being able to cross the runway. The runway was in use for landing at the time and ATC had to divert aircraft already on the approach. The hose-laying vehicle, which was on an airport familiarization exercise in the central area arrived possibly as much as a minute later than it would have done had it been at the station.

- (3) That the London Fire Brigade were not alerted until four minutes after a warning of an impending accident had been given to the British Airports Authority fire service. Some twenty-two appliances arrived, the first about five minutes after the BAA main contingent.
- (4) That the two foam appliances used in the initial attack were drawn up beyond the range of their cab-mounted monitor foam jets. Fire fighting therefore had to continue with hand lines only. Two hoses burst during the course of the operation, one three-quarters of a minute and another three-and-a-half minutes after the first appliance started to make foam.
- (5) That there was some delay in getting the hydrant system connected to the two fire-fighting appliances, so that after four and eight minutes respectively having used up their mobile supplies, they ran out of water. At no time during the operation was more than a third of the total foam potential available at the scene in use and after three-quarters of a minute the foam being applied was down to one-quarter of that available from the first appliance, or one thousand gallons per minute. The Cardox CO<sub>2</sub> drenching equipment created a good knockdown, but the gains were not consolidated with foam.
- (6) That the third foam tender, whose crew had initially been designated for rescue purposes, was brought into action later and prevented the three thousand gallons of fuel in the starboard tanks from catching fire.
- (7) That during the operation several attempts were made to enter the aircraft by firemen wearing breathing apparatus. These were frustrated by heat and, in one case, by lack of water for the necessary protective spray.

#### 1.11 Flight recorder

The aircraft was fitted with an Epsilon Flight Data Acquisition system, which recorded, on a common time base, the following parameters: indicated airspeed, pressure altitude, magnetic heading, pitch attitude and normal acceleration. Its power supply is from the Essential Radio Bus Bar which at the time of the accident was selected to No. 3 generator.

The cassette containing the wire recording medium was removed intact from the tail unit of the aircraft after the accident. Except for a degree of smoke blackening it was found to be unaffected by fire and a "playback" of the flight record was undertaken without difficulty.

Recovery of data was carried out in both analogue and digital form and from the latter the path of the aircraft throughout the accident flight was plotted. It was established that the total time between rotation during the take-off and touch-down was 3 min 32 sec, the maximum height achieved was slightly less than 3 000 ft above airfield level and the maximum speed was 225 kt.

The heading trace indicated that the aircraft touched down on a heading of 050°M and remained on that heading for a period of about 25 sec. In the following 8 sec it turned on to a heading of approximately 035°M and remained on that heading until the recording ceased 19 sec later.

#### 1.12 Wreckage

Inspection showed that the aircraft had been extensively damaged by fire. No. 2 engine and most of its pylon was missing. Part of the structure of the port wing had melted causing it to break away from the fuselage and drop on to the runway.

An examination of the wreckage at the accident site revealed no evidence of damage to the wing other than that sustained from the fire. Inspection of the flight deck controls showed that all the fire shut-off handles were "IN" i.e. not activated. When examined during the investigation the absence of soot markings on their shafts indicated that they had been "IN" when the fire torched through the flight deck. The shut-off handles had not suffered damaged other than scorching by the fire and when tested were found to be fully serviceable.

The port fire extinguisher transfer switch was found set to "transfer". The fuel booster pump switches for the main wing tanks were "ON" and the switches on the engineer's panel for the fuel shut-off valves were set to "OPEN". The shut-off valve switches are protected by a gate and must be pulled out and down for "OFF". The normal tank to engine fuel supply was set up. No cross-feeding was taking place but No. 1 tank was selected to charge the manifold. The fuel contents and fuel flow gauge readings were considered to be unreliable because power was available to their respective electrical circuits when fire and explosion damage occurred to the port fuel tanks.

The fuel and hydraulic oil shut-off valves for the No. 2 engine were located in the wreckage and found to be fully open. These valves are electrically operated through a motored gear train and their positions cannot alter due to fire or impact. They were tested and found to operate satisfactorily.

No. 2 engine was recovered from a water-filled gravel pit approximately 5 miles from the threshold of Runway 05 R. It was substantially complete and only slightly damaged by fire. A short section of the rim of its No. 5 stage LP compressor wheel was found nearby.

An intensive search was made of the ground covered by the aircraft's flight path. Just inside the airfield perimeter and close to the up-wind end of Runway 28 L some severely damaged engine stator and rotor blades from the LP compressor were found together with fragments of the LP compressor casing. In this area also was the starboard section

of the No. 2 engine cowling which had been penetrated by flying debris and torn from its fittings. Further along the flight path portions of the No. 5 LP compressor wheel rim were found and also the main fuel feed pipe for the engine. This pipe is routed round the starboard side of the engine; examination showed that it had been displaced by the bursting of the LP compressor wheel rim and engine casing.

The No. 2 engine and associated components, and the main wreckage of the aircraft, were removed for detailed examination.

(1) No. 2 Engine failure

It was clear that a major mechanical failure had occurred in this engine and a detailed examination and metallurgical study was made in collaboration with the manufacturer. Strip inspection revealed that No. 5 LP compressor wheel had disintegrated, throwing several pieces of its rim and blading through the casing. It was this major damage to the casing which displaced the main fuel pipe which in turn led to a free discharge of fuel under pressure and the resultant fire.

Examination confirmed that the primary failure of No. 5 LP compressor wheel was due to fatigue at the run-out radius where the wheel web forms the rim. There were no other material defects found within this wheel or rim which had a considerably lower cyclic life than the average in service.

All other damage was secondary to the fatigue failure; that caused by the fire was slight and confined to minor sooting and paint blistering.

(2) Electrical continuity check of fire warning and fuel valve circuits

Photographic evidence indicates that the leading edge of the port wing out to the position of the No. 2 fuel shut-off valve was intact and not burnt when the aircraft touched down on the runway. The fire resistant wiring to the shut-off valve is routed well behind the leading edge away from the seat of the fire and a modification had been embodied to ensure that the electrical circuit to a valve would remain intact even if an engine broke away from the aircraft.

Although it was not possible to check the continuity of all the wiring from the flight engineer's panel to the fuel shut-off valve after the accident, this circuit had been tested and found satisfactory during the pre-flight checks. The fact that the red warning light in the fire shut-off handle illuminated in flight confirms the integrity of the fire warning system at the time the fire occurred.

During the investigation a continuity check of the remaining electrical wiring of the fire warning and fire shut-off valve systems was carried out. The ends of the wiring were identified at the position where the port wing had broken from the fuselage and a check of the systems from this point through to the associated flight deck controls was made. The warning light in the fire shut-off handle illuminated and the warning bell rang. When the test was repeated with the bell cancel switch depressed the warning light illuminated but the bell did not ring.

A continuity check of the fuel shut-off valve wiring was also carried out from the battery bus bar through the fire shut-off handle to the switch on the flight engineer's panel and this was found to be satisfactory.

The hydraulic shut-off valve circuit operation was checked in the same way as the fuel valve circuit except that the test connexions were made to undamaged cables where they entered their conduit at the rear of the forward freight compartment. From this point the circuit was found to operate correctly.

There was no evidence to suggest that fire in the air affected the control of the fuel or hydraulic oil shut-off valves. The valves themselves still operated satisfactorily when tested after the accident.

(3) Examination of the fire extinguisher system

Detailed examination of both No. 1 and No. 2 fire extinguisher bottles revealed that both had been severely heated in the fire and both were discharged. However, strip examination showed that:

- (a) The bursting discs on both heads of each bottle were broken;
- (b) The breakage of the bursting discs was due to the firing of the cartridges;
- (c) The cartridges had fired by overheating, due to the external fire;
- (d) The fusible plug in No. 1 bottle blew out before the cartridge fired;
- (e) The fusible plug in No. 2 bottle melted after the cartridge fired;
- (f) At least one element in each head was complete, indicating that the cartridge had not been detonated electrically.

1.13 Fire

The fire was a secondary effect following mechanical failure of the fifth stage LP compressor wheel. It can be considered in two stages i.e. - Stage One following immediately upon the compressor failure and Stage Two continuing after the engine fell away from the wing.

Stage One

Fire resulted from the damage sustained when No. 5 LP compressor wheel broke up and burst through the compressor casing. This displaced and disconnected the main fuel feed pipe. Fuel (kerosene) was delivered under pressure by the booster pumps from the broken joint at a rate of about 50 gal/min (150 kg/min). Ignition, either by ingestion into the damaged compressor and thence to the combustion area, or from the hot jet pipe probably took place immediately. Much of the starboard cowling had been knocked off by the broken compressor casing. This would have rendered the engine fire extinguishant ineffective. The fuel and hydraulic shut-off valves were not closed, consequently the fire continued to burn; within a very short space of time it weakened the light alloy structure of the pylon and the engine fell away from the aircraft.

### Stage Two

Fuel, fed by the booster pumps, continued to burn as it issued from the fractured pipe in the remains of the No. 2 pylon, just forward of the leading edge of the wing. The evidence shows that in flight the flames swept back both over and under the wing. However, after landing and when reverse thrust was applied the flames were deflected round the wing itself and in towards the fuselage. When the aircraft came to a standstill the booster pumps continued to run probably for about 20 seconds until their electrical circuit was broken by the fire. Explosion released more fuel from the port tanks and the fire then spread and increased in intensity.

#### 1.14 Survival aspects

Almost immediately after take-off, the cabin staff and some passengers felt the aircraft shake and then saw that No. 2 engine was on fire. The "Fasten Seat Belts" notice was still on. After visiting the flight deck the chief steward decided that an emergency landing was about to be made. In the short time available, and with the assistance of the other cabin staff he prepared the passengers and the aircraft. Just before the landing the check pilot made a passenger briefing announcement from the flight deck by using the public address system but this was either not heard or appreciated by the majority of the passengers.

Before the aircraft came to a stop the cabin staff had opened both starboard overwing exits. After the aircraft came to rest the rear starboard door and the forward port and starboard doors were opened. The forward port overwing exit was also opened but it is not known by whom this was done.

The cabin staff supervised the evacuation, which proceeded as follows:

#### Starboard overwing exits

The first passengers to leave the aircraft left by these exits. Fourteen men and four women made their escape under the direction of the chief steward before he stopped their further use because of the smoke and flames which enveloped the starboard wing area following the main explosion. Fifteen of the eighteen passengers who left by the overwing exits sustained some form of injury when getting down to the ground from the wing.

