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## Left MLG fire on landing, Boeing 777-200ER, AP-BGL

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**Micro-summary:** While taxiing after landing, the left main landing gear was observed to be on fire.

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**Event Date:** 2005-03-01 at 0910 UTC

**Investigative Body:** Aircraft Accident Investigation Board (AAIB), United Kingdom

**Investigative Body's Web Site:** <http://www.aaib.dft.gov/uk/>

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**INCIDENT**

<b>Aircraft Type and Registration:</b>	Boeing 777-200ER, AP-BGL	
<b>No &amp; Type of Engines:</b>	2 GE 90 turbofan engines	
<b>Category:</b>	1.1	
<b>Year of Manufacture:</b>	2004	
<b>Date &amp; Time (UTC):</b>	1 March 2005 at 0910 hrs	
<b>Location:</b>	Manchester Airport, Manchester	
<b>Type of Flight:</b>	Public Transport (Passenger)	
<b>Persons on Board:</b>	Crew - 12	Passengers - 332
<b>Injuries:</b>	Crew - 0	Passengers - 31 (Minor)
<b>Nature of Damage:</b>	Slight damage to fuselage skin adjacent to door 3R, heat damage to the No 10 tyre and hydraulic hoses on the left main landing gear	
<b>Commander's Licence:</b>	Airline Transport Pilot's Licence	
<b>Commander's Age:</b>	54 years	
<b>Commander's Flying Experience:</b>	13,000 hours (of which 600 were on type) Last 90 days - 176 hours Last 28 days - 36 hours	
<b>Information Source:</b>	AAIB Field Investigation	

**Synopsis**

Whilst the aircraft was taxiing, following an otherwise uneventful landing at Manchester, flames were seen around the wheels of the left main landing gear. As the airport Rescue and Fire Fighting Service (RFFS) attempted to extinguish the flames, copious quantities of what the RFFS Watch Commander assessed as smoke were produced and, fearing that the fire was getting out of control, he advised the aircraft commander to evacuate the aircraft. Minor injuries were sustained by some passengers and several fire service personnel during the evacuation. The investigation determined that the cause of the fire, established as being in the No 10

main landing gear wheel, most likely resulted from the maintenance practice used when cleaning the wheel heat shields. It was likely that these had been immersed in a flammable solvent, which allowed the ceramic fibre insulation material contained within to become contaminated. The fire occurred on the second landing after the wheel had been fitted to the aircraft, when the brake pack temperature was likely to have been higher than on the previous landing.

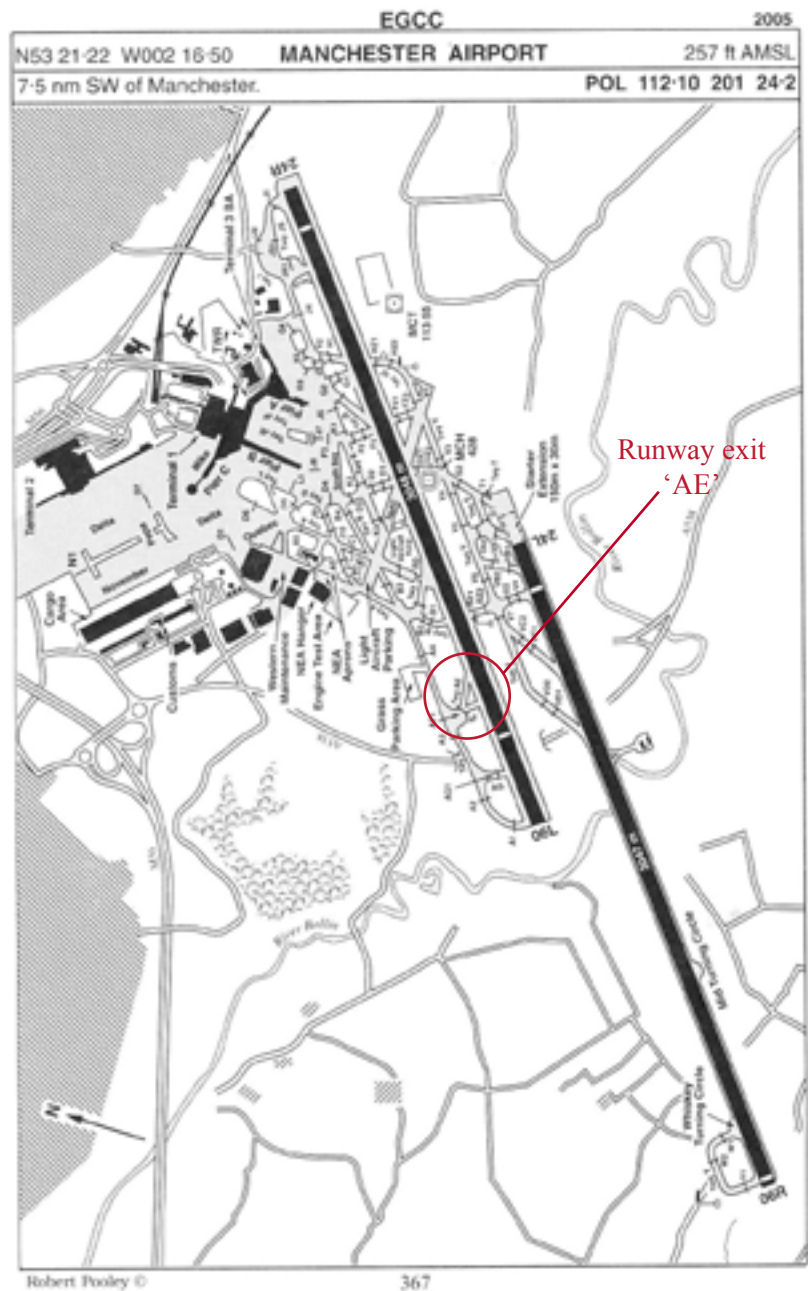
## History of the flight

The aircraft left Lahore, Pakistan, at 0047 hrs UTC for a flight to Manchester International Airport, where it was scheduled to stop for re-fuelling, catering, and cleaning, before proceeding to Toronto. Prior to this flight the aircraft had flown from Karachi at a relatively low weight where, amongst other maintenance activity, the No 10 wheel assembly had been replaced.

Approaching Manchester, the co-pilot obtained Automatic Terminal Information Service (ATIS) information 'Whiskey', which indicated that there was a light westerly wind at seven knots, the lowest cloud was FEW at 400 ft, with other layers above, the temperature was 3°C, the QNH was 1002 hPa and the runway was wet.

The commander flew an autopilot coupled approach to an automatic landing on Runway 24R, with Flap 30, a  $V_{ref}$  of 137 kt, an approach speed of 142 kt, and with Autobrake 2 selected. The touchdown was smooth and normal, following which the commander disconnected the autopilot, lowered the nosewheel onto the runway and selected reverse thrust on both engines. Assessing that the aircraft was decelerating normally and that it would reach taxi speed before the 'AE' Runway exit, see Figure 1, he reduced the amount of reverse thrust applied and disconnected the Autobrake. As the aircraft approached the exit, manual braking was applied and reverse thrust was de-selected.

The aircraft vacated the runway and, as communication with the Air Traffic Control (ATC) Ground Movement Control (GMC) controller had not been established, the commander brought the aircraft to a standstill on entry to Taxiway A. Then, having obtained clearance to taxi, the commander released the brakes, increased thrust slightly to about 23% N1 (engine fan speed) and the aircraft started moving.



