AIRCRAFT ACCIDENT REPORT 2/82

Accidents Investigation Branch

Department of Trade

Report on the accident to McDonnell Douglas DC10-30 N 83 NA at London Heathrow Airport, on 16 September 1980

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ISBN No. 0 11 513506 5

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12 July 1982

The Rt Hon Lord Cockfield
Secretary of State for Trade

Sir

I have the honour to submit the report by Mr C C Allen, an Inspector of Accidents, on the circumstances of the accident to a McDonnell Douglas DC10–30 N 83 NA which occurred at London Heathrow Airport, on 16 September 1980.

I have the honour to be
Sir
Your obedient Servant

G C Wilkinson
Chief Inspector of Accidents

Accidents Investigation Branch

Aircraft Accident Report No. 2/82
(EW/C715)

Operator:		Pan American World Airways/National Airlines
Aircraft:	*Type:*	McDonnell Douglas DC10
	Model:	–30
	Nationality:	United States of America (USA)
	Registration:	N 83 NA
Place of Accident:		London Heathrow Airport
Date and time:		16 September 1980 at 1031 hrs
		All times in this report are GMT

Synopsis

The Accidents Investigation Branch was notified of the accident shortly after it occurred and an investigation was commenced on the same day. The United States Accredited Representative, together with his advisers, arrived in London the following morning and participated in the investigation.

The accident occurred at the beginning of a scheduled flight from London to Miami, when a tyre on the right-hand landing gear bogie burst during the take-off run. The burst was observed by the occupants of a runway clearance vehicle parked to one side of the runway, who transmitted the information to the control tower. This message was overheard by the aircraft commander who, as a result, rejected the take-off and brought the aircraft to rest about 110 metres before the end of the runway. A successful evacuation was carried out using the escape slides on the left-hand side, although one passenger suffered a broken leg. Two localised fires, which had developed in the centre and right-hand wheel bogies, were extinguished by the Airport Fire Service.

It is concluded that the accident was caused by the failure of number 8 tyre, on the right-hand landing gear, probably due to the combined effects of an overload condition on a previous flight and the tyre's high retread level and age. A contributory factor was the consequential failure of further tyres on the same gear.

1. Factual Information

1.1 History of the flight

The Pan American National Airlines DC10, N 83 NA, had arrived at London Heathrow at 0605 hrs, after a flight from Miami. The crew parked the aircraft on stand 27L at 0611 hrs and shut down the engines. During the four hours before departure on the return flight, PA 99, a normal turn-around inspection, which included a pressure check on all of the tyres, was carried out and revealed no abnormalities. No relevant faults had been recorded in the technical log from the previous flight.

Prior to departure, a change of operating and cabin crews took place. After the 220 passengers and 17 crew had boarded, the aircraft left the stand at 1017 hrs and was taxied along the inner taxiway to the holding point for runway 28 Right (28R), a distance of some 3¼ km. This route did not contain any unusually tight turns and there was evidence that no excessive speed or braking occurred. Upon arrival at the holding point, the aircraft (call-sign 'Clipper ninety-nine') was cleared to line up behind a departing aircraft and, four minutes later, was cleared for take-off (see Appendix 1). The co-pilot, who had been designated the handling pilot, opened the throttles, called for maximum normal power and released the brakes. The take-off roll began at 1029.56 hrs and the crew stated that, initially, acceleration was normal and all engine instruments were in the normal range for take-off.

The take-off was watched by a runway clearance vehicle (RCV), parked at block 24(0) (see Figure 1), which had been making a routine inspection of the runway for debris. An occupant of the vehicle saw debris from a tyre burst appear behind the right-hand side of the aircraft and immediately (1030.39 hrs) transmitted on the Heathrow Tower radio-telephony (RTF) frequency *'TOWER CHECKER NATIONAL DC TEN'S BURST ITS STARBOARD TYRE'*. The commander afterwards stated that on hearing an RTF call to the effect that his aircraft had burst a tyre and feeling severe vibration, at an airspeed that he believed to be about 155-157 knots, he took over control and abandoned the take-off. Evidence from the aircraft's Cockpit Voice Recorder (CVR) shows that, during the transmission from the RCV, V_1 * had been called by an unidentified crew member, but that the call was partially obscured by the RTF message, and by noise associated with the tyre problem. Eight seconds after the completion of the transmission from the RCV, the Tower controller called 'CLIPPER NINETY-NINE YOU'VE BURST A TYRE'.

Evidence from the Digital Flight Data Recorder (DFDR) shows that the commander's decision to abandon the take-off was implemented some 2½ seconds after the end of the transmission from the RCV, when the nose of the aircraft, which had been raised

* *Note: V_1, the decision speed, is the speed at which sudden complete loss of power from the critical engine is assumed to be recognised by the pilot (ICAO definition). It could also be defined as the speed above which, in an emergency situation, take-off is normally continued and below which it is abandoned. It had, in this case, been calculated by the crew as 160 knots.*

All speeds quoted in this report, unless otherwise stated, are indicated airspeeds.

about 2° shortly after attaining V_1, was lowered at about 168 knots (Appendix 2). Subsequently, full reverse thrust and hard braking were applied and the spoilers extended. 35° flap was selected at 95 knots. Reverse thrust was reduced and ultimately cancelled as the speed fell below 40 knots. The commander afterwards reported that full right rudder and some nosewheel steering were required to keep the aircraft straight. Witness marks indicated that, at about two-thirds of the way down the runway, the aircraft commenced a slight veer to the left, but that this was contained and corrected so that by the time the aircraft came to rest about 110 metres from the departure end of the 3900 metre runway, it had regained the centre-line.

Subsequent examination showed that all four tyres of the right-hand landing gear bogie had burst and one of them had ignited, causing a fire within the gear area. The brakes of the centre bogie had also caught fire.

As the aircraft came to a halt, the crew carried out the appropriate emergency drills, which included shutting down all the engines and retracting the spoilers. The commander asked the crew for a damage report and on being informed that smoke and flames could be seen on the right-hand side of the aircraft, ordered an evacuation using the left-hand emergency escape slides. The evacuation was completed successfully and promptly but a number of passengers and one cabin attendant received minor injuries and one passenger suffered a broken leg as a result of his descent down a slide. The landing gear fires were extinguished quickly by the Airport Fire Service.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	1	–
Minor/None	17	219	

1.3 Damage to aircraft

The tyres and wheels of the right main landing gear were destroyed and the braking systems considerably damaged. Debris from the right main gear tyres and wheels punctured the right mainplane, the right inboard flap, the right stabiliser and the intake and fan of No 2 engine. Damage was also caused to the remaining tyres, wheels and brakes as a result of the emergency stop.

1.4 Other damage

Some gouging of the runway surface occurred.

1.5 Personnel information

1.5.1 Commander:	Male
Age:	55 years
Licence:	Air Transport Rating, valid
Aircraft ratings:	Landplanes including DC 10–30, valid until 6.8.81
Instrument rating:	Valid until 6.8.81
Emergency equipment check:	Valid until 26.8.81
Medical:	Class I, valid until 12.5.81
Flying experience:	
Total flying:	31,711 hours
Total in command:	26,000 hours
Total on type:	3,918 hours
Total in previous 28 days:	92 hours.

1.5.2 Co-pilot:	Male
Age:	59 years
Licence:	Air Transport Rating, valid
Aircraft ratings:	Landplanes including DC 10–30, valid until 4.3.81
Instrument rating:	Valid until 4.3.81
Emergency equipment check:	Valid until 3.4.81
Medical:	Class I, valid until 5.11.80
Flying experience:	
Total flying:	12,400 hours
Total in command:	6,000 hours
Total on type:	3,443 hours
Total in previous 28 days:	67 hours.

1.5.3 *Flight Engineer (Checker):* Male

Age:	56
Licence:	Flight Engineer, Jet, valid
Emergency equipment check:	Valid until 5.8.81
Medical:	Class II, valid until 12.6.81
Flying experience:	
Total flying:	16,000 hours
Total on type:	3,289 hours
Total in previous 28 days:	21 hours.

1.5.4 *Flight Engineer:* Male

Age:	53 years
Licence:	Flight Engineer, Jet, valid
Emergency equipment check:	Valid until 13.12.80
Medical:	Class I, valid until 13.12.80
Flying experience:	
Total flying:	14,128 hours
Total on type:	2,168 hours.
Total in previous 28 days:	0 hours

1.5.5 *Crew rest periods prior to the flight*

Commander 26.30 hours	Flight Engineer (checker) 72.00 hours
Co-pilot 26.30 hours	Flight Engineer 72.00 hours

1.6 Aircraft information

1.6.1 Leading particulars

Type:	DC 10–30
Manufacturer:	McDonnell Douglas
Date of manufacture:	1975
Construction No:	46714
USA registration:	N 83 NA
Registered owner:	Pan American World Airways (PAA) since 24 January 1980
Airworthiness date:	16 June 1975
Airworthiness status:	Aircraft maintained in accordance with USA Federal Aviation Administration (FAA) approved Continuous Maintenance Program under Federal Aviation Regulation (FAR) 121
Total airframe hours:	20,664
Total cycles:	4,596
Engines (3):	General Electric CF6–50C.