#### Forward port overwing exit

Nobody left the aircraft by this route.

#### Starboard rear galley door

After the escape chute had been rigged and inflated, it was found to be misaligned. One of the stewards had to climb down to straighten it, but then could not re-enter the aircraft. One of the stewardesses remained at the top to marshal the passengers. Only two men and three women escaped down this chute before the sparks and flames spreading from the port side of the aircraft set it alight and it burst. Two men, two women and one child jumped through this doorway after the chute became unserviceable. All the passengers who made their exit from the rear galley door sustained some degree of injury.



#### Starboard forward galley door

There was a slight delay before the escape chute for this door was put into operation, due to difficulty in getting the chute-retaining bar into its clips, but after this initial delay the main body of passengers abandoned the aircraft very rapidly by this route. The evacuation tended to slow down as passengers, both injured and otherwise, began to collect round the bottom of the chute and in front of the starboard wing. During a gap between the passengers disembarking the check pilot left the aircraft by this exit. When it appeared that all the passengers had left the aircraft, the remaining cabin crew members also used this escape route.

#### Port forward main door

At first the chute did not inflate but this difficulty was overcome with the assistance of the pilot-in-command. The flight engineer climbed down it to straighten it at the bottom, but almost immediately it caught fire and burst. One male passenger escaped from the aircraft by jumping from this doorway after the chute had collapsed.

#### Cockpit windows, starboard side

The Second Officer, the co-pilot and the pilot-in-command left the aircraft by this exit. Although they did not report much difficulty in making good their escape, hand burnswere sustained from the nylon tape rope provided.

#### General

The evacuation took place in an orderly manner but, when the rear galley door and starboard overwing routes became unusable some momentary confusion resulted amongst those passengers who had to revise their initial escape routes. In the early stages, conditions inside the cabin were quite good, but they deteriorated very rapidly when the integrity of the fuselage was breached by an explosion. There was some difficulty in helping passengers at the rear of the aircraft which was the first part of the fuselage to be overwhelmed by the fire. It was in this area that the stewardess attending to the passengers who ultimately succumbed, was last seen alive.

#### 1.15 Tests and research

See paragraph 1.12.

#### 1.16 Engine failure and engine fire drills

Set out below are the relevant portions of the two drills which were in force at the time of the accident.

ENGINE FIRE	ENGINE OVERHEAT or FAILURE
<p>NOTE: Judgement and precision are as important as speed when putting out an engine fire. Actuating a wrong control could cause more trouble than a few seconds delay in taking the correct action</p> <p style="text-align: center;">Phase I</p> <p>Warning Bell      E Cancel</p> <p>On Command from pilot-in-command:</p> <p>Thrust Lever      E Closed</p> <p>Start Lever      E Cut-off</p> <p>Essential Power E Re-selected</p> <p>Fire Shut-off    E If Lt. still                                  on PULL</p> <p style="text-align: center;">Phase II</p> <p>Eng-Anti-icing   E OFF</p> <p>Extinguisher      E Discharged</p> <p>Hyd. Pump        E OFF (No. 2 or 3)</p> <p>Visual check      E checking</p> <p>If after 30 seconds the fire warning light remains ON, or goes out then re-illuminates:</p> <p>Transfer Switch E Transfer</p> <p>Extinguisher      E Discharged</p> <p>Press Discharge of engine on fire, NOT that of second bottle</p>	<p style="text-align: center;">1</p> <p>Thrust Lever      E Closed</p> <p>Start Lever      E Cut-off</p> <p>Essential Power E Re-selected</p> <p>Generator        E OFF, Cont.                                  G.C.R.OPEN</p> <p>Eng.Fuel Valve   E Closed (if                                  danger of fire)</p> <p>Eng.Anti-icing   E OFF</p> <p>Hyd. Pump        E OFF (No. 2                                  or 3)</p> <p>19 January 1968</p>

The vertical layout of each drill, including the introductory caution to the fire drill, is that which is printed on the cockpit check lists. However, the relative horizontal layout of the two drills as given here is for the purpose of emphasizing the similarity of certain of the critical steps in each drill. E represents the flight engineer.

At the time of the accident the practice as shown in the BOAC operations flying manual was that Phase I items of the fire drill were to be performed from memory. They were not required to be verified by being repeated against the check list, as was the case for items of Phase II of the Drill.

The drills were developed by BOAC from those prepared by the aircraft manufacturers and from those in use by airlines already operating this type of aircraft. A BOAC addition to the drill is the allocation of individual functions to crew members. The responsibility for pulling the fire shut-off handle has been allocated to the flight engineer who can only do so if his seat belt is very loose. Alterations and adjustments have, on rare occasions, been made to improve the drills in the light of operating and training experience and of information obtained from the manufacturer. It is BOAC's policy to alter the drills only when a serious weakness would otherwise exist since any alteration requires not only the introduction of a new procedure which has to be learned, but also the cancellation of a procedure to which crew members have become accustomed through training and experience.

In the light of knowledge gained from the investigation into this accident, BOAC have now altered the check list in several respects. These two drills have been combined into one and re-named "engine fire or severe failure drill". It now unconditionally requires the fire shut-off handle to be pulled, whether or not a fire warning has occurred. In addition, the first item of Phase II is confirmation by the "pilot-in-command" that the fire shut-off handle has been pulled.

It is BOAC's practice, when carrying out crew drills, that the challenge and response method will be generally applied. Normally, the co-pilot reads out the items and the appropriate crew member confirms that he has taken the necessary action. However, BOAC recognize in their procedures that there may be occasions of emergency when this system cannot be used and it becomes necessary for the flight engineer both to read the items off the list and carry out the actions.

Since the accident the operations flying manual has been revised to state more specifically the procedure to be followed. It now requires that after completion of the drill the check list shall be read from the beginning and that if the nature of the emergency prevents the list being read in the normal manner, the flight engineer, once the drill has been called for, will perform and check the items himself by reference to the check list and that whenever a drill has been performed in this way it shall be checked by a normal reading of the check list from the beginning as soon as possible.

#### Route check pilot's duties

The Route check pilot's duties are designed to ensure that agreed standards of operation are maintained. The pilot-in-command under check operates the section concerned exactly in accordance with his normal operating procedures. The check pilot may not request a particular procedure and in general is expected to be as unobtrusive as possible.

To ensure that the Route check pilot keeps himself fully up to date he is required to fly on the routes in command for not less than one-third of the hours of the average of the pilot-in-command on the regular roster.

### Crew operational procedures

In addition to the pilot-in-command, co-pilot and flight engineer, a third pilot is normally carried in BOAC's 707 aircraft, but his duties, in so far as they concern assistance to the three normal flight deck members, during take-off and landing, are limited to monitoring the operation, if so instructed.

The pilot-in-command normally requires his third pilot to sit in the jump seat, immediately behind the pilot-in-command for take-off and landing and to act as an extra pair of eyes, both inside and outside the cockpit, to advise the operating crew of any unusual circumstances. On this flight the pilot-in-command agreed that the route check pilot should occupy the jump seat, since this is the best position on the flight deck to observe the take-off and landing phases. In consequence the third pilot was occupying the navigator's position for take-off, from where monitoring assistance is not possible. The pilot-in-command gave the Route check pilot the briefing he normally gives to the third pilot concerning the monitoring assistance he wished him to provide.

## 2.- Analysis and Conclusions

### 2.1 Analysis

The circumstances of this accident divide conveniently into three parts: (A) the engine failure and resulting fire; (B) matters relating to fire drills in the air; (C) evacuation and survival aspects, including the part played by the airport fire and rescue services. This analysis considers these parts separately.

#### A. Engine failure and resulting fire

The accident sequence stemmed from a fatigue failure of the No. 2 engine fifth stage LP compressor wheel, which led to a disruption of the compressor casing. The reason for this failure has not been determined. The damage caused by the burst wheel resulted in the release of fuel which ignited in the high temperature area at the rear of the engine. A few seconds later the flames flashed forward and the resultant heat rise operated the fire warning system.

Examination of the maintenance and overhaul records for this engine showed that vibration had been experienced during tests prior to its installation in G-ARWE. During this investigation this aspect has been given very careful consideration but it has not been possible to determine whether this vibration had any bearing on the ultimate failure of the engine.

Although the primary cause of the fatigue failure is not known, research into this aspect is continuing. Subsequent to this accident the following precautionary measures have been introduced by the manufacturer.

1. An improved polish finish is called for in the run-out radius to the rim of the compressor wheels and the minimum thickness dimensions in this area have been increased.
2. All compressor wheels are to be subjected to a full magnetic crack detection inspection and to be checked for distortion at each repair and overhaul.

### B. Fire drills

The examination of the wreckage revealed no evidence of damage to the fuel tanks or defects in the mechanical or electrical elements of the fire extinguisher system other than those sustained in the ground fire. Photographic and eyewitness evidence shows that after the engine and part of the pylon had fallen away, the fire continued to burn fiercely from the broken fuel pipe forward of the leading edge of the wing. When this is considered with the evidence that the fire extinguisher bottles had not been discharged electrically, it is apparent that the fire continued to burn because of the omission to pull the No. 2 engine fire shut-off handle, as required by the fire drill. That the handle was not pulled is further substantiated by the loss of hydraulic fluid which occurred after the engine fell away from the aircraft. The hydraulic shut-off valve, which is also operated by the fire shut-off handle, would have prevented this loss of hydraulic fluid if it had been closed. Hence it is pertinent to consider why the operation of the fire shut-off handle was omitted when the engine fire drill was carried out, and why the omission was not noticed by the crew on the flight deck.

When an engine fire of this magnitude occurs, there will inevitably be some doubt in the minds of the crew that it may not be possible to put it out. Therefore, fire drills must be designed in the knowledge that the situation will be treated with a sense of considerable urgency. The call for prompt action will be accentuated if the fire breaks out on take-off, since time will be short because a return to the aerodrome for an immediate landing will be made whenever possible. On this occasion, latent fears in the minds of the crew that the fire might not be controllable were heightened by the knowledge of a recent accident to a Boeing 707 aircraft at Honolulu - involving this aircraft - when the disintegration of a turbine wheel during take-off punctured a fuel tank. It is unlikely that the resulting fire in that case could have been put out in the air.

The drills in force at the time of the accident are set out in paragraph 1.16. These had been regularly practised by the crews and there is no doubt they could be accomplished successfully provided they were performed methodically and with precision. However, the circumstances of this accident show that in an atmosphere of urgency, when the fire drill supplanted the engine overheat or failure drill, confusion could occur between what actions had been completed and what still needed to be done. Apart from the action to silence the fire warning bell, the drills differed only in one critical action, namely the pulling of the fire shut-off handle.