**Figure 1**

A short time later, as the aircraft was still taxiing, an aircraft on an adjacent taxiway transmitted on the GMC frequency “AND GROUND ERR (CALLSIGN) THE PIA IN FRONT HAS FIRE IN HIS LEFT - ON HIS LEFT MAIN UNDERCARRIAGE”. The GMC Controller replied “ROGER”. Initially, the crew of the Boeing 777 did not realise that this transmission about fire related to their aircraft. There was a brief exchange of communications on the GMC frequency with other aircraft, and then the GMC controller transmitted “PAKISTAN SEVEN EIGHT NINE ERR JUST GETTING THE FIRE SERVICE OUT TO CHECK YOUR UNDERCARRIAGE CAN YOU HOLD POSITION”, to which the co-pilot responded “ERR HOLDING PAKISTAN SEVEN EIGHT NINER”. The commander brought the aircraft to a halt and set the Parking Brake. The aircraft was now parked on Taxiway J9, adjacent to the north side Airport Fire Station.

The co-pilot selected the LANDING GEAR page on one of the Multi-Function Display (MFD) and both pilots observed that the Left Main Landing Gear (MLG) indications were normal, with only the brake temperature display for the Number 1 wheel brake indicating a value, which was 3.0 units<sup>1</sup>.

The GMC controller observed the aircraft through binoculars and saw yellow and white flames coming from the left MLG. He activated the Crash Alarm, contacted the RFFS, declared an Aircraft Ground Incident (AGI) and passed the appropriate details.

In the airport fire stations on both sides of the airport the crash alarm, a loud siren, sounded. The communications equipment installed in each station is such that when the RFFS attendant manning the Watch Room in the

north side fire station picks up the telephone handset to take details of an incident, the telephone conversation is relayed by loudspeakers throughout both stations. This system had been devised to enable firefighters, whilst going to their appliances, to hear the telephone conversation and be immediately aware of the nature of the emergency, its location, and other pertinent details. Although this equipment worked correctly, the crash alarm also continued to sound, until de-selected by ATC, and the original message was rendered inaudible to firefighters. However, by the time the watch room attendant began to read the information back to ATC, the crash alarm had been de-selected and the firefighters were able to hear the conversation.

Another aircraft then transmitted “AND ERR GROUND ERR (CALLSIGN) THAT’S CONFIRMED IT’S HIS ERR LEFT MAIN GEAR IS ON FIRE”, which ATC acknowledged.

Vehicles from the north side fire station arrived within one minute of the activation of the crash alarm. The first vehicle to arrive at the aircraft was a Land Rover Discovery driven by the RFFS Watch Commander. He contacted the GMC controller on his frequency, stating that he was in attendance at the aircraft, that he required the pilots to immediately shut down their No 1 engine and to contact him on the promulgated RFFS frequency of 121.6 MHz<sup>2</sup>.

The Watch Commander had stopped his vehicle in front of the aircraft, from where he had an unrestricted view of the front of the left MLG bogie. He saw that a wheel hub appeared fully alight and observed what he described as

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**Footnote**

<sup>1</sup> The maximum indication on the scale is 9.9 units.

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**Footnote**

<sup>2</sup> 121.6 MHz is the frequency promulgated for direct communications between aircraft and Fire Service personnel at most airports within the United Kingdom.

“intense, very bright orange flames” from the rear set of wheels. Firefighters deployed two hose lines, one to the front of the left MLG and one to the rear, and began applying water in a spray pattern on to the wheels and brakes. The ATC Supervisor observed the aircraft from the Visual Control Room (VCR) and saw an intense white fire on the landing gear, which he described as “like a gas mantle” and “like white hot metal”. He did not see significant smoke and stated that the fire did not appear similar to hot Boeing 777 brakes that he had seen on previous occasions. As water was applied, significant and increasing amounts of what appeared to be ‘smoke’ emanated from the landing gear assembly.

The RFFS Watch Commander initially observed the fire and was concerned that, despite the application of water, the volume of ‘smoke’ appeared to increase as fire fighting took place. Having now established direct contact with the aircraft, he advised the flight crew that “YOUR PORT UNDERCARRIAGE IS ON FIRE SIR, FIREFIGHTING IS TAKING PLACE, I RECOMMEND AN EVACUATION ON YOUR STARBOARD SIDE”. The co-pilot acknowledged this message and the commander announced “CABIN CREW AT YOUR STATIONS” on the Public Address (PA) system, before asking the co-pilot to confirm by radio that the RFFS wished the evacuation to commence at once. The Watch Commander replied “AFFIRM SIR, RECOMMEND AN EVACUATION NOW SIR, YOUR UNDERCARRIAGE IS ON FIRE ERR EVACUATE STARBOARD SIDE”. The commander then summoned the purser to the flight deck and instructed him to evacuate the passengers from the right side. Both he and the co-pilot then began their evacuation checklist actions.

The evacuation checklist on the Boeing 777 is electronic and is displayed on one of the flight deck MFDs. The checklist items each appear in white text, with the next required action highlighted in a ‘text box’. When the

action is completed, the text changes colour to green. The fourth action on this checklist required the co-pilot to ‘*Override, pull and rotate*’ the APU Fire Switch. When he did this, the text did not change colour, as expected, but remained white. The co-pilot pointed this out to the commander, then rotated the APU Fire Switch in the opposite direction and checked that the APU BTL DISCH light illuminated, showing that the fire bottle had discharged.

With the evacuation checklist complete, the commander announced “Cabin crew commence evacuation from the right hand side” on the PA and activated the evacuation alarm.

Cabin crew at door R1<sup>3</sup> deployed the escape slide, and this was followed by the slides from doors R2, R3 and R4, in sequence. As the slides deployed, firefighters who were not directly involved in fire fighting ran to take positions at the base of the slides and began assisting passengers. Cabin crew directed the evacuation, depriving some passengers of baggage at the exits, and instructed passengers to remove high-heeled shoes and other sharp objects. Once he had completed his tasks on the flight deck, the co-pilot went into the cabin and assisted with the evacuation of disabled passengers.

Once all passengers had been evacuated, each cabin crew member carried out a check of their assigned area to ensure that no passengers had been overlooked, and then went down the slides themselves. The commander and purser also finally checked that no passengers remained, but one had initially refused to leave and so was taken down the aircraft by the slides by the commander and

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**Footnote**

<sup>3</sup> The aircraft doors are referred to by the side of the aircraft (left or right) and numbered in sequence from nose to tail. Thus, door R1 is the foremost door on the right side of the aircraft.

purser. The passengers and cabin crew were taken by coaches to the Airport terminal buildings, whilst the flight crew remained at the aircraft

When interviewed after the event, the cabin crew indicated that the evacuation command had taken them by surprise. As the landing and subsequent taxiing had appeared normal, and there were no indications within the cabin that anything was amiss, the cabin crew were relaxed. Some mentioned that the fact that the 'farewell' PA announcements which had been made earlier, gave them, and possibly the passengers, the impression that the flight was effectively over.