1.6.2 Aircraft weight and balance

Maximum certificated take-off weight:	555,000 lbs (251,742 kg)
Airfield or WAT* regulated take-off weight:	555,000 lbs (251,742 kg)
Actual take-off weight:	520,500 lbs (236,095 kg)
Centre of gravity range:	10% – 22% Mean Aerodynamic Chord (MAC)
Centre of gravity at time of accident:	18% MAC

* *Take-off weight as limited by airworthiness climb criteria, taking into account airfield elevation and ambient temperature.*

1.6.3 The take-off parameters pre-determined by the crew were as follows:

Assumed take-off weight:	523,500 lbs (237,454 kg)
Flaps:	10°
Slats:	TAKE-OFF
Stabiliser trim setting:	5.9°
Engine N_1 setting	110.6 ('reduced power' take-off) (notional temperature 36°/37°C)
Engine max normal N_1	112.5 ('maximum normal' take-off power)
V_1:	160 knots
V_R	170 knots
V_2	180 knots

In the event, the crew used the maximum normal take-off thrust setting of 112.5 N_1 rather than the reduced thrust setting of 110.6 N_1. The difference in power produced by the two settings is small.

The values of V_1 and V_R, using the assumed take-off weight and notional temperature as derived from the company operations manual after the accident, are 160 knots and 168 knots, respectively. The revised values of V_1 and V_R at the actual take-off weight (reduced as a result of a last minute change to the loadsheet) and temperature (ie assuming the use of maximum normal take-off power) are 157 knots and 166 knots, respectively.

V_1, as derived from the aircraft's Flight Manual, can, under the accident conditions, be set at any value between 143 knots and V_R, due to the fact that the take-off was not being attempted at limiting weight.

1.6.4 *Aircraft maintenance*

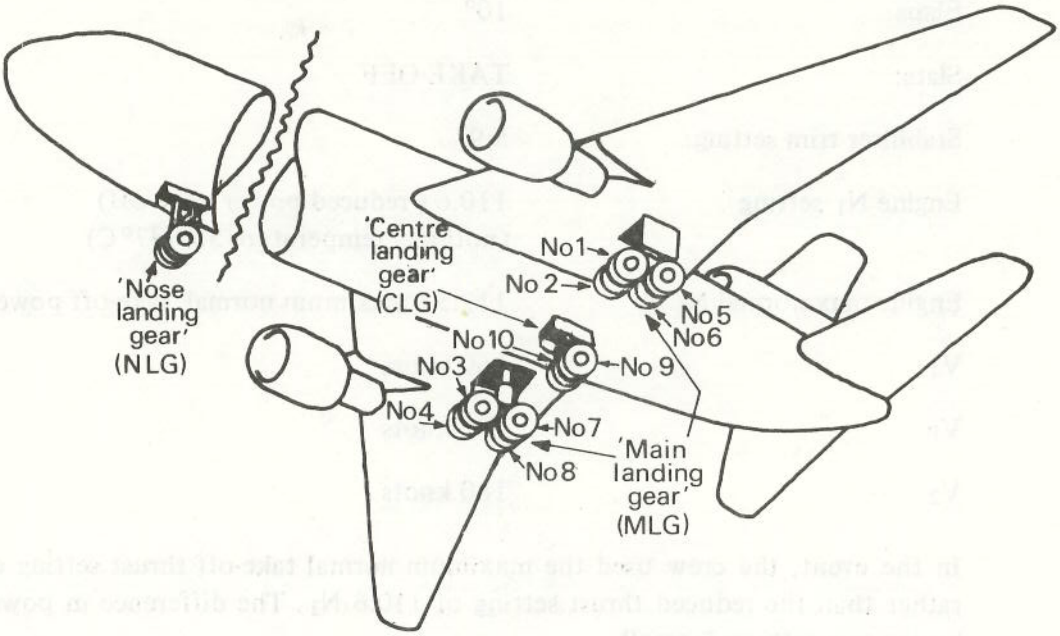
'A' check completed at Miami USA on 2 September 1980 at 20,502 airframe hours.

'P' check completed at Miami USA on 4 September 1980.

'Base' check completed at Miami USA on 8 September 1980.

'Turn around' check completed at London UK on 16 September 1980.

1.6.5 Tyre/Wheel identification



1.6.6 Tyre/Wheel data

	No 3	No 4	No 7	No 8
Manufacturer:	Goodrich	Goodrich	Goodyear	Goodyear
Size:	52x20.5–23	52x20.5–23	52X20.5–23	52x20.5–23
Serial Number:	8244AK1550	0028AK0864	43760440	43960393
Date of manufacture:	Aug 78	Jan 80	Sept 74	Sept 74
Rated load:	59,500lbs (26,989kg)	59,500lbs (26,989kg)	55,000lbs (24,947kg)	55,000lbs (24,947kg)
Ply rating:	28	28	26	26
Retread number:	Original	R–1	R–7	R–7
Install. date:	11.9.80	1.9.80	15.9.80	3.9.80
Landings:	13	24	1	21

None of the wheels fitted to the right-hand bogie were of the 'roll-flat' type.

1.6.7 *Tyre/Wheel maintenance*

A tyre pressure check was carried out during the 'turn-around' check performed at Heathrow, London, at 0800 hrs on 16 September 1980 and the following readings, in pounds per square inch (psi), were recorded by a supervisor after he had established that the pressures had been checked and were satisfactory:

Left main gear		Right main gear		Centre gear		Nose gear	
FWD (1)165	(2)165	(3)165	(4)165	LT	RT	LT	RT
AFT (5)165	(6)165	(7)165	(8)165	145	145	180	180
Recommended operating pressures							
165	165	165	165	145	145	180	180

Evidence from the engineer who performed the check was that the actual pressures were between 4 and 7 psi above the recommended inflation pressures.

Examination of the maintenance documentation for this aircraft did not reveal any indication of a pressure loss from the number 8 tyre since its seventh retread; nor was there any indication of heavy braking or hard landings having occurred.

On 11 September 1980 the pressure of number 3 tyre was found to be low (the actual figure was not recorded) and the wheel/tyre was replaced.

On 15 September 1980, during a 2 hour turn-around the pressure of number 7 tyre was found to be 30 psi below the minimum inflation pressure and the wheel/tyre was replaced. The actual pressure of number 8 tyre at this time was not recorded although it was checked and found satisfactory. The aircraft had carried out one take-off and one landing between the number 7 tyre pressure being checked and found within limits and being found 30 psi low.

There was no indication of any abnormal pressure loss from the number 4 tyre.

1.6.8 *Tyre/Wheel maintenance requirements*

National Airlines Line Service Manual, in line with McDonnell Douglas recommendations, states that tyre inflation checks will be accomplished at least once each day and at the originating station of all international flights. It also states that if a tyre is blown, or is found to be underinflated by 30 psi or more, and the pressure loss is known or suspected to have occurred while the aircraft was in motion, replacement of both tyres on that axle is mandatory.

The National Airlines Maintenance Policy and the McDonnell Douglas Aircraft Company recommendations are generally in line with those of the tyre manufacturers. However, it was noted that there was no commonality between tyre manufacturers' recommendations.

1.6.9 Tyre retread history

Because Nos 3 & 4 tyres were new and single retreaded respectively, their history is considered irrelevant to this accident.

No 7 Tyre, Serial number 43760440

Retread No	*History*
	The history prior to R–4 was not available.
R–4	The tyre was removed fully worn. Retreaded in February 1978.
R–5	The tyre was removed fully worn. Retreaded in August 1979.
R–6	The tyre was removed from service due to foreign object damage with only 10% wear. Retreaded in December 1979.
R–7	The tyre was removed fully worn. Retreaded in June 1980.

No 8 Tyre, Serial number 43960393

Retread No	*History*
	The history prior to R–2 was not available.
R–2	The tyre was removed with 90% wear and a flat spot. Retreaded in January 1978.
R–3	The tyre was removed from service due to foreign object damage with 80% wear. Retreaded in June 1978.
R–4	The tyre was removed fully worn. Retreaded in November 1978. The tyre was holographically inspected prior to return to service.
R–5	The tyre was removed from service due to foreign object damage with 70% wear. Retreaded in April 1979.
R–6	The tyre was removed fully worn and with a flat spot. Retreaded in October 1979.
R–7	The tyre was removed fully worn. Retreaded in June 1980.

Tyre processing records for No 7 and No 8 show nothing abnormal either in processing or condition on receipt. The foreign object damage noted was reported by the retread facility at Thompson Aircraft Tyre Corporation, Miami, Florida, to be minor in nature and did not effect the tyre carcass integrity.

1.7 **Meteorological information**

The relevant conditions as supplied to the crew for the purposes of the take-off calculations were:

Zero headwind component and a temperature of 20°C.

The wind condition as registered by the anemometer positioned near the 28R threshold (north-east site) and passed by Air Traffic Control (ATC) to the crew for take-off was:

south-westerly at 15 kts.

A full meteorological observation taken immediately after the accident gave:

Wind:	210° at 11 kts (recorded at south-west site)
Visibility:	15 km
Weather:	Recent rain
Cloud:	2 octas at 2,200 feet 5 octas at 8,000 feet 8 octas at 12,000 feet
Temperature:	Dry bulb 19°C Dew point 13°C
Airfield atmospheric pressure (QFE):	1015 mbs
Conditions:	Daylight; runway dry.

The airport buildings at Heathrow are south of the 28R runway. It is known that, when the wind direction is between south-east and south-west, an irregular pattern of both wind direction and strength is created along the runway, in the lee of the terminal buildings.

1.8 **Aids to navigation**

Not applicable.