On this occasion the difference between the two drills was inadvertently obscured by the flight engineer, who went for, but did not pull, the fire shut-off handle whilst carrying out the engine overheat or failure drill; it appears that this not only gave him the impression that he had pulled the fire shut-off handle as part of the fire drill, but also gave the same impression to the co-pilot.

From the flight engineer's station, directly facing the fire shut-off handles, it is not easy to see at a glance that a handle has not been pulled, as its movement, which is directly towards him, is only half an inch. When viewed from the side, i.e. from either pilot's seat, it is more easily seen. Nevertheless, because of the very small movement it is questionable whether it is sufficiently conspicuous for its position to be readily apparent to pilots whose main attention is concentrated on handling the aircraft during an approach to land in circumstances requiring accurate judgement from external cues.

It is BOAC's view that in some emergency situations the pilot-in-command will be so preoccupied with the physical handling of the aircraft that he cannot monitor in detail the performance of the drills and that he must hence place great reliance on the crew members report that the drills have been completed.

The check pilot was on the aircraft for the purpose of carrying out a check on the pilot-in-command and had also been briefed by him to draw attention to any unusual circumstances. He did not watch the fire drill being carried out but concentrated on keeping the pilot-in-command informed of the state of the fire and giving him assistance to position the aircraft for landing; he did not notice that the fire shut-off handle had not been pulled. By the time he turned his attention to the activities on the flight deck itself the engine had fallen away and consequently the warning light in the fire handle had gone out - so that his attention was not drawn in that direction.

It appears that an inherent weakness in the drill in use at the time was that the vital operation of pulling the fire shut-off handle relied solely upon memory and required no later check of this action. An additional factor leading to the breakdown of the drill was the workload on the co-pilot. In the very short time available, in addition to his other tasks he was instructed to make a "Mayday" call. It must be remembered that when he started to read the check list the flight engineer told him the check had already been completed. It is highly significant that even if he had read back the items of the fire drill, as required by the operations flying manual, in addition to carrying out his other tasks, a check of the fire shut-off handle would not have been included.

From the weight of evidence it seems that the fire bell did not ring because the co-pilot, after hearing the undercarriage horn start to sound, misidentified the action required and was pressing the fire bell cancel button at the instant when the bell would have started to ring. Therefore consideration has been given to the possible effect this may have had on the performance of the drills. No definite conclusion can be reached but there is a possibility that the flight engineer would have been alerted to a greater extent to the need to start with the memory items of the fire drill if the first action he was required to perform had been the cancellation of the warning bell.

#### C. Evacuation and survival aspects

Little time was available for the cabin staff to prepare the passengers for the landing and subsequent evacuation. Nevertheless, from the mass of favourable comment from the passengers and the evidence available it is clear that everything possible was done and the cabin staff, under the leadership of the chief steward, behaved with commendable coolness and efficiency throughout.

It seems certain that one of the stewardesses lost her life whilst trying to help passengers at the rear of the aircraft in the rapidly deteriorating conditions. It is undoubtedly due to the efforts of the cabin staff that the loss of life was not greater.

The evidence has shown that the great concern of the passengers to take their small belongings with them tends to block up the gangways.

The fittings of the galley doors escape chutes were not ideal and involved, in each case, the positioning of a bar behind clips on the cabin floor. It is understood that a modification has now been made by BOAC to facilitate the positioning of the bar but it would be much more desirable for the chutes to be designed so that they are readily available without special fitting.

It is clear that inflatable escape chutes are very susceptible to heat and flame. Since it has been shown that a very large number of passengers can escape down one chute in a short space of time, it seems highly desirable that research and development should be undertaken in the design of chutes in general and the materials of which they are made for greater fire resistant characteristics. Even an extra half-minute's use of a chute could save many lives.

#### Fire and rescue

The facts established during this aspect of the investigation are set out in detail in Annex 1. A number of points arising from them were brought to the attention of the Board of Trade and the British Airports Authority during the summer of 1968, so that where appropriate, early action could be taken on the lessons learned. Annex 1 also contains observations, some of which have no particular application to this accident; however, they are of importance when future requirements are being considered. Annex 1 generally needs no amplification, but there are four points which call for special attention. These are set out below.

The essence of fighting an aircraft fire is speed and weight of initial attack, to isolate the fuselage from the fire and preserve clear escape routes and also to attack the source, with the aim of diminishing the intensity of the fire itself as quickly as possible. Hence, seconds gained in reaching the scene of the fire are important.

With the present location of the main fire station at Heathrow in relation to the operating runways, there is a potential delay in getting to the scene of an accident. Therefore, extreme care must be taken to ensure the best possible communication and liaison between the fire service, the police and ATC, in order to minimize any delay. Since this accident some improvements have already been effected. However, there remains the longer term question, now that the airport is being used more intensively by bigger aircraft, of reviewing the number and location of fire stations.

The tactical approach to this fire was not entirely in accordance with accepted training principles. Although it is accepted that the importance of not hazarding equipment is emphasized during training, on this occasion the positions taken up by the two foam tenders brought into use in the early part of the operation were not well judged. Consequently the main foam volume potentially available could neither be applied to help to isolate the fuselage from the fire, nor to the seat of the fire itself. The design of the appliances used is such that once the snap decision to stop and make foam has been taken, they become virtually immobile and no adjustment to rectify an initial error can be made since the appliances cannot make foam and move simultaneously. This is a recognized deficiency in the equipment which the British Airports Authority will shortly be replacing by new appliances which can make foam and move at the same time.

The failure of a handline from the first foam appliance was serious as it reduced the already limited volume of foam being applied to a very low figure at a critical time. The reason for the burst hose has not been determined. Different hoses of a new design, which had been on order for some months before this accident, have now been fitted throughout as standard to all foam appliances and water tenders on the airport.

The amount of water "on wheels" called for by the licence has been calculated on the basis of the existence of the hydrant system, which is capable of delivering about 450 gallons of water per minute from either outlet at any hydrant on the airport. It is therefore vital, if there is to be a continuous supply of foam from the appliances for any length of time, that the hose-laying and coupling procedures do not fail. On this occasion,



partly because the hose-layer arrived from its exercise later than the rest of the main body of appliances, and partly because of the failure to marry one of its hoses with a hydrant, water was not available for about a minute from the hydrants when the wheel-borne water ran out.

There are clearly lessons to be learned from this operation, bearing in mind the increase in density of operations at Heathrow and the larger aircraft which will be coming into service before long.

## 2.2 Conclusions

### (a) Findings

The crew was properly licensed.

The documentation of the aircraft was in order.

The maintenance documents show that during a test run after a repair, prior to installation in the aircraft, there was vibration in No. 2 engine but this was within the limits laid down by the manufacturer.

No. 2 engine fifth stage low pressure compressor wheel failed due to fatigue. The reason for this has not been established.

The failure of the No. 2 engine compressor wheel caused damage to the starboard side of the engine and to its cowling. This resulted in a fuel leak from the engine fuel supply line and a fire.

After starting and before completing an engine overheat or failure drill, it became necessary for the crew to carry out a fire drill.

The co-pilot cancellation of the fire bell instead of the undercarriage warning horn prevented the fire bell from ringing.

The closure of the fuel shut-off valve by pulling the fire handle was inadvertently omitted by the flight engineer when he carried out the fire drill. The omission was not noticed by the pilot-in-command, the co-pilot or the Check pilot. The Second Officer was in no position to observe the situation.

The failure to close the fuel shut-off valve permitted the fire to continue.

The BOAC fire and engine overheat or failure drills in force at the time were capable of misapplication under stress.

The overall efficiency of the airport fire service was seriously reduced by some appliance deployment and equipment failures. However, they were successful in preventing the spread of the fire to 3 000 gallons of fuel in the starboard wing of the aircraft.

### (b) Cause or Probable cause(s)

The accident resulted from an omission to close the fuel shut-off valve when No. 2 engine caught fire following the failure of its No. 5 low pressure compressor wheel. The failure of the wheel was due to fatigue.

### 3.- Recommendations

From the information gained during this investigation, it is considered that the following recommendations are pertinent:

#### 1. Engine fire drills

There should be a further study of the BOAC 707 engine emergency drills, both as to sequence of operation and allocation of responsibility for individual items, to ensure that the most effective application and checking procedures are used.

#### 2. Airport fire services

The review of aircraft fire and rescue operations recommended by the Fire Services Group (Annex 1.11.11) is supported with the further recommendation that to ensure progress it should, in the first instance, be confined to the problems of Heathrow.

#### 3. Escape chutes

Research should be undertaken into the material of which escape chutes are made, to obtain greater fire-resistant characteristics and into their design and installation to ensure rapid deployment and protection against heat for those using them.

## Annex 1

Report of fire and rescue service working groupTERMS AND ABBREVIATIONS USED IN THE REPORT

ATC	Air Traffic Control
BAA	British Airports Authority
BoT	Board of Trade
Branchpipe	<p>No. 10x type - A hand held light alloy branchpipe designed to operate at a pressure of 60 psi at the water head and provides foam by self-aspiration of air. At this pressure the consumption of water and foam liquid is 95 and 5 gal/min respectively, producing 1 000 gal/min of foam.</p> <p>No. 20x type - This is similar in design and construction to the 10x type. It is designed to be used at a pressure of 100 psi at the water head and at this pressure the consumption of water and foam liquid is 190 and 10 gal/min respectively, producing approximately 2 000 gal/min of foam.</p>
Foam liquid	Protein based substance manufactured from either vegetable or animal protein and used in solution with water to produce mechanical foam.
gal/min	Imperial gallons per minute.
Hand line	Any hand held discharge line - e.g. water, foam CO <sub>2</sub> or dry powder terminating in a branchpipe or applicator.
GMC	Ground Movement Control.
imp gal	Imperial gallons.
LFB	London Fire Brigade.
LAS	London Ambulance Service.
Monitor	A foam or water outlet with a branchpipe connected to a fire appliance plumbing system. Monitors are usually located on the crew cab roof or appliance superstructure. Normally manual operation is employed and many installations are capable of 360° traverse with some elevation and depression.
psi	Pounds per square inch pressure.
Vactrol	Automatic device for supplying a foam branchpipe with water and foam liquid in the correct proportions.