### **Visibility from the flight deck**

The design of the Boeing 777 aircraft is such that, in common with many large transport aircraft, it is not possible from the flight deck to see the wing inboard of the wingtips. The aircraft was not equipped with external video cameras and so the flight crew are unable to observe the exterior structure of the aircraft and its surroundings.

### **Airport response**

Once an AGI had been declared, airport staff closed the airfield, activated the airport's Emergency Plan and opened the Emergency Response Centre for the reception of passengers. As almost all passengers were transiting through Manchester en route to Toronto, very few relatives were at the airport to meet arriving passengers from the flight and so the Family Reception Centre was not activated.

Passenger coaches arrived at the aircraft very soon after the evacuation commenced and, in fact, before any ambulances attended. A set of mobile steps was also deployed, which enabled prompt access to the aircraft after the evacuation.

### **Injuries**

Medical teams from the nearest hospital treated 24 passengers at the airport for minor injuries, including abrasions to hands, back pain, and superficial injuries to the back of the head. Five passengers were taken to a local hospital by ambulance. One had suffered a fracture to the spine, but discharged herself the same day. Three others suffered minor injuries to their backs and were also discharged later that day, whilst another passenger exhibited signs of shock and was treated overnight. Two further passengers were taken to another local hospital where one was treated for abdominal pain, the other for a high temperature, both being discharged that on the day of the incident. Five firefighters sustained minor injuries as they assisted passengers from the slides.

### **Communication between the aircraft and the RFFS**

The United Kingdom Aeronautical Information Publication (UK AIP) promulgates information on Communication Facilities, including the availability of 121.6 MHz at many airports, for communication between aircraft and RFFS vehicles. As no Air Traffic Service is provided on this frequency, there is no requirement for it to be recorded. This frequency is used at Manchester but is not recorded.

### **Firefighter training**

Manchester Airport RFFS personnel undertook their training both at the airport, where the RFFS have a competence-based training regime, and at the International Fire Training Centre on Teesside.

The advice to firefighters dealing with landing gear incidents is that when the landing gear is hot, but not on fire, it is best left to cool naturally and that the application of water or other firefighting media is not necessary. However, if fire is present, training material

indicated that it is appropriate to endeavour to extinguish the fire, and that water is an appropriate extinguishant, particularly because of its effective cooling properties.

In the 'Firefighter Initial' training module *'Tactics and Techniques – Undercarriages'*, the following advice is published under the heading *'Hazards'*:

*'Toxic Smoke/Carbon Fibres – Due to the materials that may be burning or the type of extinguishing media used there may be vast amounts of toxic smoke given off by a burning undercarriage. If this is the case, breathing apparatus should be worn.'*

The training material did not indicate that steam may 'lift' carbon deposits from landing gears and give the appearance of smoke.

### **The evacuation**

Four different video recordings of the evacuation were available, three from the RFFS and one from an airport security camera. The recordings all began at different times, three of them did not have time-bases and so there was no straightforward means of achieving synchronised playback. However, examination of these recordings showed that there was an increase in ambient light, consistent with a break in the clouds, allowing significantly more sunlight onto the scene during the incident. This shared 'time-stamp' on all four recordings made it possible to synchronise them, albeit only to an accuracy of about  $\pm 3$  seconds. None of the recordings captured the initial call-out of the fire appliances and it was not possible to synchronise the video information with the evacuation checklist actions in the cockpit.

The following observations were made from these recordings:

The slides were deployed in the sequence R1, 2, 3 and 4, with 41 seconds elapsed time from the first signs of slide R1 being deployed to slide R4 being fully deployed.

The slides took between six and eight seconds from first signs of deployment to being fully deployed. All of the slides operated by the cabin crew were effectively deployed and used.

It took four minutes and ten seconds from the first signs of slide R1 being deployed to when all of the 332 passengers had been evacuated.

It took three minutes and twenty seconds for the evacuation of passengers down slides R3 and R4. A further two minutes thirty seconds after the last passenger evacuated, a crew member evacuated down slide R3.

A light wind caused the slides to move slightly whilst they were in the process of deployment, but the slides were stable and stationary once in use and passengers were evacuating from the aircraft. The slides from the Boeing 777 are designed for dual lane use. Continuous dual lane use was not achieved, and passengers tended to come down one after another. This, together with the apparent lack of a sense of urgency and the fact that some bags were thrown down the slides ahead of passengers, contributed to the long evacuation time of over four minutes. A rate of one passenger every two seconds appeared to be the best that was achieved.

The average rate down each of the slides was one passenger every two to three seconds. For certification, an evacuation rate of approximately one passenger per second is required to be demonstrated.

The assistance given by members of the RFFS to passengers at the bottom of the slides undoubtedly assisted the speed of clearing passengers away from the immediate vicinity and this probably contributed to reducing the number and severity of the injuries. Many passengers required lifting or some form of physical assistance to clear the slides.

Once out of the aircraft and on their feet at the bottom of the slide, passengers tended to remain in bunches close to the slides towards the rear of the aircraft, and were not rapidly guided away from the immediate vicinity.

Passengers were seen to walk towards the parked busses from the rear exits towards the front of the aircraft, passing downwind of what was believed at the time to be a fire.

Following the successful evacuation of all of the passengers and crew, it took a little over three minutes to load the passengers onto buses for transfer to the terminal

### **Additional information**

#### Cap 168, Licencing of Aerodromes

The Civil Aviation Authority publication CAP 168, section 8, *Licencing of Aerodromes*, sets out the minimum requirements to be met in the provision of Rescue and Fire Fighting Services at UK licenced aerodromes, which includes the training of RFFS personnel. Section 9 of this

document is entitled Emergency Planning, the objective of which is stated as:

*'to consider and record how an emergency situation or incident can be managed in order to minimize the effects it may have on life, property and aerodrome operations, and how best the use of appropriate available resources should be applied to achieve that aim.'*

CAP 168 is not a wholly prescriptive document and does not, for example, specifically require airport personnel to be designated to assume responsibility for the movement of passengers to a safe area immediately after an evacuation. As in this case, this is often done by RFFS personnel when time permits. However, the immediate responsibility of the RFFS is to save lives and, as also stated in CAP 168,

*'this must assume at all times the possibility of, and need for, extinguishing a fire that may occur either immediately following an aircraft accident or incident, or at any time during rescue operations'.*

Therefore, it cannot be assumed that RFFS personnel will always be available for this purpose.

#### **Electronic evacuation checklist**

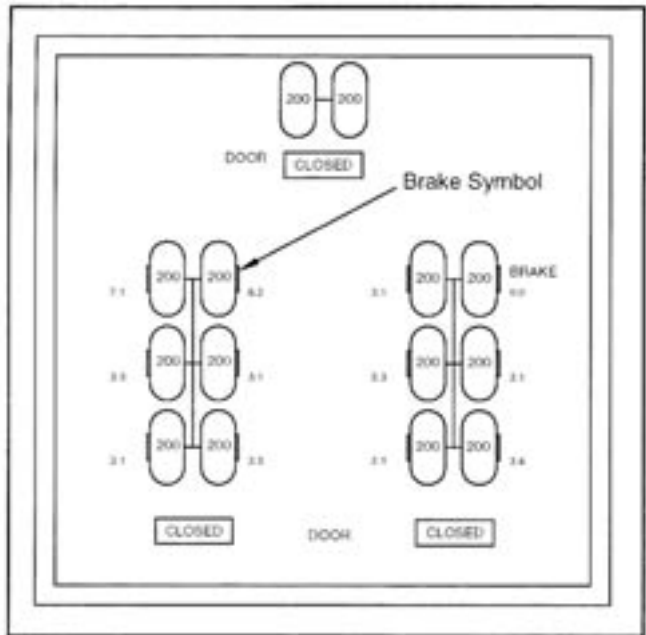
Information from Boeing indicated that the software standard of the electronic evacuation checklist installed at the time required that the APU Fire Warning Switch be pulled out and rotated, and the pressure in the APU fire bottle be sensed as low, for the checklist item to change from white to green. This reportedly takes a few seconds. However, a later software standard, now installed on the aircraft, requires that the switch just be pulled when following the evacuation checklist,



following which the checklist item will quickly turn to green. The switch is only to be rotated, to discharge the bottle, when following the APU fire checklist.