1.9 **Communications**

The radio telephony channels available and in use at the time of the accident were:

'Heathrow Ground' – 121.7 MHz – 'start-up' control

'Heathrow Ground' – 121.9 MHz – 'taxy' control

'Heathrow Tower' – 118.5 MHz – 'take-off' and runway control.

1.9 (cont) PA99 first called the Tower on 118.5 MHz at 1026 hrs, and remained on this frequency until it closed down transmission at about 1032 hrs, when the aircraft had come to rest. Communications to and from ATC remained standard until the RCV transmitted *'TOWER CHECKER, NATIONAL DC TEN'S BURST ITS STARBOARD TYRE'* (1030.39 hrs); ATC repeated this information to the aircraft some 8 seconds later and about 5 seconds after the take-off had been rejected. The subsequent communications between ATC and the aircraft, shown in detail at Appendix 1, reveal a degree of misunderstanding caused by a combination of the internal noise and vibration in the aircraft and the fact that the commander was using a hand-held microphone. This, however, did not influence the sequence of events.

The RVC was being controlled by ATC on the Tower frequency 118.5 MHz and therefore its transmissions could be heard by the flight crew of PA99.

The police vehicles and fire vehicles can be controlled on 118.5 MHz or any other airport frequency as well as having their own discrete frequencies. The watchrooms of both services are also connected to ATC by a crash line telephone, as is the internal exchange. Although immediate notification of the accident was passed at 1032 hrs on this line, the police had already intercepted the message from the RCV at 1030.39 hrs.

1.10 Aerodrome information (see Figure 1)

1.10.1 *The paved surfaces*

The stand designated 27L, upon which the aircraft had been parked, and the inner taxiway, between the stand and the runway threshold, a distance of some 3¼ kilometres, are inspected daily; they were also especially searched subsequent to the accident. This search did not reveal any surface damage or foreign object which could have contributed to the tyre failure on PA99, nor did the route followed by the aircraft necessitate any abnormally tight turns or severe braking.

The runway description is as follows:

Dimensions:	3902 x 91 metres
Elevation:	Minus 30 feet (pressure altitude)
Gradient:	Plus 0.02%
Threshold:	Not displaced
Surface conditions:	Good
Braking co-efficient:	Good
Surface type:	First 2905 metres: bitumen asphalt with friction course next 83 metres: grooved surface final 914 metres: concrete
Remarks:	Recent rain had not caused pooling and the surface was reported to be dry

1.10.1 (cont) The take-off run available (TORA), the take-off distance available (TODA) and the emergency (stop) distance available (EDA) are all 3902 metres.

1.10.2 *The runway clearance vehicle (RCV)*

The duty of the RCV is, under ATC guidance, to ensure cleanliness of the runway in use. For this reason the vehicle, prior to the accident, had been progressing up the active runway, in an easterly direction, looking for any debris left by either departing or landing aircraft. At the time of PA99's take-off, the RCV was parked clear of the runway, and on the southern side of it, at block 24(0). This placed it about half way down the runway length. It was from this position that the tyre problems of the DC10 were first observed.

1.11 Flight recorders

The aircraft is fitted with a Sundstrand V557 CVR, which uses the FAA track allocation, and with a Lockheed 209 DFDR, which records the following parameters:

> GMT, altitude, airspeed, total air temperature, heading, pitch angle, roll angle, horizontal stabiliser position, elevator position, rudder position, engine speeds, g, lateral acceleration, longitudinal acceleration, flap position, slat position, thrust reverser position, RTF transmit key event, error flags for speed, altitude and temperature readings, event marker.

All parameters were read out successfully. Relevant sections of the graphical read-out of the FDR are shown at Appendix 2. A diagram showing the aircraft's performance, including significant events deduced from runway markings and debris, and from the DFDR and CVR, is at Appendix 3. The accuracy of the time correlation between the DFDR and CVR is estimated to be within half a second.

Subsequent to the accident, the Auxiliary Power Unit (APU) of the aircraft was re-started in order to facilitate recovery. This supplied electrical power to the CVR, which retains only the previous 30 minutes recording, thereby erasing all information except that commencing from the time just after the aircraft lined up for take-off. Relevant extracts from the CVR transcript are shown on the diagram at Appendix 3.

1.12 Wreckage and impact information

1.12.1 *On site examination*

1.12.1.1 *Wreckage trail and runway marks* (see Figure 2)

The wreckage trail consisted of the remains of the tyres, wheels and brakes from positions 3, 7 and 8 together with hydraulic and electrical items from the right gear area. Details are given below, the distances being in metres from the beginning of the runway:

1.12.1.1 (cont)	1098 metres	– Tyre number 8 started to throw its tread
	1433	– Scuff marks on the runway indicated that the number 8 tyre had deflated
	1707-1890	– Debris from number 8 tyre started to decrease in quantity and the first pieces from number 7 tyre were found
	1890-1920	– Pieces of number 8 tyre carcass and number 7 tyre tread with the inner tyre liner were found
	1920 approx	– A small piece of the number 7 wheel rim, an anti-skid accumulator gauge dial face and the lower rear corner of the right main gear fly (fixed) door were found
	1930	– Scuff marks on the runway from number 7 tyre indicated that it was deflated
	1932	– Number 8 tyre scuff marks had become uniform, heavy and continuous, indicating that the wheel was skidding
	1938-1952	– Numbers 7 and 8 wheel rims contacted the runway
	1982-2105	– Pieces of number 3 tyre tread and side wall were found, together with pieces of wheel rim, brake cooling plates and some protective covering from hydraulic pipes
	2028	– Marks on the runway indicated that the rims of numbers 7 and 8 wheel were starting to break up
	2090	– Broad tyre skid marks on the runway in the number 7/3 wheel position indicated that tyre number 3 was deflated and breaking up
	2100-2600	– Pieces of tyre from numbers 7 and 3, a wheel rim, brake cooling plates, hydraulic pipe protective covering and pieces of number 2 engine intake liner were found. Marks on the runway showed the continuing break-up of numbers 7 and 8 wheel rims
	2592	– Wheel rim track marks showed that the aircraft had started to veer to the left
	3264	– Wheel rim track marks indicated that the left veer had stopped
	3446	– Marks on the runway showed that number 3 wheel rims had contacted the runway, number 4 tyre was producing a continuous heavy rub mark and that the aircraft had started a veer to the right. There were also indications of moderate to heavy braking taking place at the left main gear.

1.12.1.1 (cont)	3538-3721	–	Pieces of number 4 tyre, complete from outer tread to inner liner and pieces that were charred from fire damage, were found
	3790	–	The aircraft came to rest with the nose and centre gear wheels on the runway centre-line

1.12.1.2 Aircraft

Examination of the landing gear showed that all the main gear brake units except numbers 3, 7 and 8 had sustained heat damage and that number 2 unit was unable to rotate freely due to sintered brake material expansion caused by severe overheating.

There was clear evidence of fires having taken place in areas of the centre and right main gears.

Both centre and right main gears had moderate to heavy hydraulic fluid leakage from the areas of the brake packs.

The right main gear wheels had suffered severe damage consistent with rolling for a considerable distance with deflated and missing tyres (Figure 3).

The tyres from wheel numbers 3, 7 and 8 were missing except for the bead and ply turn-ups of number 3 tyre. The majority of the tyre from number 4 wheel was on the wheel rim but it was deflated, severely abraded in the area in contact with the runway and badly fire damaged.

The numbers 7 and 8 wheels had similar damage in that both inner and outer rims were missing, the majority of the inner and outer bead seat areas were missing, all the brake cooling plates were missing and the brake assemblies were exposed. The remains of the wheels had severe abrasions consistent with prolonged rolling contact with the runway. The number 3 wheel had similar damage to numbers 7 and 8, but not as severe; more of the bead seat area was present and it was less abraded. The number 4 wheel was complete except for an area of inner and outer rim and bead seat area that had been abraded away. This area corresponded to the area of abraded tyre.

The exterior of all the brake assemblies of the right main gear had only minimal damage. Two pistons were missing from the brake assembly of number 3 wheel and one from number 7. All the brake hydraulic pipes had suffered impact and fire damage and two of the inboard pipes had been fractured.The rear anti-skid electro-hydraulic unit from the right gear had impact damage which disconnected the electrical input; this anti-skid unit had no protective shield fitted. Both anti-skid wheel transducer electrical harnesses had sustained damage.

The right main gear fly (fixed) door had fire and impact damage. A piece (approximately 0.06 m^2) was missing from the lower rear edge and 50% of the door was fire damaged.

Debris had damaged the right inboard flap, right elevator, right stabiliser, right rear lower fuselage and the intake and fan blades of number 2 engine.

1.12.1.2 (cont) All slide/rafts had been removed from the aircraft and placed on the grass before the arrival of AIB personnel. Examination of photographs that were taken a short time after the evacuation showed that numbers 2, 3 and 4 slide/rafts were fully inflated and in their correct evacuation positions (Figure 4). Number 1 slide/raft was removed before it could be photographed, but evidence from eye-witnesses suggests that it, also, had inflated fully and had been in the correct evacuation position.

1.12.2 *Detailed examination*

1.12.2.1 *Tyres*

The remains of the tyres from wheels number 3, 4, 7 and 8 were sent for detailed examination to the Transportation System Centre (TSC), Cambridge, Massachusetts, USA. The results are given under 'Tests and Research', paragraph 1.16.3.

1.12.2.2 *Wheels*

All the fractures were examined and no evidence of pre-emergency defect or pre-existing overload could be seen. Each of the wheel assemblies from positions number 3, 4, 7 and 8 were examined, stripped and had their components tested.