### 1. SUMMARY

At 1527 hours G-ARWE took off from Runway 28L at Heathrow. Shortly after lift-off, No. 2 engine caught fire. The aircraft then made a visual circuit and approach to Runway 05R; during this manoeuvre, No. 2 engine became detached. The pilot made a smooth landing on Runway 05R with a fire at the No. 2 engine position on the port wing. Two British Airports Authority (BAA) airport fire service appliances and an ambulance from the central area sub-station were in attendance very shortly after the aircraft came to rest. The main body of the airport fire service from the north side HQ station, consisting of seven units, arrived some two minutes later. Twenty-two vehicles from the London Fire Brigade (LFB) also attended and provided back-up assistance to the BAA fire service. Of the 126 occupants, four passengers and one stewardess died as a result of the fire. No other aircraft or ground installations were involved in the large fire which developed.

### 2. FUNCTIONS OF THE FIRE SERVICE

The primary aim of the aerodrome fire service is to save lives. The tactics employed at the scene of an aircraft accident must be governed by this philosophy. The minimizing of damage to the aircraft or any other structures is incidental to the primary aim and must always be subordinated to it.

### 3. NARRATIVE OF EVENTS

#### Timing

In order to maintain a clear relationship between one event and another, times in this report will be given both in GMT and relative to the time the aircraft came to rest - 1531 hrs or "A" time.

#### Take-off

At 1527 hrs (A-4m.) G-ARWE took off on Runway 28L with a complement of 11 crew and 115 passengers. The fuel load was 22 000 kg of aviation kerosene using the wing tanks only with an empty centre fuselage tank.

#### Engine fire

Shortly after lift-off a portion of engine cowling was seen to fall from the aircraft and a fire was observed on the port wing. At 1527.52 hrs (A-3m.8secs) "WE" reported a fire in No. 2 engine. At 1528.7 hrs (A-2m.53secs) Air Traffic Control (ATC) confirmed a fire visible on the port wing. At 1528.35 hrs (A-2m.25secs) "WE" broadcast a distress message and requested a landing on the first available runway. At 1528.45 hrs (A-2m.15secs) ATC offered Runway 05R for landing, which was accepted by the pilot. The aircraft made a smooth touchdown and came to rest in Block 49 at approximately 1531 hrs (A). It was slightly to the left of the runway centre line and slewed to port on a magnetic heading of 035°, with the port wing tip close to the grass verge at the edge of the runway; there was little wind.

#### Crash alarm

The BAA fire services were alerted at 1528 hrs (A-3m.) by means of the crash bells and the direct telephone crash line from ATC. They were informed at 1529 hrs (A-2m.) that an aircraft accident was imminent on Runway 05R.

Rendezvous point for outside services was designated as "South-east"; at 1530 hrs (A-1m.) the rendezvous point was changed by ATC to "North", which is situated outside the BAA main north side fire station.

There was some uncertainty by ATC as to where the aircraft would eventually come to a stop and this caused a time interval between the crash bells sounding and the loud speaker announcement by the BAA fire service watchroom attendant giving the type and location of the emergency. This interval has been variously estimated as being between 30 and 45 seconds.

#### Sub-station attendance

When the two fire appliances and ambulance from the central area sub-station turned out they saw the aircraft on short final for Runway 05R. They observed the landing and followed the aircraft down the runway, arriving at the aircraft at approximately 1531.30 hrs (A+0m.30secs). As they drew up by the aircraft there was a large explosion from the area of the port wing, which threw wreckage over the fuselage. The foam/CO<sub>2</sub> tender (VXN 863) positioned to the left of the port tailplane and about 70 ft astern of it. The accompanying water tender (SXT 120) then started to transfer water to the foam/CO<sub>2</sub> tender. The monitor and both near and offside hand lines were brought into operation, concentrating on the area of the fuselage adjacent to the port rear cabin door, which was closed. The monitor was shut down, possibly due to a fault in the foam proportioning equipment; in any case, it was too far away to allow it to be used effectively. When the monitor was shut down, the offside hand line burst. The nearside hand line was too far away from the fire to make any significant contribution to the control of the fire. At the time the offside line ruptured, the fire following another explosion spread rapidly towards the tail of the aircraft, bursting the starboard rear escape chute. Up to this time people had been using it to escape. The burst length of hose was replaced in about a minute and both hand lines continued to produce foam for an estimated further four minutes before both VXN 863 and SXT 120 ran out of water at about 1538 hrs (A+7m.). An attempt was then made to use the 400 lb CO<sub>2</sub> on the appliance. However, the hose reel became disconnected and the gas was discharged uselessly.

#### Main station attendance

During the time that the sub-station appliances were operating, there were a series of explosions, the largest of which caused the aircraft to break its back in line with the wing root trailing edge. This occurred at about the time that the main body of the BAA fire service arrived, at about 1535 hrs (A+2m.). The port wing was burning vigorously, fed initially by fuel under pressure and passengers were evacuating in a steady stream from the starboard side forward door using the inflatable escape chute.

At the time of the crash alarm sounding, three aircraft were making approaches to Runway 28R, the first two separated by about 90 secs. The first aircraft had already started its landing flare manoeuvre and carried out a normal landing; the second and third aircraft were instructed to - and did - overshoot. It was not possible for ATC to give runway crossing clearance to the appliances from the north side station until the aircraft concerned had either landed or accepted overshoot instructions. The Air Controller was the only person in a position to co-ordinate the movements of aircraft and the airport fire service. The actual delay in getting clearance to cross the runway has been estimated as being between 30 and 45 secs.

One foam tender (SXT 118) was positioned on the grass clear of the runway roughly in line with the aircraft nose on the port side and some 65 ft from the edge of the runway. The supporting water tender (SXT 119) stopped adjacent to it and started to transfer water to the foam tender. As the appliance was sited out of range, the monitor was not used. Two side lines were deployed, but shortly after the offside line had started to produce foam, the hose burst. The defective line was replaced in about a minute and the foam applied to the port wing area. At about 1541 hrs (A+10m.), i.e. after some 8 min of operation, both SXT 118 and SXT 119 had used up their mobile supplies and ran out of water.

#### Hose-layer

The hose-laying vehicle, (182 BLR), whose task was to connect both VXN 863 and SXT 118 to the hydrant system, was in the central terminal area on an exercise at the time of the accident and did not hear the R/T messages relating to the emergency. However, the crew saw the smoke pall from the fire and proceeded to the site as quickly as possible, arriving at 1534 hrs (A+3m.) approximately a minute after the north side station vehicles. Two hoses were connected to the nearest hydrant, No. 253, and laid as far as SXT 118. When water pressure was applied, one hose coupling refused to remain married with the hydrant and blew out, so water to that line was shut off. Whilst the crew of the hose-layer were occupied with the blown coupling, the charged serviceable line from hydrant No. 253 was not connected to any appliance. When VXN 863 and SXT 120 ran out of water, one of their crew drove the hose-layer up to VXN 863 and connected with the charged line from the hydrant. The coupling that would not marry with the hydrant was later connected satisfactorily to hydrant No. 254 after the hose had been man-handled there from hydrant No. 253, a distance of about 300 feet; this latter operation took about 8 min, by which time SXT 118, SXT 119, VXN 863 and SXT 120 were all out of water. It is estimated that between approximately 1541 hrs (A+10m.) and 1542 hrs (A+11m.) no fire extinguishing media was being applied to the fire. By this time all survivors had left the aircraft.

#### Cardox

The Cardox CO<sub>2</sub> truck (VXN 876), being the slowest appliance, arrived at the accident just after the majority of vehicles and positioned adjacent to the aircraft nose on the port side. It discharged CO<sub>2</sub> in burst and, moving forward as the flames were suppressed, achieved a good knockdown of the fire as far as the wing root. Unfortunately, it had used up its charge of gas as it was achieving a measure of control over the fire but there was no foam jet in a position to consolidate the gains it had made; consequently, the fire then spread rapidly.

#### Domestic tender

The third foam tender (SXT 111) designated by BAA as the "domestic" fire tender, was at first positioned at the port side forward of the aircraft nose on the grass. The crew then proceeded to assist in the rescue as instructed. This appliance was not used in the initial attack on the fire but was later moved to the starboard side of the aircraft, ahead of the wing tip, where it successfully prevented the fire taking a hold on the starboard wing, which contained about 3 000 gal of fuel.

#### Rescue tender

The rescue tender, VXN 878, crewed by its driver and a fire officer, positioned initially by the nose of the aircraft. The driver subsequently donned breathing apparatus (BA) and tried to make an entry through the port forward cabin door. Two firemen wearing BA

made repeated attempts to enter through both port and starboard forward doors without success, due to the intense heat. A water hose line they started to use ran out of water at about 8 min after the commencement of operations. The 200 lb dry powder from the rescue tender was then used albeit unsuccessfully on the ceiling of the aircraft cabin near the starboard forward door.

All early attempts to enter through the starboard rear door failed, due to the intense heat. Later, firemen with BA entered through this door, supported by foam and water spray.

#### Land Rover

The senior BAA fire officer on duty travelled to the scene by Land Rover in company with the main station appliances. People were leaving the aircraft in a steady stream by means of the starboard forward door and escape chute. He gave general assistance and helped a woman down who had collapsed at the top of the chute; she was followed by two men who were the last people to leave the aircraft alive.

#### LFB attendance

The London Fire Brigade (LFB) and London Ambulance Service (LAS) were alerted at 1533 hrs (A+2m.) by the BAA watchroom attendant and the first fire appliance arrived at the "North" rendezvous point at 1538 hrs (A+7m.). There was some delay before the first group of LFB appliances moved off under BAA police escort.

The LFB and BAA do not agree as to the reasons for this delay. The senior LFB officer with the first attendance of the LFB left his appliance and entered the BAA watchroom. He maintains that he was informed that a Boeing 707 aircraft with 131 persons on board had caught fire on emergency landing and its port wing was alight; the fire was under control and his appliances were to remain at the rendezvous point. In view of the apparent size of the fire, however, he decided to go forward with his appliances. The BAA watchroom attendant recorded in the log that the LFB were "on station" at 1537 hrs (A+6m.) and given all information regarding the accident. At 1538 hrs (A+7m.) a signal was received from the senior BAA officer at the scene of the accident requesting that the LFB should be sent forward. The LFB were informed and left under BAA police escort. When further LFB appliances arrived at the rendezvous point, they were held up awaiting escort vehicles to take them to the accident, as all the available BAA police vehicles had departed with the first LFB contingent. In the event, off duty BAA firemen acted as guides and directed the appliances to the scene of the accident. The LFB attendance comprised 22 vehicles and provided water, manpower and equipment in support of the BAA fire service.