**MLG/wheel description**

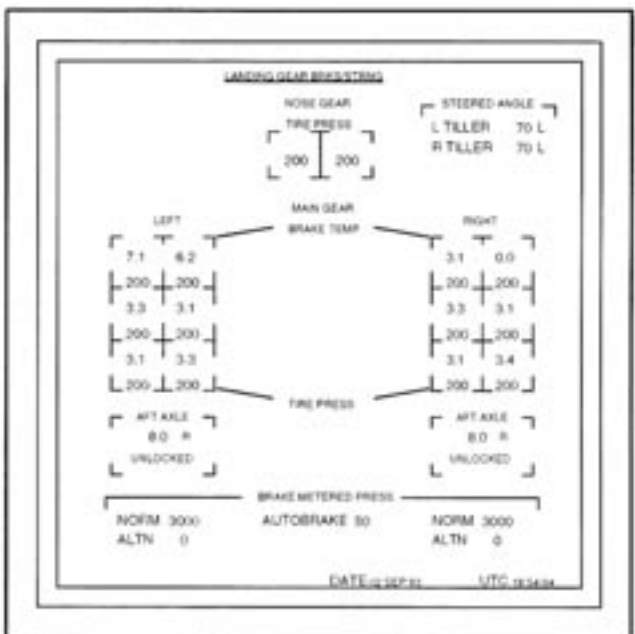
Each of the two MLGs on the Boeing 777 has six wheels on a three axle truck, each wheel being equipped with a hydraulically actuated multi-disk carbon brake. They are numbered across the aircraft, No 1 wheel being the front left unit on the left MLG, No 12 being the right rear unit on the right MLG. Each main wheel is also fitted with a thermal wheel fuse plug, a thermocouple, a wheel speed transducer and pressure transducer. The brake temperature and tyre pressure is displayed on the landing gear synoptic and brake and steering maintenance pages, see Figures 2 and 3.



**Figure 2**

Landing Gear Synoptic Display

An advisory “BRAKE TEMP” message will appear in the Engine Indication and Crew Alerting System (EICAS) engine format page, Figure 3a (next page), when any brake temperature indication reaches or exceeds 5.0 and will stay on until all brake temperatures go below 3.5. Brake temperatures equal to or above 5.0 indicate that the thermal wheel fuse plug may melt. The hottest brake on each gear, if below 5.0 and equal to or above 3.0, will be indicated by a solid white brake symbol. If any brake temperature reaches or exceeds 5.0, then the value and the associated brake symbol will be amber. This amber symbol will extinguish if the brake temperature decreases below 3.5. A 0.0 indication is equivalent to a BTMS peak temperature of 38°C and 9.9 to 1038°C.



**Figure 3**

Brake and Steering Maintenance Page

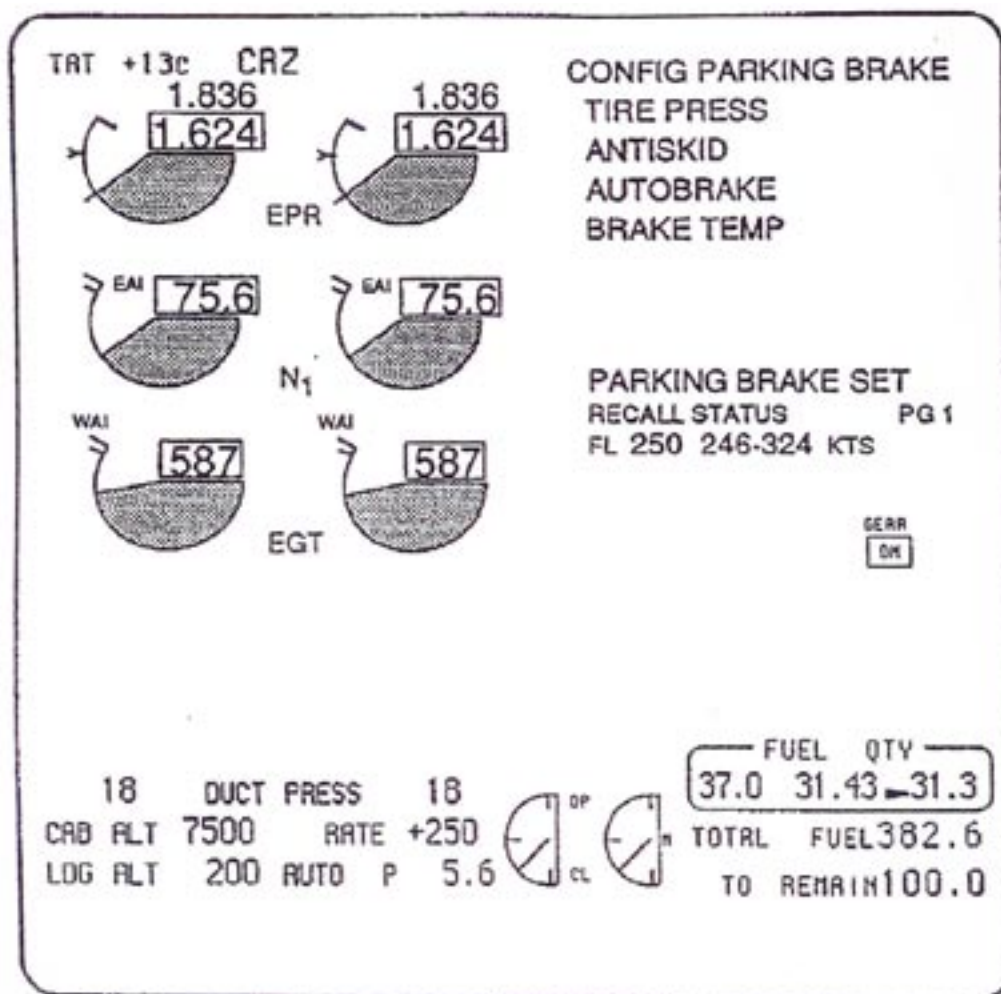


Figure 3a

EICAS Main Format

aluminium hub from the high temperatures generated by the carbon brake pack. The heat shields are constructed from two thin sheets of stainless steel, spot welded around their edges, and which contain an absorbent ceramic insulation material. They have a hole on the outer edge to allow the brake pack drive keys to be secured to the hub, and rubber bumpers fitted along the outside surface to prevent fretting against the wheel hub.