The wheels were split and the 'O'–ring seals did not show any evidence of air leakage.

The inflation valves were pressure tested and found to have no leakage.

The overpressure valves were pressure tested and those from wheels number 3 and 4 were found to have no leakage. The valve from wheel number 8 had suffered damage and blew at approximately 140 psi when tested. The valve from wheel number 7 was found to have an air leak which equated to a pressure loss at sea level of 12 to 15 psi per week.

The thermal plugs from wheels number 3, 7 and 8 were examined and found not to have melted. Pressure testing revealed no leakage. The plugs from wheel number 4 were found to have melted, but only after the pressure had been released from the tyre.

All valve and plug wheel seats and 'O'–rings revealed no defect or evidence of air leakage.

1.12.2.3 *Brakes*

The brake packs from number 3, 4, 7 and 8 wheels were taken to the Goodyear Tyre & Rubber Company's (Great Britain) facility at Heathrow Airport, London, for a strip inspection and the following observations were noted:

The brake packs from number 3, 7 and 8 wheels appeared to have peformed normally and without above average high energy inputs. There was no evidence of dragging/overheating. The number 3 wheel pack was covered with oxide deposits due to the use of fire extinguishers. There was evidence from the retraction of alternate cylinder sleeves on number 3 and 7 wheel packs that only one hydraulic system was operative during the latter stages of the braking operation. The wear pins had extensions of 26 mm, 38 mm and 34 mm respectively.

1.12.2.3 (cont) The brake pack from number 4 wheel exhibited good evidence of having been involved in a fire. The wear pin was in the flush position and all the rotating discs showed 100% wear, indicating that the aircraft must have started its take-off roll with the assembly near its minimum wear extension. There was evidence of high energy inputs to the assembly; this may possibly have initiated a brake fire. There was no evidence to suggest that a dragging condition was present before the rejection, as the grips and tubes were tested satisfactorily and no excessive dishing/shrinkage of the discs was noted.

During the detailed examination of the brake assemblies, no evidence of any pre-existing defect was found.

1.12.2.4 *Service centre (galley)*

The forward service centre cupboard door and drawer fittings and fasteners were examined aboard the aircraft. Each cupboard door and drawer had a single fastener which was of the flush door, snap close, type. All of them were badly worn, consistent with heavy use; two were ineffectual when a moderate force was applied. Also, due to wear, three of the doors/drawers were difficult to place in the closed/secure position. The bottom drawer of the unit was found to be incorrectly fitted onto its guide rails and impossible to close and secure correctly.

1.12.2.5 *Slides/rafts*

The results of the examinations of the slides/rafts are contained in paragraph 1.16.2.

1.13 Medical and pathological information

The crew all possessed valid medical certificates and there is no evidence which suggests that they were other than medically fit. They had had an adequate rest period before the flight.

The passengers successfully evacuated the aircraft, but 29 passengers and one flight attendant received minor injuries, mainly abrasion burns, during the descent down the various slides. One passenger suffered a broken leg, as a result of his descent, at the foot of slide No 1.

1.14 Fire

Two serious fires occurred, one in the area of the right-hand landing gear assembly, the other in the centre gear assembly. The left-hand gear assembly had overheated but displayed no evidence of fire having occurred.

The first fire was initiated in the No 4 wheel assembly, either by the heat from No 4 brake or that generated by the tyre skidding on the runway for the last 350 metres of the aircraft's ground run, or possibly both. However, in spite of severe discolouration of the brake discs, the balance of visual evidence favours the suggestion that the fire started at the tyre itself.

1.14 (cont) The second fire took place in the centre gear assembly. This was initiated by heat from the brakes and possibly fed by hydraulic fluid, leaking from the brake packs.

The evidence displayed by the runway debris indicated that the fire in the right-hand gear started at the 3530 metre point on the runway, and that in the centre gear, as the aircraft came to rest. These fires were not initially detected by the crew until advised by the Tower.

At Heathrow, the main Fire Station headquarters (HQ) is situated on the north side of the airport, with a sub-station in the central area, near to the end of Pier One.

At approximately 1032 hrs, the Fire Service Watchroom initiated emergency action and the Airport Fire Service vehicles proceeded to the accident site. The route followed by the vehicles from HQ was via Block 1 and Block 9, where they entered the runway, then along that runway to the accident site at Block 112. The sub-station vehicles routed past Pier 7, Blocks 70(I), 60(I), 52(I), 36 and 9 to 112.

The first vehicles to arrive on site were two foam tender pumps which were positioned fore and aft of the right-hand gear assembly of the aircraft. Side lines were deployed and water spray was used to extinguish the fire. Additional lines were provided by these two appliances and also by a Rapid Intervention Vehicle (RIV); they were used to combat the situation encountered in the centre and left-hand gear assemblies.

The fires were quickly extinguished and the Watchroom was sent a 'Stop' message at 1038 hrs. A total of 6 sprays were used, the water being supplied by a fire hydrant north of Block 112 and a third foam tender pump.

In all, approximately 6000 gallons of water were used to extinguish the fires and cool the gear assemblies. The Airport Fire Service supplied ten vehicles. A further 17 vehicles were provided by the London Fire Brigade, but, in the event, were not required.

1.15 Survival aspects

1.15.1 The evacuation

The evacuation was carried out according to the company training instructions and was successful, all personnel being evacuated within 90 seconds; it was not possible to obtain a more precise time estimate. Because of the unknown nature of the fire on the right-hand side of the fuselage, the commander had ordered that the evacuation should be carried out using only the left-hand side slides. This evacuation was achieved rapidly and in a generally orderly fashion; however, the service centre drawers flew open during the deceleration, seriously hindering the passage of persons across the aircraft: this problem was subsequently found to have been caused by worn catches. The matter has been brought to the notice of the operator. The one serious injury, the passenger with the broken leg, was taken to Ashford hospital by a British Airports Authority (BAA) ambulance and of the minor injuries, 8 were treated at the Queen's Medical Centre and 2 were taken to Ashford by the London Ambulance Service. The remainder did not require medical attention.

1.15.2 *The escape slides*

Although all the slides on the left-hand side of the aircraft were deployed and successfully used, a number of difficulties in their operation were reported by the flight attendants:

(i) No 2 slide kinked into an 'L' shape when it contacted the ground and needed external assistance to straighten it out. It must however be noted that the slide was ejected into wind.

(ii) No 3 slide required the inflation of the overwing ramp to be manually operated and the flight attendant subsequently stated that the inflation indicator-patches had been difficult to see and were not of the colour expected.

(iii) No 4 slide's ejection straps did not operate to the satisfaction of the flight attendant, so he physically pushed the 'pack' over the door sill in order to start the inflation sequence.

(iv) All the flight attendants expressed surprise at the length of time which the slides required to achieve full inflation and their apparently steep angle when deployed.

As a result of the above reports, detailed inspection and tests were carried out at the PAA engineering base in Miami, in the presence of representatives from AIB, PAA and the slide manufacturer. The results are detailed in paragraph 1.16.2.

1.16 **Test and research**

1.16.1 *Performance considerations*

An expert who had been researching the effect of the Heathrow central area buildings on the wind velocities encountered along the airport runways gave as his opinion that, in the comparatively light south-westerly wind conditions existing at the time of the accident, the component along the runway could be assumed to be approximately halved in the lee of the central buildings and unaffected elsewhere. Allowing for the difference in height between the anemometer and the aircraft sensors, this would give a headwind component of about 4ft/second (2.37 knots) along the first 1,500 metres of the runway and 8ft/second (4.73 knots) thereafter.

On this assumption, a comparison was made of the aircraft's groundspeed obtained by integrating the longitudinal acceleration, using throughout a constant zero error of –0.030g (the mean of the readings while the aircraft was stationary on the runway), with that obtained from the DFDR indicated airspeed, during both the accelerating and decelerating phases of the rejected take-off. This comparison showed good linear correlation between the two values of groundspeed and also indicated that the ratio of the accelerometer reading to the acceleration derived from the airspeed was constant and approximately equal to 0.88.

1.16.1 (cont) A comparison of the acceleration phase, up to V_1, with the measured take-off performance of another DC10–30 and with the calculated performance using the manufacturer's co-efficients, gave good agreement.

Subsequently, using the DFDR airspeed trace, the assumed windspeed variation and a computer model, a curve was constructed of true airspeed (TAS) against time and distance along the runway, assuming the start of the take-off roll to be 45 metres from the beginning of the runway (see Appendix 3). This gives an overall distance to the final stop of 3750 metres, which compares closely with the measured stopping point of 3790 metres from the beginning of the runway.

Further calculations showed that, under the accident conditions, the balanced field length required for a V_1 of 160 knots (ie runway length required to accelerate to 160 knots and then stop in the shortest possible distance, assuming standard reaction times and use of full wheel braking and reverse thrust) would be about 2840 metres.

Assuming full wheel braking (and reverse thrust) had been available throughout and had been applied at the same times as on the subject take-off attempt, it is calculated that the aircraft would have stopped at about the 3400 metre point along the runway.

Post-accident calibration of the airspeed indicators (ASI's) showed that the commander's instrument read about 1 knot high, and the co-pilot's ASI nearly 1 knot low, between 160 and 170 knots. In the same speed range, the aircraft's TAS is approximately equal to corrected IAS, therefore the commander's ASI would have been reading about 1 knot higher than the aircraft's TAS at any given moment, and the co-pilot's ASI approximately 1 knot lower than the TAS. In the diagram at Appendix 3, TAS has been shown in preference to IAS because, during the decelerating phase, IAS suffered from errors due to abnormal static pressures caused by the effect of reverse thrust.