The fire was finally extinguished and five bodies were recovered from the extreme rear of the cabin.

#### 4. MEDIA AND EQUIPMENT SCALES

The scales of provision of fire fighting and rescue services at aerodromes are promulgated by the International Civil Aviation Organization (ICAO) as guidance material and specified by the Board of Trade (BoT) as part of the UK licensing regulations.

The Board of Trade sets out its standards in Section VI of Civil Air Publication (CAP) 168, "The Licensing of Aerodromes". This includes quantities of media, rescue equipment, personnel, training and emergency organization. ICAO and the BoT use a different



process in calculating the basic fire fighting requirements. However, for a given aerodrome it is possible to compare the two scales directly. For Heathrow Airport, London, the details were as follows:

Aerodrome category	Principal agent			Secondary agent		
	Water imp gal	Foam liquid imp gal	Discharge rate - water/foam solution imp gal min (5% foam liquid)	CO <sub>2</sub> lb	or	dry powder
ICAO Cat X	5 280	(a) not specified	880 (d)	1 200	or	600
BOT Cat IX	5 280	269	600 (d)	1 500	or	750
Provided by BAA at Heathrow	4 050 plus hydrant supply (b)	670	1 200 (d)	6 400 (c)	and	200

- (a) Depends on solution strength required by equipment.
- (b) Supported by hose-layer/foam liquid carrier (300 imp gal) to link with airport hydrant system, giving a continuous supply of water.
- (c) The ICAO exchange rate for excess provision of secondary agent equates the extra CO<sub>2</sub> to 880 imp gal of water.
- (d) Foam expansion rate 10:1.

Due to the existence of the water hydrant system at Heathrow, the 4 050 imp gal of mobile water is considered by the licensing authority to be adequate, when supported by the hose-laying appliance. When this vehicle is out of service, it is replaced by two water tenders, in which case the amount of mobile water available exceeds the minimum licensing requirement of 5 280 imp gal.

At the time of the accident, the disposition of fire appliances at Heathrow was as follows:

Main Station and HQ North Side  
(Situating north of Runway 28R/10L)

2 foam tenders	SXT 111/SXT 118	7 crew (total)
1 water tender	SXT 119	1 crew
1 rescue tender	VXN 878	2 crew
1 Cardox CO <sub>2</sub> tender	VXN 876	2 crew
1 Land Rover	ALF 676.B	1 crew
1 ambulance	SXT 98	1 crew

Sub-Station, Central Area  
(situated in No. 1 passenger pier)

1 foam/CO <sub>2</sub> tender	VXN 863	4 crew
1 water tender	SXT 120	1 crew
1 ambulance	SXT 95	2 crew

In Central Area  
(roving)

1 hose-laying vehicle	182 BLR	2 crew
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This appliance was on a topography exercise in the central terminal area.

All these vehicles were equipped with single channel VHF radio sets operating on the BAA fire service frequency. In addition, two portable radio pack-sets were available tuned to the same frequency. One set was in the rescue tender and the other was in the ambulance, which was based at the main station.

The firemen were dressed in the standard protective clothing for airport fire services in the UK. This includes a helmet with movable transparent visor, heavy cloth tunic, serge trousers with waterproof leggings and leather knee boots. A total of four sets of breathing apparatus (BA) equipment were provided - two in the rescue tender and two in one of the foam tenders at the main station.

5. SITING OF FIRE STATIONS

There are two BAA fire stations at Heathrow Airport, London. The main station is situated to the north of and roughly midway along Runway 28R/10L. There is also a sub-station located to the south of the central terminal area at the extremity of Number 1 passenger pier.

The geography of the airport is such that appliances from the main fire station situated outside the runway system must cross a main runway for any turnout other than to Runway 28R/10L.

ICAO in its "Aerodrome Manual" recommends that rescue and fire fighting operations on an airport should be initiated within 3 minutes "under optimum conditions of visibility and surface conditions".

Tests carried out subsequent to the accident showed that the running time for vehicles from the main station to the site of the accident at Block 49, following the same route as was used by the appliances travelling to the accident, i.e. crossing 28R at Block 2/11 then via outer taxiway, was 2 min 30 secs for the fastest vehicle and 3 min 5 secs for the slowest vehicle. To these times must be added 25 to 35 secs for the average turnout time between the crash bell sounding and the vehicles moving off. The time for vehicles from the sub-station to reach Block 49 was 1 min 20 secs plus 25 secs for the turnout. There were no runway crossing delays encountered on these trial runs. Test runs to other parts of the airport indicated that with the runway crossing delays that are inherent with the location of the main station, response times of 5 min or more could be expected before units from the main station were in attendance at the remoter corners of the airport, although on many occasions the sub-station foam appliance and water tender could attend within the ICAO recommended time.

Prior to the creation of the BAA there was a long history associated with the siting and number of fire stations at Heathrow. Plans ranged from a main central station with two satellites at strategic points between the runways east and west, to the present configuration.

#### 6. AIRPORT HYDRANT WATER SYSTEM

A high pressure water ring-main system designed to operate at a pressure of 125 psi and capable of delivering 450 gal/min at any outlet is installed at Heathrow for fire fighting purposes. At the relevant time 248 outlets were provided. The hydrants are inspected by the BAA fire service every three months. Record cards are maintained and defects are logged as and when they are noticed and the BAA Engineering Department informed for action. In the past it is apparent that appreciable delays have occurred before faults have been rectified. Nine weeks after this accident, hydrants Nos. 253 and 254 were seen to be in a poor state of repair: one had a bent valve spindle and the other had a washer missing. Random checks on other hydrants showed that a number had heavy deposits of paint on them.

#### 7. PERSONNEL

The BAA fire service at Heathrow is commanded by a Deputy Chief Fire Officer. He also acts as deputy to the BAA Chief Fire Officer at headquarters in London. Nevertheless, he gives priority to his airport duties. This officer has full-time responsibilities at Heathrow for organization, administration, operational matters, liaison and fire prevention. He is assisted by two Aerodrome Fire Officers, Grade I (AFO I). One of the officers is responsible in the main for all operational matters, whereas the other is more concerned with administrative duties. These three senior officers are normally available during normal working hours. After normal office hours including Saturdays and Sundays the command of the airport fire service is vested in an AFO II.

The minimum manning requirements for aerodrome fire services are not precisely defined either by ICAO or in CAP 168, except for the lower categories of aerodromes. Both authorities state that "sufficient personnel" should be available to man the appliances provided. Also, the minimum number of men should be available in the immediate vicinity of the equipment to deploy one major fire appliance or alternatively appliances carrying one third of the extinguishing media required, whichever is the greater, and in addition to bring into immediate use any light rescue vehicle.

ICAO gives guidance on the scope of fire service training programmes in the "Aerodrome Manual", Part 5, which also reflects the UK policy in this matter. CAP 168 requires personnel employed on fire and rescue duties to be fully trained in the use of fire and rescue equipment and in aeroplane fire fighting and rescue techniques. To give real meaning to the expression "fully trained" the Board of Trade introduced in 1966 a system of voluntary training and certification for airport fire service personnel based on the courses at the BoT Fire Service Training School. This voluntary scheme calls for 50 per cent of the aerodrome fire and rescue personnel to be in possession of certificates of competence and for these to be renewed every 5 years.

The BAA sends all of its fire service officers and men to the BoT Fire Service Training School and returns them for continuation training every third year of service. This corresponds with the practice established by the BoT for its own fire service, from which the greater proportion of BAA's fire service staff were transferred.

Since there are very few breaks in flying activities at Heathrow, it is not possible, between their three-yearly visits to the Fire Service Training School, to give firemen many realistic "hot" fire practices without bringing the operational cover below standard. This is a problem common to all aerodrome fire services.

A fire service watchroom is permanently manned at the main fire station. The watchroom in the sub-station is manned by a fireman who is the water tender driver; after responding to a call out, the sub-station is unmanned.

The main station watchroom attendant, who amongst his other duties has to maintain a written log of signals and events, experiences a very high workload during the early stages of an aircraft emergency. During normal working hours, five days a week, a storeman who is an ex-fireman can, when available, assist in the watchroom to relieve the attendant of some of his duties.

At the time of call out for the subject accident, the available BAA fire service personnel on duty were as follows:

2 Aerodrome Fire Officers (AFO)	Grade I
1 Aerodrome Fire Officer	Grade II
1 Section Leader	
6 Leading Firemen	
16 Firemen	

Twenty-one men responded to the initial call. One AFO I was in the stores and made a late attendance. One Leading Fireman was on duty as the watchroom attendant and one Fireman - a foam tender crew member - was acting as the duty driver and was not available. Two men were in the central area in the hose-layer and made a late attendance, arriving at the scene of the fire at about 1534 hrs (A+3m.).

#### 8. COMMUNICATIONS

Three separate direct telephone lines are provided between Air Traffic Control (ATC) and the BAA fire service watchroom:

Crash line - a unidirectional line from ATC to the fire service watchroom. A call from ATC illuminates a light on the watchroom console and sounds the alarm bells. This line is monitored by the airport PBX, the BAA police information room and the fire service sub-station watchroom.

Emergency line - a two-way line between ATC and the fire services watchroom. It is used for all Full Emergency and Standby procedures. This line is monitored by the PBX, the BAA police information room and the fire service sub-station watchroom.

Liaison line - a two-way line between ATC and the fire service watchroom. This line is not monitored by either the PBX or the BAA police.

Direct lines are also available between the BAA fire service watchroom and (i) the London Fire Brigade control room at Wembley, Headquarters Northern Command; (ii) the London Ambulance Service, Kenton; and (iii) the BAA police information room. At the time of the subject accident the third line was not available due to maintenance work being carried out.

### Rendezvous points

The purpose of the rendezvous points is to provide convenient rallying points for the off airport emergency services; they have no relevance as far as the position of the airport fire service appliances is concerned. Each rendezvous point is provided with an airport PBX extension, except rendezvous point "North" which is in front of the main fire station.

### Fire service watchrooms

When ATC operates the crash switch, alarm bells ring in both main and sub-station watchrooms. The attendants cancel their respective bells, note down the message and immediately relay the information over their loudspeaker systems. The main station attendant then alerts the LFB and LAS on the direct telephone lines.

### VHF radio

The following BAA services have their own single discrete VHF radio frequencies - Fire Service; Police; MT and Marshalling Section.