#### Initial aircraft examination

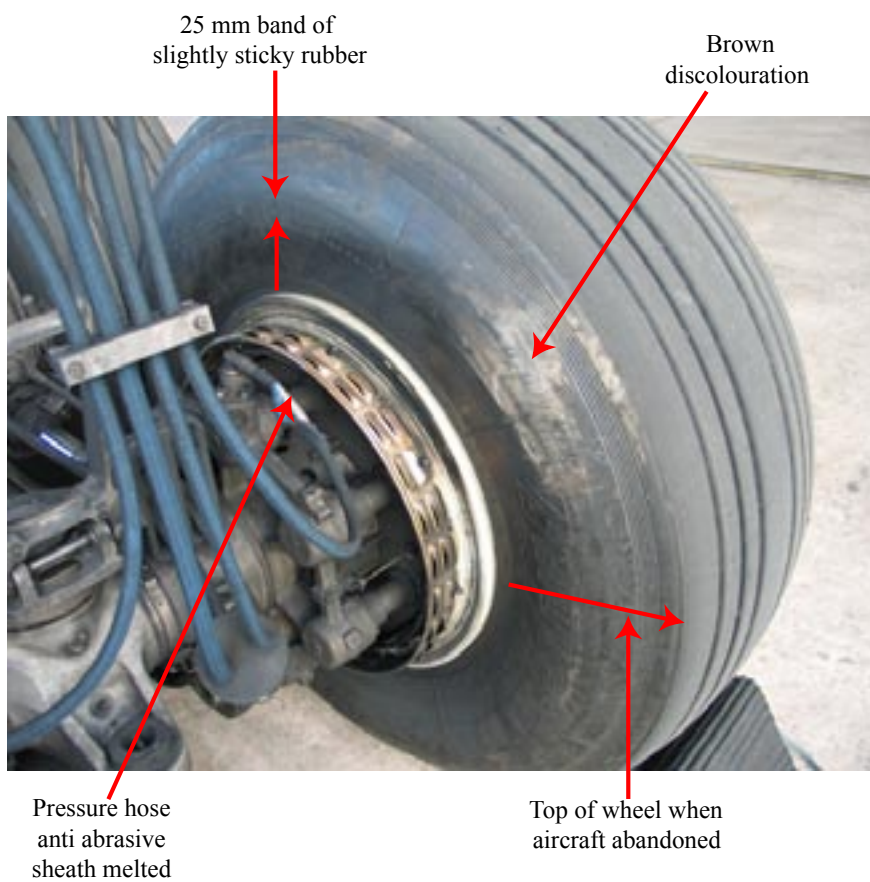
The only visible heat damage on the left MLG was melting of the anti-abrasion sheaths on the No 10 brake unit hydraulic pressure hose and temperature probe conduit.

The damage on each pipe was approximately 16 cm long and was on the side of the pipes facing the wheel. There was also slight damage to the inside of the No 10 tyre, consisting of a small brown area of discoloration at the 12 o'clock position, and two areas where the rubber had just started to turn sticky, indicating that these areas had been exposed to temperatures between 100°C and 150°C. Apart from this slight damage, the tyre appeared to be in good condition, Figure 5.

There were no indications of hydraulic or fuel leaks on the left MLG leg, or in the wheel bay. With the bogies covered in a layer of black dust, it was difficult to trace



**Figure 4**  
Construction of main wheel



**Figure 5**

the path of the fire. Nevertheless, there was evidence of light sooting around the top of the No 10 inner wheel rim and on the lower part of the door attached to the MLG leg. The soot pattern indicated that the smoke from the fire passed over the inside of the No 10 wheel at the 11 o'clock position, looking inboard.

A comparison of both MLGs revealed that the left bogie was considerably cleaner than the right.

### **Detailed examination**

#### **General**

As there was no reported significant damage to the aircraft it was towed, with the permission, and prior to the arrival, of the AAIB from Taxiway J9 to parking Bay 84, where a more detailed examination took place. Prior to the move, the left MLG was jacked up and it was established by maintenance personnel that the No 10 wheel could be spun with little resistance.

The MLG tyre pressures were noted from the EICAS, as follows: the No 10 tyre was indicating 191 psi, the remainder on the left bogie indicated pressures of between 198 psi and 210 psi. The tyre pressures on the right MLG bogie were between 200 psi and 217 psi. A tyre pressure gauge was used to confirm that all readings were accurate; nominal tyre pressure is 200 psi.

There was no sign of fluid staining on the walls of the left MLG bay, or on the tyres or components of the left MLG itself. Fuel and hydraulic system leak checks were carried out by pressurising the hydraulic systems and fuel lines in the left main landing gear bay, and the hydraulic systems on the left main landing gear. No evidence of leaks was discovered. During these checks, the left brakes were repeatedly applied and the No 10 brake pack was found to operate smoothly with no binding.

In order to establish if wheel bearing grease had played a part in the fire, wheel Nos 6, 9 and 10, which are positioned on the rear of the left bogie, were removed from the aircraft and the grease, bearings and seals inspected. All three wheels had been released from the operator's overhaul facility in December 2004, and fitted to the aircraft on 21 January (No 6), 6 February (No 9) and 28 February (No 10). The grease from all three wheels exhibited a normal light brown colour with no evidence that any grease had migrated beyond the bearing seals. The seals themselves and the wheel bearings all appeared to be in good condition and correctly fitted. The axles associated with these wheels all had a light smearing of grease with no evidence that excess amounts had been applied. When the No 10 wheel brake pack was removed, the grease on the axle was found to be covered in a black coating, believed to be carbon dust from the brakes. An intact layer of light brown grease was discovered under this coating. In summary, no evidence was seen on the three wheels or axles that excess grease had been applied, or that any grease had melted or burnt.

The opportunity was taken to examine two of the operator's spare MLG wheels stored at Manchester, the spare wheels carried on AP-BGL and on another of the operator's aircraft, AP-BGK, which staged through Manchester during this investigation. The wheel bearing grease on all these wheels was light brown in colour, their seals and bearings had been correctly fitted and there was no evidence that excess grease had been applied.

#### **No 10 wheel brake pack**

There were no visual signs of damage to the brake pack. The brake wear indicator pin was found extended by 1.59 cm (brake 80% worn with approximately 200 landings remaining). The torque tube was in good condition and there was no evidence of excess grease.

The torque tube heat shield exhibited signs of sooting, but this appeared to have entered the pack through ventilation holes and not to have originated from the wheel bearings. A high and low pressure leak test was carried out on the unit and the brake operated normally at 3,000 psi. Whilst there were signs of wetness around two of the pistons, there was neither any sign of fluid leakage, nor any evidence of hydraulic staining on the brake pressure plate. The overall assessment was that, apart from sooting on the torque tube heat shield, there was nothing unusual about the brake pack.

#### No 10 wheel hub

The No 10 wheel and brake pack were placed in a warm store room prior to being dispatched to the manufacturers overhaul facility. After several hours, a slight smell, similar to kerosene, was noted coming from the hub. Several days later, a very strong smell of kerosene was evident in the hub when the wheel was removed from the plastic wrapping in which it had been transported.