1.16.2 *The escape slides*

Although it was not possible to carry out an inflation check on the No 1 slide, because of damage sustained during its recovery, the other 3 slides inflated normally when workshop tested.

All the operating cylinders were recharged and together with the regulator valves and aspirators (outside-air induction system), were operated and found to be satisfactory. The regulator valve assemblies were also strip examined and showed no abnormalities.

Slide 3 was fired manually and operated normally. The reason for the failure of the automatic sequencing is known and modification, at overhaul, is in hand. This particular slide had not yet become due for overhaul. No 3 slide is situated in the overwing position and does not always deploy far enough from the door sill to give sufficient movement to cause the firing lanyard to operate. The PanAm National Airlines Flight Attendant Manual describes the inflation indicator patches as orange. Those from the accident aircraft could perhaps best be described as of a dark pink colour which, according to the manufacturer, has not varied during the course of production.

1.16.2 (cont) Slides Nos 2 and 4 (interchangeable). It is noted that, during the normal automatic firing sequence, the slide pack does appear to stand, for a period, poised on the door sill, until the door is fully open and the straps tighten to throw the pack out. Thereafter, until full inflation is attained, the slide takes up an awkward and distorted shape, thereby appearing to be malfunctioning. When fully deployed, and resting on the ground, the slide angle does appear to be steep. In this connection, it is noted that the flight attendant's school does not demonstrate an actual firing, but uses a slide which is inflated flat on the ground.

Tests have shown that, in the most adverse case of a completely collapsed main landing gear, with nose gear and opposite main landing gear down and locked and centre gear retracted, none of the slides would exceed a 50 degree angle from the horizontal.

1.16.3 *The tyre failures – general*

At the request of the AIB, the NTSB arranged for the Transportation Systems Center (TSC) of the USA Department of Transportation to perform a failure analysis of the tyres on the right-hand landing gear. This was carried out mostly in the presence of AIB, and partially observed by representatives from NTSB and the two tyre manufacturers, Goodyear and B F Goodrich, together with Thompson, the retread organisation, and the operator, Pan American.

This analysis involved such items as visual and microscopic inspection, materials testing and analysis, including cord strength measurements and cord to rubber adhesion tests (peel tests), dynamic analysis of the tyre/bogie/aircraft interaction and accident circumstance analysis.

The examination of the tyres, together with the markings and debris location on the runway, showed that:

(i) The tyre of the number 8 wheel failed first; evidence of excessive cord fatigue and overheating in the shoulder area within the R–7 tread life period strongly implied a previous overload condition.

(ii) A high number of retreads and tyre age adversely affected the survivability of tyre number 8.

(iii) The tyre of number 7 wheel failed from overload, exacerbated by age. The trigger mechanism was possibly foreign object damage (FOD) from a distintegrating tyre.

(iv) The tyre of number 3 wheel failed, apparently, from foreign object damage.

(v) The tyre of number 4 wheel wore through sufficient plies in a locked brake mode to cause failure. It subsequently caught fire from self-generated heat.

1.16.4 *The tyre failures – dynamic considerations*

The TSC, as part of their investigations, asked the University of Michigan Department of Applied Mechanics and Engineering Science to determine, through inspection, measurement and analysis, the forces on the other tyres of a DC10–30 bogie when one tyre fails. Conclusions from this study indicate that the accepted values of static loads (see Figure 5) are approximately correct and that dynamic effects during free rolling or braking cause no major change from the static values.

McDonnell Douglas assessed, by computer wind tunnel co-efficients, that the following changes in main gear loading could occur under the conditions shown:

			*Main gear single tyre loads **
Aircraft all-up weight	–	520,500 lbs (236,094 kg)	51,062 lbs (23,161 kg)
Static main gear loading	–	469,000 lbs (212,734 kg)	46,010 lbs (20,870 kg)
During rotation at 159 kts	–	460,000 lbs (208,651 kg)	45,127 lbs (20,469 kg)
Peak loading when spoilers & brakes are applied (reverse thrust effect excluded)	–	581,900 lbs (263,944 kg)	57,085 lbs (25,893 kg)

1.16.5 *Tyre pressure gauge*

The tyre pressure gauge used to check the inflation pressures at Heathrow during the turn-around check on 16 September 1980 was subjected to a calibration check and found to be within limits (± 1%).

1.16.6 *Tyre pressure increase after landing*

From tests conducted by the TSC, the pressure immediately after landing of a 52 x 20.5–23 tyre with a rated inflation pressure of 165 psi would be in the order of 180 psi. One hour after landing it would be in the order of 172 psi. These figures are very approximate, as there are a large number of variables to be taken into account which are specific to each landing.

* *AIB estimates*

1.17 Additional information

1.17.1 Accelerate-stop distances

Prior to 1 July 1979, public transport aircraft were certificated, in the United Kingdom, according to the provisions of British Civil Airworthiness Requirements (BCAR) and, in the USA, according to the Federal Airworthiness Requirements (FAR). The sections in these two documents, relevant to performance requirements for the accelerate-stop ('rejected' or 'aborted' take-off) case, differ insofar as BCAR take into account wet runway conditions, whereas FAR do not.

In 1979, the UK and some other European countries adopted, whilst providing for filed 'differences', a combined set of requirements known as Joint Airworthiness Requirements (JAR). The requirements laid down in this document are applicable only to aircraft for which certification was requested after 1 July 1979, or to the aircraft of those manufacturers who voluntarily applied them prior to that date; they do not apply retrospectively. The United States adhered to FAR.

1.17.2 Service Bulletins

Prior to the accident, the McDonnell Douglas Aircraft Company issued a number of Service Bulletins that provided improved integrity and protection to systems on the landing gear and in the landing gear bay. Only one of these Service Bulletins was made mandatory by an Airworthiness Directive in the United States of America whereas all of them, with one exception, were made Additional Directives in the United Kingdom and therefore mandatory. One of the Service Bulletins detailed the installation of a protective shield to the brake anti-skid manifolds mounted on the landing gear leg. Only the FAA Airworthiness Directive, requiring the fitment of non-return valves on numbers 1 and 3 hydraulic systems and the re-routing of some hydraulic pipework, had been complied with on this aircraft.

1.17.3 Hand-held microphones

On 12 September 1980, another DC10–30, in an emergency situation, departing from London (Heathrow) on the same schedule, PA99, also experienced poor RTF communications as a result of the use of a hand-held microphone. Because this seriously affected aircraft operations, Heathrow ATC filed a Mandatory Occurrence Report (MOR).

The UK Air Navigation Order, Article 35(7), states that UK registered aircraft, flown for the purpose of public transport, shall not use a hand-held microphone in controlled airspace below flight level 150 or for take-off or landing.

1.17.4 Accident to a Continental Airlines DC10–10 at Los Angeles on 1 March 1978 (NTSB report AAR–79–1)

The Continental flight 603 overran the departure end of runway 6R, following a rejected take-off. The take-off was rejected just before the aircraft attained the V_1 speed of 156 knots. As the aircraft departed the wet, load-bearing surface of the runway, 1.17.4 the left main landing gear collapsed and fire erupted from the left wing area. The aircraft slid to a stop about 664 feet past the departure end of the runway. Of the 200 people on board, 2 passengers were killed and a number of passengers and crew seriously injured.

The NTSB determined that the probable cause of the accident was the sequential failure of two tyres on the left main landing gear and the resultant failure of another tyre on the same landing gear, at a critical time during the take-off. A contributory factor was the cumulative effect of the partial loss of aircraft braking because of the failed tyres and the reduced braking friction available on the wet runway surface.

As a result of the accident, the NTSB made fourteen Safety Recommendations, a number of which have been implemented, either in part or in whole. Because most of them are relevant to the subject accident, they are attached as Appendix 4.

1.17.5 *Incident involving Air Florida DC10–30 at Gatwick, London on 12 August 1981*

A DC10–30 on a scheduled flight from Miami to London landed at Gatwick and during the landing run numbers 3 and 4 tyres deflated in fairly rapid succession. Examination of the aircraft revealed that the only serious damage to the airframe was to the fan of number 3 engine, damage to brake hoses on the right landing gear and minor indentations to the right flap, inboard aileron and a non-structural inspection panel. The approximate landing weight was 391,500 lbs (177,580 kg) and the two tyres failed at approximately 80 knots. The rims of number 4 wheel were a combination of original specification inner rim and semi non-frangible outer rim. Both rims were in contact with the runway. The inner semi non-frangible rim survived a 1900 metre roll whereas the outer rim broke up. Both number 3 wheel rims were of original specification and both remained intact due to the beads of the tyre having remained on the rims, cushioning them from the runway surface.

2. Analysis

2.1 General

It is noted that, during their pre-take-off calculations, the crew adjusted V_R upwards from 168 knots to 170 knots to make a 'round figure'; and that, later, they did not adjust their pre-calculated take-off speeds following the last minute reduction to the aircraft's estimated take-off weight and the commander's decision to use maximum normal take-off power instead of reduced power. Although these practices could not be condoned had the take-off been attempted at a weight limited by aircraft performance or runway length considerations, in the subject case there was a considerable margin in reserve in both respects and, accordingly, the crew's actions as regards these take-off speeds must be considered as entirely reasonable.