The Metropolitan Police, the London Fire Brigade and the London Ambulance Service have various VHF frequencies of their own.

The ATC Ground Movement Controller (GMC) had one VHF frequency, now increased to two.

At the time of the accident there were twenty-one different VHF frequencies operated by seven separate agencies concerned with fire fighting and rescue operations at Heathrow, but no provision had been made for direct communication between the various authorities or for monitoring other services' frequencies, apart from a selective calling (SELCAL) facility provided between some of the BAA fire service vehicles and the GMC position in ATC, whereby actuation of a switch by the fire officer illuminates a light and sounds a buzzer in ATC. A switch is then made in ATC which allows direct R/T contact between the GMC and the fire vehicle. When the fire officer wishes to sever contact the SELCAL switch has to be reset by ATC. If this is not done, GMC signals can saturate the fire service frequency.

## 9. AMBULANCES

Two ambulances are provided by the BAA at Heathrow, manned by firemen. One ambulance is based at each airport fire station. These vehicles are in constant use for domestic purposes: for example, carrying incapacitated passengers to and from aircraft. In an emergency, the London Ambulance Service can provide a dozen or so two-stretcher ambulances at Heathrow within 15 minutes.

At the time of the subject accident, the ambulance located at the main fire station was allocated the duty of following the hose-layer to the appropriate hydrant and then provide a temporary communications link between the hydrant and the fire appliances, using the radio pack set.

## 10. OBSERVATIONS

### 10.1 Response time

The first intimation ATC had of an impending accident was the call from "WE" which terminated at 1527.58 hrs (A-3m.2secs) reporting a fire in No. 2 engine. The Air Controller confirmed a fire visible on the port wing in his transmission ending at 1528.14 hrs (A-2m.46secs). Due to heavy R/T traffic on the tower frequency the first opportunity that the Air Controller would have had to speak on the crash line would have been for a 15 secs period between 1528.18 hrs (A-2m.42secs) and 1528.33 hrs (A-2m.27secs). At that time "WE" was cleared for a visual circuit for a landing on Runway 28L. From the evidence of the Air Controller it is apparent that he operated the crash switch at about 1528.20 hrs (A-2m.40secs) but it was not then clear where the aircraft would land. After "WE" broadcast a "Mayday" message requesting a landing on the first available runway, the Controller offered the pilot Runway 05R, this was accepted. The next opportunity the Controller would have had to speak on the crash line was for a 26-secs period between 1528.50 hrs (A-2m.10secs) and 1529.16 hrs (A-1m.44secs). It seems probable that he passed the message recorded by the BAA fire service between these times. This would correlate with a longer than usual interval between the sounding of the crash bells and the loud-speaker announcement of the details of the impending accident that was commented on by most firemen. It would seem that the Air Controller made the crash switch at the earliest time that could be considered reasonable, i.e. subsequent to confirmation, in this case visual, of the initial fire report. Detailed information as to the pilot's intentions at that time was not available to the Air Controller. When a decision was made to land on Runway 05R this information was passed to the fire service without delay.

The watchroom attendants at Heathrow, after cancelling the crash bells, noted down the message and re-broadcast it over the loudspeaker systems in both fire stations. Experience, at some other airports where the ATC message is broadcast over the loudspeaker system at the same time as it is recorded by the watchroom attendant, indicates that a saving of some 15 secs in response time may be achieved by this method. In addition to reducing the workload on the watchroom attendant, automatic recording of fire service R/T and telephone channels would have made a detailed analysis of the sequence of events easier and more precise. On leaving the main station, it is necessary for the officer in charge to make an immediate decision whether to turn right or left. In this instance, as he knew that the aircraft was on fire and attempting to land on Runway 05R he decided to turn right and to cross Runway 28R at Blocks 2/11. This would ensure the most direct routing to the threshold of Runway 05R. In the event, as the aircraft came to rest well down the runway, the most expeditious routing to the accident site would have been via Blocks 4/14, saving about 20 secs but this would have required the vehicles to have turned left immediately on leaving the station.

Due to landing aircraft, the north side appliances were delayed in their crossing of Runway 28R. With a fire station situated outside a runway complex, as at Heathrow, runway crossing delays are to be expected as a matter of course. When the fire vehicles received crossing clearance, relayed via the watchroom, a large smoke cloud was seen beyond the central area building; from other evidence this would indicate that the runway crossing time was, at the earliest, 1531 hrs (A) i.e. when the aircraft came to rest at Block 49. Taking turn-out and running times into account this would give a runway crossing delay of between 30 and 45 secs. This time interval also relates closely to the third aircraft approaching Runway 28R overshooting. When the fire vehicles saw the smoke pall they changed direction and proceeded via the outer taxiway to the north of the central area to Block 49.

The London Fire Brigade (LFB) and the London Ambulance Service (LAS) were not notified, by the BAA fire service on the direct telephone lines, until 1533 hrs (A+2m), four minutes after the emergency was notified to the fire service watchroom. This can partly be attributed to a high watchroom workload. Arrangements are being made for the LFB to be alerted at the same time as the BAA. LFB appliances will receive details of the accident by radio whilst on the run-in to the airport.

The first appliances of the LFB arrived at the "North" rendezvous point, which is situated outside the north side fire station, at 1538 hrs (A+7m.). There was some delay at the rendezvous point, sufficiently long for the senior LFB officer to enter the watchroom and make inquiries as to the details of the accident. The first LFB group then moved off with a BAA police escort, arriving at the accident at about 1543 hrs (A+12m.). If the LFB had been informed of the impending accident at the same time as the BAA fire service, i.e. 1529 hrs (A-2m.) and there had been no delay in moving off from the rendezvous point then it would be reasonable to expect the first LFB appliances to have arrived at the accident at 1538 hrs (A+7m.), 5 min earlier than they did. As the attendance of the LFB is automatic for aircraft accidents and aircraft ground incidents there should have been no doubts as to the LFB participation in an actual aircraft accident. There should be no delay in moving the LFB appliances on from the rendezvous point under police escort. As the LFB send fire appliances from a widely scattered network of stations it follows that the LFB vehicles tend to arrive at the designated rendezvous point piecemeal rather than in a body.

Due to problems of communication and the complexity of the runway and taxiway systems at the airport, it is essential that escorts for outside rescue services should have a sound working knowledge of the airport layout and if possible R/T contact with ATC.

The BAA police are charged in the Heathrow Emergency Orders with providing escort vehicles to lead the local authority rescue service vehicles from the designated rendezvous point to the scene of the accident. Two radio-equipped police cars are required to be provided but not infrequently due to manning and equipment problems only one such vehicles was available. In the case of the subject accident there were no police escort vehicles present to provide guides to ambulances and fire appliances arriving after the first LFB attendance. In the event it was fortuitous that BAA firemen off duty were available to act as guides.

It is felt that there is room for improvement in the liaison between the BAA fire service, the BAA police and the LFB and LAS. In the circumstances of a major aircraft accident the saving of time is vitally important and it is imperative that all the rescue services should respond smoothly and rapidly to a well integrated and organized plan.

The fire appliances from the central areas sub-station responded rapidly to the crash call and in fact followed the aircraft down the runway on its landing run. Under the particular circumstances of this accident it is considered that these two appliances could not have gone into action sooner than they did.

## 10.2 Deployment of fire appliances

### VXN 863 and SXT 120

The first two fire appliances to reach the scene of the accident were the foam/CO<sub>2</sub> tender (VXN 863) and the water tender (SXT 120) from the sub-station. From the evidence available, it is apparent that VXN 863 stopped at about 70 ft short of the port



tailplane of the aircraft; SXT 120 drew up adjacent to it so as to be in a position to transfer water. The monitor and two hand lines were then brought into action. Whilst the alignment of the vehicle was in accordance with accepted practice, it was too far away for the monitor to be able to bring its output of 2 000 gal of foam per min to bear significantly for the protection of the fuselage.

It must be remembered that with the type of equipment being used, once the snap decision to stop and make foam has been made, then the appliance is virtually immobilized. The monitor was therefore hurriedly shut down, which was possibly the cause of the offside hand line bursting, due to a pressure surge. The absence of pressure reducing valves in the foam system requires the pump and monitor operators to execute a closely synchronized drill. As a result, the potential output of 4 000 gal/min of foam from this appliance was reduced in a very short while, possibly less than a minute, to 1 000 gal/min.

The offside hand line operator placed himself in a position to apply foam to the port side rear passenger door, which was closed, and achieved some success in preventing the spread of fire under the fuselage in the vicinity of the starboard rear escape chute. The near side hand line operator was standing too far from the fuselage to contribute significantly to the suppression of the fire. Therefore, the bursting of the offside hand line significantly reduced the efficiency of this fire unit during the critical period when evacuation was taking place. In addition to the loss of foam-producing capacity, the burst line would have resulted in the loss of a considerable volume of valuable water which, in view of the delay in connexion to the airport water main, could have usefully extended the period that foam could be produced before the two appliances ran out of water.

The two hand line operators were faced with a situation involving explosions and an extensive fuel spillage fire. With the limited range of their 10X branch pipes they had to concentrate on the spillage fire, although to have been most effective they would have needed to have extended their lines and taken up positions level with the port rear door.

When an attempt was made to use the CO<sub>2</sub> the gas escaped after the hose became detached from the reel. The equipment manufacturer states that if it is properly assembled this should not happen. It has not been possible to determine the exact circumstances in this case. However, as an extra precaution a locking washer has now been added. Although it is doubtful if 400 lb of CO<sub>2</sub> could have contributed much to the suppression of the fire, this failure cannot be dismissed lightly.

#### SXT 118 and SXT 119

The first foam unit from the north side station to arrive at the accident was the foam tender SXT 118 and its attendant water tender SXT 119. The logical position for these vehicles to have taken up would have been adjacent to the port forward cabin door. As it was, the remote initial positioning of these vehicles, out of range of the 20X monitor, immediately reduced the potential foam output from 4 000 gal/min to the output of the two hand lines, i.e. 2 000 gal/min. The two hand line operators gave their initial attention to the fuel spillage and outer wing fires on the port side and not the critical port wing root area. From the evidence available, it would seem that the large explosion which occurred just as the north side vehicles arrived ruptured the fuselage and caused the internal fire to take a firm hold. If this was in fact the case, then it is considered doubtful if better positioning of these vehicles would have prevented the loss of life that did occur. The burst that occurred on the offside hand line further reduced the output of this unit to 1 000 gal of foam per minute. As one of the crew from SXT 118 was absent on

administrative duties, the full foam output of 4 000 gal/min using the 20X monitor plus 2 hand lines could not have been achieved initially. With the present equipment it is necessary for a foam tender to be fully manned with a crew of at least 4 men to enable it to be operated to its full potential.