The chin ring was intact with no signs of overheating, but soot was present around 75% of the circumference of the inner part of the hub. However, there were no soot deposits around the bearing installation. The bearings, which were in good condition, were correctly greased with a 'light brown' coloured grease, and all the grease dams were undamaged and correctly fitted. There was no evidence of the grease having burnt, melted or leaked out of the bearing housing and the wheel's fuseable plug was intact. Paint was removed from the inner hub and a conductivity check was carried out, in order to establish if the wheel had become excessively hot. This indicated that there had been no change to the hardness of the hub material, indicating that the hub temperature had not exceeded 120°C.

#### No 10 wheel hub heat shield examination

All three of the heat shields from this wheel were coated in black soot-like deposits, which was considered to have been wear dust from the carbon brakes. One of the heat shields displayed blue and straw coloured interference patterns on its outside surface, a typical signature of heat on the shield material. This emanated from the edge closest to the axle, indicating that the shield section had been subject to abnormal heating, concentrated on the outer edge of the heat shield. Whilst there was slight discolouration on the inner surface, it was less intense and widespread. This was unusual in that the inner surface of the heat shield is normally exposed to the high temperatures from the brake pack, whilst the outer surface is close to the significantly cooler hub. The rubber bumpers showed no evidence of heat damage. The normal weight of a wheel heat shield is 900 g. The measured weights of the three heat shield sections removed from this hub were 1.013 kg, 1.008 kg and 1.009 kg.

#### Previous incidents

There have been 19 reported occurrences of wheel brake fires on Boeing 777 aircraft since June 1999, of which 10 occurred in the first 20 months of the period. Eight of the fires were attributed to the presence of excessive grease, five to the solvent used in cleaning the wheel components, one to a hydraulic leak, and five where the cause is unknown. Seven of the fires occurred within one or two cycles of a wheel change and one occurred six weeks after a wheel change. The remaining incidents make no mention of when the wheel was last replaced. Wheel No 10 was fitted to AP-BGL one flight prior to the aircraft's flight to Manchester, and this was a relatively short flight from Karachi to Lahore, at a relatively low weight, following maintenance. Upon landing, the braking demands, and the consequent heat

generation within the brake packs, was therefore low. The AAIB are aware of other unreported incidents of smoking brakes on Boeing 777 aircraft, some of which were attributed to excessive use of de-icing fluid. The operator took delivery of their first of three Boeing 777 aircraft in January 2004, since when six wheel fires have occurred. Five of these occurred at Manchester Airport. Seven days after the incident to AP-BGL, another of the operator's aircraft was seen to have smoke coming from both the No 3 and No 6 wheels. The smoke from the No 6 wheel was described as "suddenly stopping, as if a tap had been turned off".

The incidents which occurred in 2004 were the subject of AAIB Bulletin 9/2004, which was an omnibus report based on information provided by the operator. The report highlighted that brake fires could be the result of the wheel hub heat shields being contaminated with flammable solvents during maintenance, and the build up of excessive grease.<sup>4</sup> In June 2004, the operator introduced new maintenance procedures to ensure that excessive grease did not accumulate in the wheels and changed the grease from NYCO 22 to Aeroshell 22, which is the grease specifically approved for use on the Boeing 777. At the same time, an internal memorandum was circulated highlighting the potential risk from cleaning heat shields by immersing them in a flammable solvent.

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**Footnote**

<sup>4</sup> Contamination by de-icing fluid, hydraulic fluid and cleaning products can also result in a brake fire. These are well known risks that the manufacturer highlighted in Maintenance Tips issued in 1995 and 2001, and which the operator brought to the attention of its engineers in June 2004.

**Testing****Grease**

Previous fires on the operator's Boeing 777 aircraft have been attributed to using excessive amounts of Nyco 22 grease, a type not specifically approved for use by the manufacturer on Boeing aircraft. However, a comparison of three approved greases with Nyco 22 (see Table 1) indicates that the specifications and upper temperature range are similar; therefore, there is no apparent reason that any excess accumulations of Nyco 22 would be more susceptible to catching fire than the approved greases.

A grease sample taken from both the No 10 wheel and the spare wheel carried on AP-BGK was compared with a sample of Aeroshell 22, using a Fourier Infrared Transform technique. The infrared spectrum of the three samples was essentially identical, with no unique peaks in any of the samples. Therefore, it is highly likely that the grease in the two wheels was Aeroshell 22. As the grease samples taken from the other five wheels were also light brown in colour there was little doubt that they were also Aeroshell 22.

**Heat shields**

Two of the heat shields from wheel No 10 were sent to an independent laboratory for further analysis. Upon dissection, it was noted that there was considerable charring of the internal ceramic insulating material, particularly at the edges and around the rubber inserts. The material felt damp to the touch and there was a strong smell of a hydrocarbon substance. Two samples of the material weighing 0.9 g and 0.8 g were heated to 50°C and a weight loss of approximately 31% was recorded after one hour and 43% after 12 hours. Further analysis determined that the material contained a number of volatile organic components, similar to products used

Grease	Colour	Temp Range	Specification	Approved
Nyco 22	Red	-54°C - +177°C	Mil-PRF-81322 DEF Stan 91-52 AIR 4222 XG 293	No
Aeroshell 22	Light Brown	-54°C to + 177°C	Mil-G-81322C DEF STAN 91 -52 AIR 4222 G-395 XG-293	Yes
Mobil 28	Dark Red	-54°C to + 177°C	Mil-G-81322E DoD-G-24508A G-395	Yes
Mobil Aviation SHC100	Red	-58°C to + 180°C		Yes

Table 1

as solvent for paints or de-greasing agents. A 10 cm long sample of the contaminated ceramic material was introduced into a cool Bunsen burner flame. On removal from the burner the material continued to burn with the flame moving slowly along the sample with a yellow, slightly smoky, flame.

### Wheel overhaul

The operator's wheel overhaul facility services wheels from their Boeing 747 aircraft, which are fitted with steel brakes, and the A320, fitted with carbon brakes, in addition to those from the Boeing 777. The wheel hubs from the Boeing 747 and A320 aircraft are also fitted with heat shields, but these differ from those on the Boeing 777 in that they do not contain ceramic insulation material. The operator's normal procedure for cleaning the heat shields from the Boeing 747 and A320 is to dip them in a Type II solvent bath. However, the Maintenance Manual for the overhaul of Boeing 777 wheels states:

*'Clean the heat shields with a cloth that is dampened with P-D-680 Type II or III solvent or clean it with steam'.*

A previous investigation by the Pakistan Safety & Investigation Board identified that the operator had experienced difficulty in obtaining the specified solvent and had, therefore, used an alternative product, which had not been specifically approved by the aircraft manufacturer. It was established by the Board that some of the maintenance personnel were cleaning Boeing 777 heat shields by dipping them in a solvent bath, thereby allowing the ceramic filler to become saturated with the solvent. The operator was unable to establish when the incorrect solvent was introduced or when individuals began the practice of dipping the heat shields into the solvent. It is understood that the alternative solvent used was also Type II, and so would have a similar ignition temperature to the approved solvent. It was, therefore, most likely that the saturation of the ceramic

insulation filler by the solvent, rather than the use of an unapproved substance, allowed the heat shields to subsequently catch fire.

### **Safety equipment**

All four escape slides on the right side of the aircraft successfully deployed and sustained no damage from the passenger evacuation. Damage appeared to have occurred to the wing fuselage fairing (panel 198FR) during deployment of the No 3 slide which consisted of a dent 1.2 cm long and a hole approximately 2.5 cm x 1.2 cm in size. The damage had no effect on the subsequent evacuation.