The evidence indicates that the aircraft's performance during the early part of the take-off run was normal until the commander heard the RTF message from the RCV to the effect that his aircraft had burst a tyre and took the decision to reject the take-off at a speed he believed to be just below V_1. In fact, the RTF message coincided with, and overlapped, the call 'V_1'. The commander, being the non-handling pilot, would, under normal company procedures, have made the call himself; but it appears that his attention was pre-occupied by the transmission from the RCV and that he did not hear the call, which must have been voiced by one of the other crew members. However he would certainly have known that the aircraft was close to attaining the V_1 speed.

Detailed examination of the evidence from the DFDR has shown that the nose was raised shortly after V_1; it is concluded that this action probably emanated from a belief on the part of the co-pilot that the vibration the crew were then experiencing may have been due to contact with the runway centre-line lighting. The first action in the reject procedure, a down elevator movement resulting in the lowering of the nose, occurred at an IAS some 8–9 knots above V_1 and about 3½ seconds after reaching this 'decision speed', above which the take-off should normally have been continued. It should be remarked that only 2½ seconds elapsed between the end of the RTF call and the start of the reject procedure; also, that the commander took the decision to stop in the knowledge that the runway length was not a limiting factor for this particular take-off. The balanced field length, or runway length required to accelerate to the scheduled V_1 speed of 160 knots and then stop, was only some 2850 metres out of a total runway length available of 3900 metres. In the event, due partly to the higher speed at which the take-off was rejected and partly to the reduced braking capacity available as a result of successive tyre failures, the aircraft came to rest 110 metres from the runway end. Appreciating that he could stop the aircraft before the end of the runway, the commander had begun to cancel reverse thrust as the speed passed 40 knots, but this action would have had little effect on the overall stopping distance. Conversely, the selection of the flaps to 35° at a speed as high as 95 knots may have slightly increased this distance.

Had the commander decided to continue the take-off he would than have had the time to consider the various options such as taking the flight on to its destination, diverting to another airfield, or jettisoning fuel and landing back to Heathrow at a lighter weight and a comparatively low speed, with less risk of wheel or brake fires. However, he was not in a position to know the amount of damage to the aircraft that he would have been taking into the air; as it happened, this was confined to the right main landing gear, but could well have been more widespread. It is therefore concluded that, in the circumstances, the commanders' decision to reject the take-off was justified. The entire subject of tyre failures during the take-off run and related decision speeds is an extremely complex one and, accordingly, is discussed in more detail.

The evidence suggests that, the decision to reject the take-off having been made, the flight deck and cabin crews carried out their duties in a generally professional manner. The evacuation was completed within 90 seconds, the time required to be achieved during demonstrated evacuations for certification purposes. That there were a number of comparatively minor injuries was unfortunate, but was to be expected in such an emergency. The one serious injury, to a passenger who sustained a broken leg, is believed to have been due to his abrupt deceleration at the foot of the slide. Following a detailed investigation, individual criticisms of the escape slides were found to be unjustified, but are the subject of detailed comment later in the report.

2.2 Failures on take-off and the related decision speed (V_1)

The present method used by certificating authorities to define the decision speed depends on a number of assumptions, the most important of which is that the decision whether or not to continue the take-off is being taken because of an engine problem. This assumption has usually been valid in the past, when engine failures were responsible for the great majority of take-off incidents/accidents. However, with the advent of ever higher wheel loadings and tyre speeds, the percentage of incidents/accidents due to tyre problems is gradually increasing.

This being the case, it is appropriate to re-examine the concept of V_1 in relation to tyre failures. V_1 is at best an arbitrary figure based solely on the engine failure case, but, with most operators, it is all the pilot has to guide him in making what may be a very critical decision – whether to continue into the air, taking his problem with him, or to reject the take-off. V_1 is arbitrary because it assumes that the aircraft will reach a given speed at a particular distance along the runway, and does not take into account its actual, as compared with its theoretical, progress. In the tyre failure case, V_1 does not take into account the increased wheel drag, and reduced braking capability, caused by the tyre failure(s), but does include the effects of a non-existent engine failure. Only occasionally will these factors balance each other in effect and result in the pre-calculated V_1 reflecting the true position.

To resolve these shortcomings, it has long been argued that the pilot's task would be much alleviated if a realistic 'go/no go', or 'take-off progress' meter, could be developed so as to provide a continuous monitor of the aircraft's progress throughout the ground run. Successful development of such a device has up to now foundered due to the difficulty of measuring accurately all the necessary parameters. With the advent of transport aircraft fitted with inertial navigation devices and computers, the provision of much of the accurate data required and its assessment has been facilitated. However, such a device will necessarily need to take into account the extent of the engine/tyre failures and the consequential effect on the aircraft's performance. As these failures will continue to occur, although, hopefully, less often, it is recommended that development of such a take-off progress monitor be continued with all urgency despite the complications involved.

At the present time and in the absence of such a monitor, in the case of a tyre failure or suspected tyre failure, the pilot's decision is an extremely difficult one. To assess the extent of the problem when positioned a considerable distance away from the probable source, surrounded by extraneous cockpit noise and vibration and often without any instruments to assist, calls for inspired guesswork aided only by experience. Is the sensory input caused by a tyre burst or some other problem such as an engine break-up? Is more than one tyre involved? Is there likely to be any consequential damage, and if so, how serious? Above all, is there a likelihood of fire? These are all questions which the pilot should, ideally, take into account, as well as the aircraft's progress relative to its take-off speeds. To compound his problem, the time available for decision-making is often minimal because tyre failures are most likely to occur at high groundspeeds. In this connection, evidence from a number of accident inquiries, including the subject one, suggests that, except in the clear-cut engine failure case, the time interval allowed by some certificating authorities for pilot reaction at the decision point (normally, one second) is inadequate. Accordingly it is recommended that this allowance be substantially increased.

On consideration of the number of unpredictable factors involved in the case of tyre failure on take-off, it is not surprising that there is no general agreement on the question of whether, in principle, it is better to continue, even though below V_1, or to stop, with the attendant risk, as in the case of the subject accident, of further tyre and wheel failures resulting in reduced braking capability and, possibly, of fire. For example, the series of consequential tyre/wheel failures typified by this accident can, in more critical take-off cases, such as the DC10 Los Angeles accident in 1978 (paragraph 1.17.4), result in the aircraft over-running the runway, with very serious consequences. The alternative option of taking the problem into the air where there is time to make a reasoned assessment of the problem and, in due course, land at a much reduced weight and therefore speed, is basically an attractive one. However, it has the great disadvantage that, in the present state of landing gear design, the aircraft could already have suffered serious damage due to debris, perhaps sufficient to affect its airworthiness, consequent on the initial tyre failure(s).

In view of the complex considerations, already discussed, which the commander of a large transport aircraft has to take into account when a tyre failure is suspected at a late stage in the take-off roll, it is apparent that *in these circumstances* the V_1 speed, as presently defined, can only be regarded as a guide. Indeed, in the accident case, as the take-off was being attempted at well below limiting weight, V_1 could theoretically have been adjusted upwards to the same value as V_R. Accordingly, it must be concluded that the commander's action in abandoning the take-off, although commenced above his pre-determined V_1, was justified. The consequential damage to the aircraft may have been increased because of the high speed from which the take-off was rejected; conversely, however, there was every possibility that had this action been taken at a slightly lower speed, for example at V_1, subsequent tyre failures and related damage would still have occurred.

A question which immediately arises from the inadequacies of the present V_1 in the context of tyre failures is whether an additional decision speed, related specifically to these failures, could be introduced with advantage*. However, in view of the sometimes unpredictable factors involved, and, in particular, the often present difficulty in recognising such tyre failures in the current state of the art, it is considered that this concept is not, at present, a viable one. More productive results are likely to be achieved by a concentration of effort on minimizing the incidence of tyre failures and consequential damage.

There is, therefore, a patent need for action with regard to the recommendations which follow later in the report, regarding landing gear and wheel bay area design. In this connection, it is noticed that, following the accident to the DC10 at Los Angeles mentioned above, the NTSB made a number of pertinent recommendations (see Appendix 4) concerning landing gear, tyre and wheel design and practices, only a proportion of which have been fully implemented.

As an incidental matter arising from the subject investigation, it is noted that there is no general agreement between states' airworthiness requirements as to whether or not wet runway conditions should be taken into account in the take-off, rejected take-off, and landing, cases. When assessing performance requirements it would seem unrealistic not to do so and, accordingly, it is recommended that, where necessary, states' requirements should be aligned in this respect.

2.3 Sequence of events, commencing with the initial tyre failure.

In order to obtain a better understanding of the remedial measures recommended as a result of this accident, it is relevant to note the sequence of events from the time of the initial tyre failure:

* *A procedure used by some operators is to prescribe an entirely arbitrary figure, such as 100 knots, as the decision speed for all failures other than the engine failure case. Although having considerable merit, the limitations of this arrangement in relation to the tyre failure case are obvious.*

At 1098 metres from the beginning of the runway, the tyre in the number 8 position started to throw its tread. This tread throw continued until the tyre was running on an inflated carcass.