#### SXT 111

The so-called "domestic" tender, SXT 111, was a fully manned foam tender with a crew of four men, including a Section Leader. This vehicle was not used as a foam-producing unit in the initial attack on the fire as the crew had been told that their primary function was that of rescue. It is estimated that after their arrival with the other north side appliances some 10-16 passengers and crew left by the starboard forward cabin door unaided. In the circumstances they were not able to be of much assistance in the evacuation. SXT 111 was later moved from its original position near the nose on the port side to the area of the starboard wing tip and made a useful contribution by preventing the fire from extending to the starboard wing, which contained some 3 000 gal of fuel.

In retrospect, it would appear that to have achieved the maximum effect it would have been necessary for SXT 111 to have gone into action as a foam tender immediately on arrival at the scene of the accident. Due to its non-involvement during the initial stages of the operation approximately 8 000 gal of foam was not then used as a fire suppressant medium. In this particular accident, it is doubtful if the decision not to use this appliance as a foam-producing unit very soon after arrival at the scene can be justified. It is important that the maximum volume of fire extinguishing medium should be applied to the fire as early as possible in the operation.

#### VXN 876

The Cardox CO<sub>2</sub> tender, being the slowest vehicle from the north side station, was the last to arrive at the scene of the accident. The Leading Fireman in command of the appliance placed it in a most effective position, to the port side of the nose. After dealing with a fuel spillage fire, he moved the vehicle in towards the port wing root section. He was hampered by smoke and poor visibility. The application of CO<sub>2</sub>, did, in fact, achieve a substantial knockdown of the fire whilst the gas lasted. The presence of foam to follow up the gains made by the CO<sub>2</sub> could have led to an earlier control of the fire. However, it is doubtful if this action would have resulted in any more lives being saved as, by the time that the Cardox unit came into operation, the integrity of the fuselage had already been breached and the interior of the cabin was on fire. The weather being almost calm was fortunately ideal for the application of CO<sub>2</sub>.

#### 182 BLR

The hose-laying appliance is a vital link in the fire plan, ensuring as it does that a continuous supply of water is available from the airport hydrant system. It was most unfortunate that this particular unit did not respond immediately to the initial callout for the subject accident. The need for the mobile water supply to be supplemented from the mains is essential for any extensive aircraft fire, allowing as it does the continuous application of foam whilst the 300 imp gal of foam liquid carried on the three foam tenders and the 300 imp gal on the hose-layer lasts.

#### VXN 878

The rescue tender was parked near the starboard side of the aircraft nose. There was no call for its special equipment; however, the dry powder extinguishant, breathing apparatus and a ladder were used.

### 10.3 Equipment

#### 10.3.1 Scale of equipment and media

The Board of Trade Southern Divisional Office, as the aerodrome licensing authority, approved the fire fighting facilities available at Heathrow. The fire fighting facilities provided exceed the minimum requirements for the class of aerodrome as defined by CAP 168, with the variation that the provision of 4 050 imp gal of water to be carried on vehicles, when supported by the hydrant system, is accepted by the licensing authority in lieu of the 5 280 imp gal appropriate to the aerodrome category.

The aerodrome licence requires 4 050 imp gal water on wheels and a foam discharge rate of 6 000 gal/min. With the existing appliances available at Heathrow, BAA provide the requisite amount of mobile water in three foam tenders and two water tenders. The foam discharge rate can, however, be met by the output of two foam tenders. The licensing authority has not stipulated how many foam tenders must be included in the number of appliances provided.

BAA have categorized their third foam tender as the "domestic tender" to be used, as its name implies, for domestic fires. This vehicle normally attends aircraft fires except when it is involved in a domestic call. All domestic fires are handed over to the LFB as soon as possible, so as to maintain the airport fire strength. At the time of the subject accident, the designated "domestic tender" was SXT 111. Excluding this appliance, the amount of mobile water was therefore 3 250 imp gal.

No clear instructions have been prepared by BAA as to how the third foam tender would provide back-up water supplies for the two "active" foam tenders. This situation indicates inadequate liaison between the BoT Divisional Office and the BAA fire service.

From the fire fighting point of view the needs of Heathrow are those of a medium sized town. Whilst the main responsibility for handling domestic fires remains as heretofore with the LFB, it is considered that the immediate domestic fire risk should be assessed and catered for separately from the aircraft accident risk. Ideally, airfield fire appliances should be concerned solely with aircraft accidents and incidents.

In the past, the scale of fire fighting equipment required to be provided at any given aerodrome has been determined largely by empirical means. With the advent of "jumbo" size aircraft, carrying very large numbers of passengers, some thought should be given to a more practical approach in the assessment as to what scale of fire equipment is required rather than the present method.

The development and evolution of the new equipment and techniques necessary to cope adequately with very large aircraft should be vigorously encouraged.

#### 10.3.2 Foam tenders

The "Nubian" type of foam tender used at Heathrow was introduced into service during the summer of 1957. At that time it was considered that the type was able to cope adequately with the size of aircraft then operating. The introduction into airline service of large jet aircraft posed a much greater problem to airport fire services. A solution was found by increasing the number of fire appliances available and doubling the output of the monitors. However, the bigger size of jet aircraft with fuselage lengths of nearly 170 ft coupled with greatly increased fuel loads - for example about 20 000 gal as compared with 7 000 gal, much increases the problems presented in an aircraft accident involving fire.

The inherent limitations of existing foam tenders in service, both in rate of application and length of throw of foam, when related to the increase in aircraft size and fuel capacity, would seem to indicate that aircraft development has outstripped the evolution of fire fighting appliances.

The Nubian foam tender cannot generate foam whilst moving. In the initial stages of an aircraft fire the ability for the appliance to make foam whilst moving is valuable. It must be remembered, however, that of necessity the amount of water carried on each vehicle limits its foam making ability before replenishment. It is necessary for a nurse water tender or hydrant hose to be connected to the foam tender to ensure a continuous supply of foam. Once such connexion is made then the appliance is immobile. Nevertheless, it is considered that all airport fire fighting appliances should have the ability to produce the appropriate fire suppressant medium whilst moving.

New equipment shortly to be introduced into service by BAA will go a long way to remedy the shortcomings of existing foam tenders.

With the introduction of the Boeing 747 type of aircraft, the problems are magnified. The fuselage height and fuel capacity for instance are both roughly twice that of the Boeing 707. To enable foam, or indeed any other fire fighting medium to be projected accurately on to a high structure, consideration should be given to some means of elevating the monitor above the normal vehicle roof level.

Modern foam tenders represent a sizable capital investment; the licensing authority should ensure that a fair balance is achieved between the conflicting requirements of operational and fiscal policies as far as the provision of airport fire equipment is concerned.

#### 10.3.3 Rescue tender

The present day concept of a rescue tender is for a light vehicle with good cross-country capability on which are mounted various items of specialist equipment: breathing apparatus and 200 lb of dry powder extinguishing medium. The provision of rescue equipment, elaborate or otherwise, is of no value unless manpower is available to use it. With the large increase in aircraft passenger loads in the near future, self rescue in the event of an accident will be the prime means of saving life. There are several roles to be played by a rescue tender:

- (i) The transport of rescue personnel to the accident site;
- (ii) Provision of a means of access to high wing/fuselage structures, remembering ladders are not necessarily the best way of achieving this;
- (iii) The provision of specialist equipment to assist rescue (e.g. cutting tools);
- (iv) Provision of some means whereby passengers can reach the ground quickly and safely from high exits, preferably flame-resistant;
- (v) Water spray or fog equipment for attacking aircraft cabin fires.

A critical re-appraisal should be made of the functions and design of the rescue tender.

#### 10.3.4 Hose-laying vehicle

This appliance is the vital link between the foam tenders and the aerodrome hydrant system. It is essential that it attends at an aircraft accident early enough to ensure a continuous supply of water.

Since the accident, tests have been made at Heathrow to establish the facts related to the use of the hose-layer in an aircraft accident.

It was established that water could be provided from a hydrant through 1 700 ft of twin 3½ inch diameter hose at a rate in excess of 900 gal/min at 125 psi.

The time taken to deploy the hose and for water to reach two foam tenders was 4½ min. A foam tender and water tender unit provides a total of 1 750 imp gal of water, with the appropriate quantity of foam liquid this will produce 1 838 imp gal of solution. With a discharge rate of 400 gal/min from each foam tender (the planned maximum) both units will be empty in 4¼ minutes. If a foam/CO<sub>2</sub> tender replaces a foam tender, as was the case in the subject accident then the time taken to empty the unit would be 4 min.

To satisfy the requirements of the aerodrome licence two foam tenders are required to produce solution at a combined rate of 600 gal/min. At this rate both foam tender units would use up the 3 500 imp gal of water available in 6 min. Again, if a foam/CO<sub>2</sub> tender replaces a foam tender in these circumstances then this unit would be empty after 5¼ min.

It can be seen, therefore, that under the test conditions it would have been possible to have maintained the minimum rate of foam discharge required by the aerodrome licence. However, at the planned maximum discharge rate there would have been a margin of only 15 sec for a foam tender and an interruption of water flow of 30 sec for a foam/CO<sub>2</sub> tender.

The tests were carried out over representative ground under ideal conditions and the distance of 1 700 ft was considered to be representative of the maximum distance that the fire service could be expected to operate from a hydrant. Although in many cases the nearest hydrant could be appreciably closer than 1 700 ft to an aircraft accident, it must be appreciated that at night or in conditions of poor visibility the hose deployment times could be adversely affected.

#### 10.3.5 Hose and miscellaneous equipment

The failure of a light alloy male hose coupling from the hose-layer to mate with a pillar hydrant is considered to have been caused by the hydrant and not the coupling. There is no evidence to show that light alloy couplings, which are used very widely throughout the country, are less reliable than the old type heavy metal couplings, provided that they are properly maintained. Of the four hand foam lines deployed in the initial attack, two burst. Examination of BAA records shows that their hose inspection cycles are in line with currently accepted standards.

The BAA fire service have not been able to put forward any definite reasons for the failure of the two hoses. There is a possibility that the burst hose experienced by VXN 863 was caused by over-pressurizing as a result of poor monitor shut down drill. There is no evidence as to the cause of the burst hose deployed by SXT 118. By the end of the operation a total of 31 lengths of hose had been deployed by the BAA fire service.