After the No 4 slide had been deflated and removed from the aircraft, engineers discovered that the battery cover of the emergency locator beacon fitted to that slide was broken. It was not possible to establish if the cover was broken when the slide was transported the short distance to the maintenance facility, or when the slide was packed and originally fitted to the aircraft prior to delivery to the operator. The beacon, however, was capable of normal operation.

### **Discussion**

#### Wheel heat shields

Smoke and the occasional fire associated with aircraft brakes, has often been attributed to contamination of the brake pack by grease. Excess grease can either leak through the bearing seals, or be scraped along the axle by the wheel bearing when the wheel is installed, and be thrown off the rotating wheel onto the brake pack. In the incident to AP-BGL, there was no evidence of any such excess grease or that any grease had burnt or melted. In June 2004, the operator introduced new maintenance procedures to ensure that excessive grease did not accumulate in the wheels and changed the

grease from NYCO 22 to Aeroshell 22, which is the grease specifically approved for use on the Boeing 777. Therefore, grease build-up was not considered to have been a cause for the wheel fire in this case.

Also in June 2004, an internal memorandum was circulated by the operator highlighting the potential risk from cleaning heat shields by immersing them in a flammable solvent. The ceramic fibre insulation from two wheel heat shields from AP-BGL's No 10 wheel that were sent for analysis, were damp to the touch, smelt strongly of a hydrocarbon like substance, and reduced in weight when heated. Another sample, when ignited, continued to burn. This strongly indicated that the insulation material had been contaminated with a solvent, most likely when the wheel had been overhauled, as the aircraft had not been de-iced or experienced any hydraulics leaks associated with the left MLG since the No 10 wheel had been fitted.

A review of the incidences of wheel fires on the operator's Boeing 777 aircraft indicated that all the affected wheels had been fitted to the aircraft at Karachi, with the fires all occurring on the 'second' landing at Manchester. It is likely that, in these incidents, solvent escaping from the heated heat shields was ignited and briefly burnt and/or that any excessive grease either on the axle or thrown onto the brake pack during the first landing, could have been ignited when the aircraft landed at Manchester. Either way, the most likely explanation for the majority of the fires occurring at Manchester is that it is here the aircraft normally undertakes its first landing with a full payload following a wheel change at Karachi. Hence the brake packs would likely be hotter than on landing at Lahore, with the result that the heat shields became sufficiently hot for the entrapped solvent to escape as a vapour and ignite, probably, on contact with the hot brakes.



The firemen could see the flames on the inside of the No 10 wheel and, therefore, used water spray to fight the fire. On contacting the hot brake units the water turned to steam which then started to lift the heavy layer of carbon dust which covers all the landing gear components. From video recordings taken at the time, it could be seen that the combination of carbon dust, steam and water spray closely resembled smoke. The apparent increase in 'smoke' emanating from the landing gear led the fire officer to believe that there was an uncontained fire. Consequently, he advised the commander to evacuate the aircraft through the right side doors. However, the damage to the left MLG was relatively minor, indicating that this was a fairly low temperature, short lived fire which appeared to have been contained inside the chin ring of the No 10 wheel.

Since taking delivery of AP-BGL, the operator had undertaken 125 wheel changes with only eight known incidences of brake fires; however, a small fire resulting from the venting solvent vapour, is difficult to see and it is possible that other incidences may have gone unnoticed. Nevertheless, a fire incident rate of around 7% following wheel changes suggests that the cleaning of Boeing 777 heat shields by immersion in solvent, rather than by wiping, was not common practice amongst the maintenance staff employed in the wheel overhaul facility. As a result of this incident, the operator recalled all their spare wheels and dried any suspect heat shields in an oven. It has been suggested that the weighing of heat shields would be sufficient to determine if the ceramic filler had been contaminated. However, laboratory tests showed that the entrapment of even a relatively small amount of solvent is a significant fire risk. The presence of such a small amount of solvent could be masked by the normal variation in the weight of the heat shields and thus this method of determining if solvent contamination is present is unlikely to be reliable. To

remove the possibility of such fires completely, it would be preferable for the heat shields to be cleaned with a water based detergent. However, if the recommended solvent is used, it is essential that operators follow the manufacturers instructions and take sufficient measures to prevent contamination of the absorbent ceramic filler.

In response to this incident, the operator has retrained their maintenance personnel and now use a steam cleaning process on the Boeing 777 wheel heat shields. The wheel manufacturer has also introduced a warning in the maintenance manual regarding the risks of dipping the heat shields in a flammable solvent.

### **The evacuation**

The evacuation of a large passenger carrying aircraft is, fortunately, a fairly rare event, but always worthy of serious consideration whenever one occurs. This is especially so when, as in this case, injuries, albeit minor, were sustained by both passengers and RFFS personnel. An investigation into such an event becomes more valuable should it have been recorded, as was the case with AP-BGL and, therefore, it was decided to examine the circumstances of the evacuation in detail. This was conducted with the assistance of an acknowledged expert in aircraft evacuation studies<sup>5</sup>.

#### **The decision to evacuate**

The decision to evacuate a passenger aircraft must rest with the commander and is not a decision that any commander, particularly of a large aircraft, would take lightly as, even in a well executed on-airfield evacuation, injuries may occur.

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#### **Footnote**

<sup>5</sup> Professor Helen Muir OBE MA (Hons) PhD CPsychol AFBPsS FRAeS, Professor of Aerospace Psychology, Director of the Cranfield Institute for Safety, Risk and Reliability, Head of Department of Human Factors, Director of Passenger Safety Group, Cranfield University, UK.

Due to the restricted view from the flight deck, the commander was unable to see events outside for himself and was reliant upon reports and advice from others. Being aware that another aircraft's crew had reported 'fire' in the landing gear, and with the RFFS Watch Commander recommending an evacuation, the aircraft commander effectively had no alternative but to order the evacuation.

Similarly the Watch Commander, was in a situation which demanded a rapid and effective analysis of the circumstances. Given that he did observe fire, at least initially, rather than evidence of heat alone in the landing gear, it was appropriate that he immediately contemplated the possibility of evacuation. Had he been absolutely satisfied that the apparent fire could be contained and extinguished, then it is probable that he would not have recommended the evacuation to the commander. Given that the firefighting taking place did not appear to reduce the severity of the 'fire', but rather that the volume of 'smoke' increased as firefighting went on, the Watch Commander had doubt about containing the 'fire', unaware that the 'smoke' was in all probability dirty steam coming from the hot brakes. Therefore, his decision to recommend an evacuation was understandable, and it was effectively communicated to the flight crew.

#### The evacuation process

Flight and cabin crews are generally aware that the most 'risky' periods during a flight are during the take-off and landing. At the conclusion of a long flight, both crew and passengers might be expected to be less mentally prepared for an evacuation than they would be at the start of the flight. In particular, as both the aircraft commander and the cabin crew had made their 'farewell' PA announcements, the cabin crew felt that the flight had to some degree reached its conclusion.

The commander communicated effectively with the purser and cabin crew, first instructing them to take their stations when the first signs of an impending problem presented themselves, and then by issuing the evacuation command by PA. However, the evacuation was not commenced immediately at all doors, but rather, the process of opening the doors and deploying the escape slides seemed to occur with a 'domino effect' towards the rear of the aircraft.