At approximately 1433 metres the carcass deflated, causing an approximate 100% overload to the number 7 tyre, its axle pair. At about 1525 metres the crew of the RCV advised the Tower that the aircraft had burst a tyre. At approximately 1900 metres the crew initiated the rejected take-off procedure and at about the same time, or shortly afterwards, at a groundspeed of approximately 163 knots, the number 7 tyre burst. By the time number 7 tyre failed, very little of the number 8 tyre remained on its wheel, and consequently the rims of numbers 7 and 8 wheels contacted the runway. At about this time some tyre debris was thrown up into the wheel well area, causing damage to one of the brake anti-skid units. Within 50 metres of the wheel rims contacting the runway they started to break up, causing pieces of rim metal and wheel parts to be thrown at high energy in all directions, but principally upwards and rearwards.

At approximately 1990 metres, some 70 metres after the number 7 tyre failed, the number 3 tyre burst. At 2100 metres, the first braking action began. The aircraft continued along the runway, running on its nose, left and centre gears and number 4 tyre, number 3 tyre beads and numbers 7 and 8 wheel rims. At about 2275 metres, the rejected take-off action was completed by the deployment of the thrust reversers. By 2400 metres down the runway the number 7 and 8 wheels were rolling on the centre bolted portions, the rims having disintegrated.

At approximately 2600 metres the aircraft started a slow drift to the left which was corrected by 3260 metres.

At 3446 metres the number 4 tyre started to skid and deflate and the number 3 wheel rims contacted the runway. The skidding of number 4 tyre and wheel continued until the aircraft came to rest at 3790 metres from the beginning of the runway.

There was no evidence of fire until some 90 metres into the number 4 tyre skid. Once the aircraft had come to rest the heat from the number 4 tyre and brake and the centre gear brakes initiated static fires.

2.4 Landing gear considerations.

2.4.1 The tyre failures – probable causes.

Analysis of the remains of numbers 3, 4, 7 and 8 tyres produced the following conclusions as to the causes of the various failures:

2.4.1.1 *Number 8 tyre*

The tread of number 8 tyre was initially separated from the carcass and thrown; subsequently the ageing carcass failed to remain intact and disintegrated at both shoulders. It is noteworthy that, in the majority of cases, when a tread is thrown, the carcass will have sufficient integrity to remain inflated for a time. However, in the case of this failure, there was evidence that excessive cord fatigue and overheating in the shoulder area had occurred within the R-7 tread life period, strongly implying a previous overload condition. The high number of retreads and tyre age had adversely affected the survivability of the tyre.

Examination of the aircraft's maintenance records showed only two reports of occurrences that could possibly have produced an overload situation on this tyre. One report was of a significant pressure loss from tyre number 3 and one of a similar loss from tyre number 7, both on the right-hand gear. It can be seen that, from dynamic considerations (paragraph 1.16.4), the decrease in pressure of number 3 tyre would have had the effect of relieving the load on number 8 tyre, whereas a decrease in pressure of number 7 would have increased the load. Therefore it would appear that the 30 psi pressure loss of tyre number 7 the day before the accident probably was the cause of the overload discovered in the remains of tyre number 8. In this connection, it is noteworthy that the maintenance requirements of the operator and manufacturer were not complied with in that the axle pair of tyre number 7, that is,tyre number 8, was not replaced when a loss of 30 psi was discovered at tyre number 7, which is exactly the critical figure at or above which both tyres should be changed. It is interesting to note that, had the pressure loss of number 7 tyre been only 29 psi, which would not have required the replacement of number 8 tyre, the failure would probably still have occurred, although slightly further down the runway.

2.4.1.2 *Numbers 3, 4 and 7 tyres*

The number 7 tyre, of the same age and at the same retread level as number 8, was subjected to an overload of approximately 100% after the number 8 tyre failed. The overload would have caused an overdeflection and overheat, resulting in an increase in pressure which would have made it more susceptible to foreign object damage. It was established that in fact the main cause of the failure was overload, with the possibility that foreign object damage was the trigger mechanism. It is considered that the initiation of the rejected take-off procedure, which occurred at about the same time as the number 7 tyre burst, did not contribute to the failure.

The leak found from number 7 wheel overpressure valve was a minor one; the tyre/wheel combination had been fitted the previous day and the tyre pressure had been checked prior to departure from Heathrow. It is therefore concluded that this leak did not contribute to the tyre failures.

The number 3 tyre failed from foreign object damage, probably emanating from the previous tyre failures.

The number 4 tyre wore through sufficient plies from skidding to cause its failure. It subsequently caught fire from self-generated heat.

2.4.2 *The wheels and brakes*

Examination of the wheels and wheel components from numbers 3, 4, 7 and 8 wheels showed nothing that would have contributed to the tyre failures.

Examination of the brake packs from the numbers 3, 4, 7 and 8 wheels showed no evidence of brake drag that would have caused excessive heat build-up within the wheels during taxying and the take-off roll, nor was this reflected in the DFDR data.

Although, in the opinion of the brake manufacturer's representatives, the brake pack from wheel number 4 showed indications of having started its take-off roll with a minimum wear-pin extension, a more probable explanation of the 100% wear condition apparent after the accident could be that, from a very early stage of the rejected take-off, the number 4 brake pack was the only functional brake pack on the right landing gear, and thus the only one to exhibit an extremely rapid wear rate consistent with that normally found following a take-off rejected from a high speed.

2.4.3 *The tyre failures*

2.4.3.1 *Tyre redundancy*

Tyres manufactured to present day standards cannot be guaranteed to survive foreign object damage or severe mishandling and therefore the risk of a failure will always be present. While that risk exists, measures must be taken to minimise the consequences. Large modern transport aircraft are designed of necessity with more than one tyre and wheel per axle. However, it is a highly unsatisfactory state of affairs when, following the failure of one tyre/wheel combination, in many cases the axle pair tyre/wheel cannot survive the ensuing take-off and landing, or rejected take-off, without in turn failing and in so doing, possibly jeopardising the safety of the flight. This state of affairs has been demonstrated in both the subject accident and that involving the Continental Airlines DC10 at Los Angeles in 1978, as well as other cases. With the continuing increase in maximum permissible certificated weights and groundspeeds of many modern aircraft, the problem is ever becoming more critical. Therefore, on such aircraft, and especially those with identified high tyre/wheel failure rates, the ability of an axle pair tyre/wheel to accept a 100% increase in load and remain inflated through the most critical phase of tyre/wheel operation is seen as the single most desirable remedial measure. The USA FAR Part 21 Technical Standard Order (TSO) C62c, which has been adopted by the UK, details a requirement for an overload take-off cycle at a load factor of 1.5. This figure of 1.5 only goes part of the way to meet the actual overload figure to which a mate tyre/wheel on a multiple tyre/wheel axle will be subjected during a rejected take-off in the event of a tyre/wheel failure at maximum certificated weight (paragraph 1.16.4 and Figure 5).

2.4.3.2. Tyre underinflation/overloading

It is not possible, from external examination, to assess the damage to a tyre carcass caused by running under-inflated or overloaded for one or two landings or take-offs. An aircraft of this category is typically serviced by many engineers all over the world, who cannot be expected to know its recent operating regime or history to the extent necessary to enable them to make accurate judgements on tyre serviceability. As tyre maintenance on wide-bodied aircraft has proved to be critical, the decision whether or not to replace a tyre should not be left to non-specialist judgement. It is therefore considered that if any tyre/wheel combination on a multiple-wheel axle has to be removed due to low pressure, then all the other tyres/wheels on that axle should also be removed for internal inspection to assess their serviceability.

Of prime importance in the minimizing of tyre-related incidents is the provision of some means of early warning to ground and flight crews of pressure loss. It is therefore recommended that the installation of tyre status monitoring equipment*, with a cockpit display or warning, be expedited.

2.4.3.3. Retread levels

The retread level of tyres numbers 7 and 8 was in both cases R-7. A degradation of carcass strength during each retread process is known to occur, but definite figures have not yet been established. One leading authority has stated that an unused tyre's burst pressure is reduced by 10% at R-1, stabilising at a degradation of 20% at R-4, while another authority states that the burst pressure for an in-service tyre is reduced by 15% at each retread, stablising at a 50% reduction level. Clearly, there is degradation in a retreaded tyre's strength, but the extent appears to vary, depending upon a number of factors, which include the type of retread process used and the cycles per tread life. To end this anomalous situation, it is strongly recommended that the extent of tyre degradation caused by retreading, age and usage be established by experiment.

TSO C62c prescribes the minimum performance standards applicable to all new tyres produced after 31 December 1979. However, there is no present minimum performance standard requirement applicable to retreaded or repaired tyres. Retreaded and repaired tyres are required to perform the same task as new tyres and while they continue to do so it is only logical that they should be required to meet the same minimum performance standards.

** Such as the bogie beam strain-gauge installation now fitted to Concorde aircraft on a trial basis or other installations now being made available by McDonnell Douglas and other manufacturers.*

2.4.3.4. *Tyre age*

Numbers 7 and 8 tyres were manufactured in 1974, which made them 6 years old at the time of the accident. Evidence from the remains indicated that age was a contributing factor to their failures. Unfortunately, no experimental evidence appears to be available to show the exact degree of degradation of a tyre's strength due to age (both physical and usage) although it is a known fact that the material used in the composition of a tyre will deteriorate with age and usage. A tyre that has a low usage will still suffer a change, dependent on the compound used, due to normal ageing of that compound. No allowance is made for old and/or high usage tyres in TSO C62c, although such tyres are required to carry out the same function as new tyres that do meet the standard. It is therefore recommended that maximum tyre age and usage criteria, based on test results, be detailed in TSO C62c.