The failure of the CO<sub>2</sub> hose reel on VXN 863 was apparently due to faulty assembly which should have been detectable during routine examination of the equipment.

The monitor operator of VXN 863 stated that he shut down his monitor due to a poor throw. He attributed this to a faulty Vactrol unit.

A detailed and critical analysis of all equipment failures should be made after an aircraft accident as a matter of course.

#### 10.3.6 Hydrant system

The standard of maintenance of the hydrants at Heathrow was poor. There also appeared to be differing standards of inspection, depending on individual interpretations of what was required. A close liaison between the BAA fire service and the engineering department is necessary in order that rectification and repair work on the hydrants is carried out promptly as and when necessary. The presence, for example, of heavy deposits of paints in the bore of hydrant outlets where there should be none is inexcusable.

#### 10.3.7 Foam liquid

The BoT require 269 imp gal of foam liquid to be immediately available at Heathrow to satisfy the terms of the aerodrome licence. The BAA provides 670 imp gal of foam liquid carried on appliances; 100 imp gal in each of three foam tenders; 35 imp gal in each of two water tenders and 300 imp gal in the hose-layer.

The combined maximum foam output of the three foam tenders is 12 000 gal/min which will exhaust the available supply of foam liquid in about 10 min. After this time only water will be available from the hydrant system. To cover the case of long-lived and extensive fires some thought should be given to planning for the transport of additional foam liquid to the scene of an accident.

#### 10.3.8 Breathing apparatus

Prior to the accident to "WE" the provision of BA by airport fire services was not universal. Where it was provided as at Heathrow it was with the domestic risk in mind. Analysis of the subject accident would seem to highlight a requirement for BA to be available at all airports used by large passenger aircraft. The equipment should be capable of being brought into use immediately on arrival at the scene of an accident. The wearing of the standard aerodrome fireman's helmet is incompatible with the use of BA. Although another type of helmet was provided by BAA, it would appear desirable that more work should be done on this problem.

#### 10.3.9 Clothing

The traditional fireman's uniform has been in use for many years and has proved satisfactory. A considerable amount of work has been done on protective clothing for firemen and the development of a suitable fire resistant one-piece garment which can easily be donned over normal clothing is showing promise.



#### 10.4 Manning

The number of men available on watch at any one time at Heathrow is well in excess of the minimum requirements as described in CAP 168. The watch strength of 21 men, excluding the 3 ambulance crew members, provides each fire fighting vehicle with a minimum crew complement to enable it to carry out its primary functions.

The rescue tender, which is primarily a specialist equipment carrier, was provided with a driver in addition to the Duty Station Officer. Out of normal office hours the Duty Officer would be the senior fire service officer present at the first attendance. In an aircraft accident, if all three foam tenders and the Cardox appliance were used to produce either foam or CO<sub>2</sub>, as appropriate, at their maximum rate, then no manpower would be available for rescue coincident with the fire being suppressed. The rescue tender driver normally acts as a communications link for the senior officer present, with a radio pack set.

With the existing level of manning at Heathrow, the withdrawal of a single fireman, in this case a foam tender crew member, to act as a duty driver, reduced the maximum potential rate of output from his appliance by 25 per cent. When hand lines are deployed, the allocation of one man to handle each foam line would tend to limit the mobility because of the physical effort required to manhandle 100 ft of charged 2½ in diameter hose.

If the hand line has to be extended, then mobility is further reduced. If fire fighting tactics require, as a standard practice, the deployment of hand lines, some thought should be given to improving the mobility of the branchmen. With the new equipment due to be introduced, it will be possible for a driver and monitor operator to apply foam at a high rate. However, hand lines will still be required in order to reach areas which are inaccessible to the monitor and for mopping up operations. Appliance manning levels should therefore still be related to the use of hand lines. It is imperative that the maximum amount of fire fighting effort should be brought to bear on an aircraft fire in the shortest possible time. In the case of large international airports, such as Heathrow, where large numbers of people are at risk, the Board of Trade, as the licensing authority, should stipulate more precisely than has hitherto been their custom, the number of men necessary to man the fire appliances that are required to be available.

#### 10.5 Command

This investigation has demonstrated how important it is for the senior officer present at an aircraft fire to devote his efforts to co-ordination and control of the attack on the fire; to do this, it is essential that he has good communications with all the units under his command and that irrespective of the licence requirements he should be able to make the maximum use of the facilities available to him at the fire.

The investigation has also highlighted the requirement for a high calibre of appliance commander; this will become even more important with the introduction of more powerful equipment.

It was noted that in accordance with the recommendations of the BoT, operations of the fire services at Heathrow are normally under the command of an AFO II, although during office hours the DCFO, who is in charge of Heathrow, or an AFO I, may take over command and add to the senior effort available. There is no formal requirement for senior officers to return to duty out of hours. This is done on a voluntary basis. In view of the size of the commitment, which is still growing, it would appear desirable for the level of the duty commander to be reviewed.



From the size of the overall fire service responsibilities, it would appear also to be desirable to consider whether it is reasonable to expect the officer in command of the Fire Service at Heathrow also to carry out duties as Deputy Chief Fire Officer of BAA.

#### 10.6 Communications

With the number of agencies actively involved immediately following an aircraft accident at Heathrow, good communications are vital to the rapid response of the emergency services.

The provision of multi-channel R/T equipment in the BAA fire service and police vehicles would greatly improve the communications between the rescue services.

A greater degree of integration of the communication networks of the various agencies involved is very necessary. At the present time, contact is intermittent and slow, relying as it does on land lines and relays through two watchrooms.

The SELCAL facility could provide a valuable link between ATC and the BAA fire service vehicles. However, it would appear that revision of the drill for using it is needed. It is obviously necessary for a fire officer to have uninterrupted R/T contact with his other fire vehicles.

The existing system of passing accident information to both the airport fire service and the LFB is time-consuming and ponderous. Thought should be given to alerting the LFB at the same time as the BAA fire service. The use of the crash bells to alert personnel for all callouts is highly undesirable. The crash alarm signal should be quite distinctive and different from that used to signify routine and domestic turnouts. Ideally, it should only be heard in connexion with aircraft accidents and ground incidents.

To enable the BAA watchroom attendant to function efficiently, some form of automatic recording equipment is necessary, incorporating a time injection facility and covering both telephone and R/T inputs.

Consideration should be given to the evaluation and provision of a small, waterproof, personal radio for all Fire Officers, the Section Leader in charge of the rescue crew and the crew of the hose-layer appliance.

#### 10.7 Tactics and training

Analysis of a number of accidents over the past few years indicates that when an aircraft catches fire it is, initially, primarily a fuel fire. A secondary fire then develops in the fuselage which is little different from a "domestic" type of fire. Whereas foam in large quantities is required to attack the fuel fire, water spray or some similar medium is necessary for suppressing the internal fire. In the past it is apparent that maximum attention has been given to the fuel fire and not enough to the internal fire. Tactics should be evolved so that the fuselage internal fire is attacked at the same time as the fuel fire if possible. Certainly, as the saving of life is of paramount importance, then the "two pronged" attack, with foam and water, would seem to be attractive. In the case of "WE", however, the timing of the arrival of the BAA fire appliances from the north side station was such that, even if water spray had been introduced into the fuselage immediately on arrival, it is considered unlikely that more lives would have been saved.

With the need for continuous and extensive fire cover at Heathrow, it is evident that neither men nor equipment can be allocated for "hot" fire practices as often as is desirable. There is also a lack of a suitable training area near Heathrow. This means, in effect, that between three-yearly visits to the fire service training school, an individual fireman could well not have a fire practice involving burning aircraft wreckage. This state of affairs is peculiar to aerodrome fire services, as local authority firemen are fighting fires literally every day, whereas an airport fireman can serve for years without attending an aircraft accident.

#### 10.8 Ambulances

Under existing conditions, some 14 two-stretcher ambulances can be available within 15 min of an accident at Heathrow. As aircraft with passenger capacities in excess of 200 are already using the airport, with even larger loads in the near future, it would appear that a re-assessment of ambulance requirements is overdue. The provision of an ambulance service at Heathrow is the responsibility of the GLC.

Although at first sight the manning of the BAA ambulances by fully trained fireman would seem to be profligate, in fact, as the manning of the ambulances is calculated separately from the fire service watch strength, there would seem to be some merit in the arrangement, as it does allow some flexibility in planning. To a lesser extent, it also keeps personnel up to date with the constantly changing layout of the airport.

#### 11. CONCLUSIONS

11.1 The number of appliances, the amount of fire extinguishing media and the staff available to the airport fire service were in excess of those required by the terms of the airport licence.

11.2 The first attendance of the airport fire service, from the sub-station, arrived within 30 sec of the aircraft coming to rest. The appliances from the main station arrived two minutes later.

11.3 The deployment of BAA fire appliances, with the exception of the Cardox unit, was poor. There were a number of equipment failures which reduced the rate of foam application substantially below the capacity of the available appliances.

11.4 The airport fire service was successful in preventing the spread of fire to the starboard wing containing 3 000 imp gal of fuel.

11.5 The attendance by the LFB at the scene of the accident was delayed due to poor communications and inadequate liaison.

11.6 The communications networks of the various agencies involved in an aircraft accident at Heathrow require integrating and rationalizing. There is an immediate need for the provision of multi-channel R/T equipment for the BAA fire service and police. Also, the provision of telephone and radio recording equipment in the BAA fire service watchroom.

11.7 Although all the staff attend the BoT fire service training school more frequently than recommended, the BAA fire service require more frequent and realistic "hot" fire practices.

11.8 Faults reported in the water hydrant system at Heathrow should be rectified without delay.

11.9 The level of manning of the BAA fire service, although well in excess of the licensing requirements, was below that necessary to carry out fire fighting and rescue duties efficiently and simultaneously at a major conflagration.

11.10 To take full advantage of the hydrant system and allow the sustained production of foam, plans should be made for the transport of additional supplies of foam liquid to the scene of an accident.

11.11 A broadly based working party, including members from Home Office Fire Service Department, local authorities, BoT and BAA should be formed to study and report on the problems of aircraft fire and rescue operations. Their terms of reference should include liaison between airport and local authorities, the siting of fire stations, manning (including command structure), fire and rescue equipment, media scales, the training of firemen and the scale of ambulance cover.

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Scheduled international Take-off Fire in flight Flight engineer - misuse, engine controls
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