When interviewed, the cabin crew members who operated doors all recalled opening their respective doors on hearing the command to evacuate and the evacuation alarm. The fact that the door at the front of the aircraft was opened first, and that at the rear, last, suggests that the cabin crew also responded to the actions of their colleagues at adjacent doors, given that none of them perceived a threat or reason to evacuate the aircraft.

All of the slides operated by the cabin crew were effectively deployed and used, a situation which does not occur in over 50% of accidents<sup>6</sup>, and all of the passengers and crew were successfully evacuated. However, the speed of the evacuation was relatively slow, and was much longer than the evacuation time required to be demonstrated for certification<sup>7</sup>. Studies show that in the event of a major fire involving kerosene there may be less than two minutes before the conditions in the cabin would become non-survivable<sup>8</sup>. The apparent lack of an obvious reason to evacuate the aircraft seemed to instil a sense of normality, not urgency, amongst the cabin crew and passengers in this case and this factor alone probably contributed most to the relatively long

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#### Footnote

<sup>6</sup> NTSB Safety Study NTSB/SS-00/01

<sup>7</sup> Certification requires evacuation of a full load of passengers from 50% of available exits in 90 seconds

<sup>8</sup> AAIB report on accident to G-BGJL 8/88; WAAS report on accident to N388US, CAP479; ICAO Summary 1984-2; NTSB report on accident to N93119; et al

evacuation time. Other contributory factors included the sequential opening of the exits, limited dual lane use of the slides, passengers sitting rather than jumping onto slides, and hand baggage sent down slides.

### Safety Recommendations

The fire crew played an important role assisting passengers at the bottom of the slides and the evacuation would have been more difficult for the passengers, and more injuries may have been sustained, if this assistance had not been available. However, the video recordings showed that, once deplaned, most of the passengers congregated close to the slides towards the rear of the aircraft with the potential risk that further injuries could have inadvertently been caused by the activities of the RFFS personnel, fire or fumes, had the fire been sustained. The passengers subsequently walked to the busses located in front of the aircraft on the right side, and in doing so, passed directly downwind of the apparent fire. The RFFS are usually the first to attend the aircraft and would be best able to determine a safe area in which to collect passengers prior, in this case, to the arrival of paramedics and busses. However, the immediate responsibility of the RFFS is to save lives and, as stated in CAP 168:

*'this must assume at all times the possibility of, and need for, extinguishing a fire that may occur either immediately following an aircraft accident or incident, or at any time during rescue operations.'*

Hence, the RFFS manpower resources deployed to an event may, at some point, all be needed for firefighting duties.

In an evacuation such as this, the cabin crew are required to remain in the aircraft until the evacuation is complete. It would therefore seem appropriate that the immediate responsibility for the welfare of deplaned passengers should reside with specific airport personnel, designated by the Airport Authority. As airports such as Manchester are licenced in accordance with the CAA publication CAP 168, which includes the requirement for an Emergency plan, the following safety recommendation is made:

#### Safety Recommendation 2005-131

It is recommended that the Civil Aviation Authority review the advice given in CAP 168 in regard to aerodrome procedures for leading passengers, evacuated from an aircraft, to secure areas away from the scene of the incident and ensure that the relevant Aerodrome\ Emergency orders suitably address this topic.

The commander's decision to order the evacuation of the aircraft was based upon the information available to him at the time, and was made because he perceived that there was a real threat to the aircraft from the 'uncontained fire' in the left MLG. It is highly likely that in the commander's considerations, this risk to the aircraft and its occupants would have outweighed the risk that some passengers could be injured in the evacuation itself. Once such a decision is initiated, it is incumbent upon cabin crews to execute an evacuation as expeditiously as possible, irrespective of whether they perceive a risk to the aircraft or not. The relatively long time taken to evacuate the aircraft could have been reduced had all the doors been opened promptly and dual lane use made of the escape slides. The following recommendation is therefore made.

**Safety Recommendation 2005-097**

It is recommended that Pakistan International Airline Corporation review the training given to their cabin crews with the intention of ensuring that, in the event of an evacuation command being given by the aircraft commander, the evacuation is carried out as expeditiously as possible, irrespective of the lack of any threat to the aircraft perceived by the cabin crew.

Where an ATC service is provided on specific frequencies at such airfields as Manchester, there is a requirement for these frequencies to be recorded by the Airfield Authority, and for them to be held for 30 days, so that any data contained is available for investigative purposes following an accident or incident.

With the incident to AP-BGL, the Cockpit Voice Recorder (CVR) provided a recording of communications between the aircraft, ATC and the RFFS on 121.6 MHz, until the time at which both the aircraft's engines were shut down. Therefore, the investigation was able to confirm the recollections of the flight deck crew and RFFS Watch Commander's dialogue. However, had the CVR not been serviceable, or had the second engine been shut down sooner, no recording would have been available at what could have been a critical time. Clearly, communications on the promulgated RFFS frequency of 121.6 MHz may include critical decisions affecting safety, relating to matters such as evacuation, and a recording of such communications provides valuable information to those investigating such events.

Since 1989, the AAIB have made, on several occasions, safety recommendations relating to the provision and recording of radio frequencies used by the RFFS at major airports. Specifically, following the event at London Gatwick Airport, on 12 April 1988 (AAIB

Report No. 2/89) when a BAC 111 landed in error on the active taxiway at night, having mistaken it for the active (emergency) runway, one of the safety recommendations made (4.9) was as follows:

*'The radio frequencies used by the Airport Fire Service should be recorded at all major airports.'*

In response to this recommendation, the CAA stated:

*'The frequencies used for Air Traffic Control/ Airport Fire Service [AFS] communications are already required to be recorded. This recommendation is directed specifically at the frequency used to provide a direct, AFS to aircraft, communication link (121.6).*

*Provision of this direct link is not a mandatory requirement, nevertheless the Authority recommends that all major airports make such provision. We now propose to consult with the airport operators with a view to recommending that whenever this direct communication link is provided, it should be recorded.*

*Monitoring this communications link will of course also be covered by the aircraft CVR, but we appreciate that as in the case of this accident, the CVR record may not always be available.'*

As the provision and recording of a radio frequency for use by the RFFS and flight crews during emergencies remains a CAA recommendation, the following safety recommendations are made.

**Safety Recommendation 2005-092**

The Civil Aviation Authority should require at aerodromes, where the Rescue and Fire Fighting Category is 3 and above, or where an air traffic control

service is provided, that a radio frequency to facilitate direct communications between an aircraft and the Airport Rescue and Fire Fighting Service, in the event of an accident or incident to an aircraft on the airfield, is made available and appropriately promulgated.

**Safety Recommendation 2005-093**

The Civil Aviation Authority should require that any radio communication frequency used to facilitate direct communications between an aircraft and the Airport Rescue and Fire Fighting Service, in the event of an accident or incident on the airfield, should be recorded, in order that it may be reproduced to assist in accident and incident investigation.

**Safety Actions**

Since this incident, Manchester International Airport is reviewing its Emergency Plan, with regard to placing the local Hospital on standby when an Aircraft Ground Incident is declared. Also, the Manchester International Airport Emergency Planning Operations Sub-group is examining the functioning of the RFFS Crash Alarm system, with the intention of ensuring maximum speed of response and clarity of communication, consistent with current regulations.