2.4.4 *Wheel design*

During the rejected take-off phase of the subject accident pieces of broken wheel rim caused a large amount of structural damage, including the penetration of the upper wing skin from underneath and, probably, number 3 tyre failure. It was established that the rims of numbers 7 and 8 wheels failed very early in the rejected take-off sequence. Once the rims broke up all braking from the brake packs became ineffectual due to the loss of the wheel keyways. If the wheel rims had remained intact, then a finite, though small, amount of wheel braking and therefore directional control would have been maintained. The incident to an Air Florida DC10 mentioned in paragraph 1.17.5 illustrates how effective reinforced wheel rims can be. While there are tyres fitted to multiple tyre/wheel axles that cannot withstand a 100% increase in load during the most critical conditions, there will always be a requirement for non-frangible wheel rims. When tyres are able to survive a 100% increase in load there will still be a requirement for non-frangible wheel rims in order to allow for foreign object damage to tyres in the overload case. The requirement is even greater for aircraft of the single wheel per axle configuration.

The FAA have recently prescribed a roll-on-rim test requirement in TSO C26c and it is recommended that the CAA do likewise.

2.4.5 *Consequential damage*

Examination of the aircraft revealed that there was minimal protection of equipment and systems in the wheel-wells and on the landing gear. The aircraft manufacturer has issued a number of Service Bulletins detailing modifications to protect systems and equipment from failed tyre fragments and debris. Only one of these Bulletins is in the form of an Airworthiness Directive (AD), and therefore mandatory for United States registered aircraft, whereas, with one exception, they are all mandatory for aircraft on the United Kingdom register, so as to comply with BCAR Chapter D4-5 or JAR 25.729. FAR 25.729 (f) requires that equipment essential to the safe operation of an airplane which is *located in wheel-wells* must be protected from the damaging effects of a tyre bursting from overheat or loose tyre tread. However, in the subject accident, essential equipment on the *landing gear* (not in the wheel-wells) was damaged and two tyres burst from causes *other* than overheating or loose tyre tread. Accordingly, it is highly desirable that FAR and JAR be aligned to cover this type of eventuality.

Tyre failures due to foreign object damage will continue to occur and they will sometimes cause varying degrees of damage to equipment in and around the wheel wells. A method of greatly minimising the damage caused by a flailing tyre within the wheel well of an aircraft is to have all the landing gear doors closed when the landing gear is extended, as recommended in BCAR's Appendix 1 to Chapter D-4-5, paragraph 1.3. The safety advantages inherent in this arrangement are commended to aircraft manufacturers for incorporation in future aircraft designs.

2.4.6 *Landing gear design and maintenance*

Because safety is one of the most important aircraft design criteria, the structure and systems are designed with the fail-safe principle foremost. Unfortunately, the design of most commercial aircraft in use today is such that there is no fail-safe capability in the area of the landing gear and its associated components. In recent years a tyre/wheel problem has been identified with the DC10, L1011, B747 and Concorde, caused by the fact that they are operating of the top end of tyre speed and load technology.

An accident on the ground during take-off, involving the landing gear, can be as catastrophic as an accident in the air. It is for consideration, therefore, as regards future design philosophy, that landing gears, especially on wide-body aircraft and those with high weight/speed requirements, should have the same fail-safe capability as the systems and structure.

As regards aircraft already in service, to provide fail-safe landing gear systems retrospectively is not a viable proposition. Therefore, the highest possible standards must be applied to the existing equipment. To this end it is recommended that the maintenance requirements for tyres and wheels, especially on those aircraft with an identified tyre/wheel failure problem, be accurately defined and standardised for all tyres and wheels of a particular size and load rating, regardless of manufacturer or retread organisation. In addition, all personnel involved with the maintenance of aircraft tyres and wheels should be regularly made aware of the associated maintenance requirements and of the consequences of failure to comply with them.

2.5 The escape slides

The tests undertaken on the aircraft's escape slides subsequent to the accident indicated that the criticisms, voiced by some flight attendants, of the slides' operation, although made in good faith, were largely unjustified. It is considered they arose from the fact that the majority of the flight attendants had never witnessed an actual deployment from the aircraft or from a mock-up; they had only had demonstrated to them an inflation sequence on the ground. It is recommended, therefore that flight attendants' training be revised in this respect.

2.6 The service centre (galley) cupboard doors and drawers

The fasteners on the service centre cupboard doors and drawers were of the 'snap-close' type which relied upon a spring to activate a lock device that was not visible. Therefore, a failure of the spring or lock device to engage correctly was not obvious when the door or drawer was in the closed position. Accordingly, it is recommended that service centre doors and drawers be fitted with a fail-safe device that is manually engaged and is visible when in the locked position. Such a device would only be required for critical phases of flight such as the landing or take-off, normal in-flight security being achieved with the 'snap-close' device.

2.7 The use of hand-held microphones and loudspeakers

During the rejected take-off phase there was some misunderstanding in the course of the RTF communications between the operating crew and ATC. Four days previously, during another emergency involving a DC10 aircraft, ATC reported a similar difficulty in communicating with the aircraft which, like N83NA, was equipped with hand-held microphones and loudspeakers. From experience gained in the UK and elsewhere, it is considered that the use of headsets with boom microphones is a more efficient and effective means of communication than the alternative system and that in an emergency the difference can be vital. It is therefore recommended that consideration be given by airworthiness authorities to the introduction of a requirement that headsets and boom microphones be used by flight crews during the departure, climb, descent and arrival phases of all public transport flights.

3. Conclusions

(a) *Findings*

(i) The aircraft was correctly loaded and its documentation was in order.

(ii) The crew were properly licensed and fit for the flight.

(iii) The taxying phase and the early part of the take-off run were normal until number 8 tyre began to disintegrate.

(iv) The failure of number 8 tyre was probably caused by the combined effect of an overload condition, brought about by the loss of pressure from number 7 tyre on a previous flight, and the tyre's high retread level and age.

(v) The subsequent failure of number 7 tyre was mainly due to overload, but with the possibility that foreign object damage was the trigger mechanism.

(vi) In the circumstances, the commander's action in rejecting the take-off at 168 knots was justified.

(vii) Because runway length was not a limiting factor, the commander was able to stop the aircraft before the end of the paved surface, despite the reduction in braking capacity caused by successive tyre failures.

(viii) The failure of the number 3 tyre during the deceleration phase was due to foreign object damage which probably resulted from the preceding tyre/ wheel failures.

(ix) Number 4 tyre subsequently deflated due to skid wear.

(x) Fires which started at the centre and right-hand gear assemblies as a consequence of the rejected take-off were quickly extinguished by the Airport Fire Service.

(xi) The rejected take-off and aircraft evacuation procedures were completed in a professional manner, although one passenger was seriously injured due to his abrupt deceleration at the foot of number 1 slide.

(b) *Cause*

The accident occurred as a result of the failure of number 8 tyre, on the right-hand landing gear, probably due to the combined effect of an overload condition on a previous flight and the tyre's high retread level and age. A contributory factor was the consequential failure of further tyres on the same gear.

4. Safety Recommendations

It is recommended that:

4.1 For existing aircraft designs, all tyres, retread or new, fitted to a multiple tyre/wheel axle should be able to survive a rejected take-off, or take-off and landing, when one tyre/wheel on that axle has failed.

4.2 When a tyre/wheel assembly on a multiple tyre/wheel axle has to be replaced for pressure loss reasons, all tyre/wheel assemblies on that axle should also be replaced.

4.3 The extent of degradation of tyres caused by retreading, age and usage be established by experiment.

4.4 Maximum tyre age and usage criteria, based on test results, be detailed in the requirements of FAA Technical Standard Order (TSO) C62c.

4.5 A Technical Standard Order be issued detailing the minimum performance standards required for retreaded or repaired tyres and containing certification requirements equivalent to those detailed in TSO C62c.

4.6 The UK CAA introduce a roll-on-rim test requirement for aircraft wheels.

4.7 The protection of essential systems and equipment on landing gears and in wheel wells be made mandatory; and consideration be given to aligning USA Federal Airworthiness Requirement (FAR) part 25 25.729(f) and Joint Airworthiness Requirement (JAR) 25.729(f) in this respect.

4.8 For future large public transport aircraft, all the landing gear doors be designed to close when the landing gear is extended.

4.9 Consideration be given, in future landing gear design, to the incorporation of a fail safe capability, in order to ensure that a single tyre or wheel failure does not result in a serious incident or accident.

4.10 Maintenance requirements for tyres and wheels be accurately defined and standardized for all tyres/wheels of a particular size and load rating.

4.11 All personnel involved with the maintenance of aircraft tyres and wheels should be regularly made aware of the associated maintenance requirements and of the consequences of failure to comply with them.

4.12 All 'service centre' (galley) doors and drawers should have secondary, manually operated and visible, fasteners.

4.13 Flight attendants' training should include the opportunity to view a typical escape slide deployment on an appropriate aircraft, or on a realistic mock-up of the type concerned.

4.14 Consideration be given to the introduction of a requirement that headsets and boom microphones be used by flight crews during the departure, climb, descent and arrival phases of all public transport flights.

4.15 Development of a 'take-off performance monitor', with a cockpit display, be undertaken as a matter of urgency.

4.16 In respect of aircraft certification and take-off performance calculations, the allowance for pilot reaction time at the Decision Point be increased from the presently accepted value of one second.

4.17 The installation in large public transport aircraft of tyre status monitoring equipment, to include a cockpit display or warning, be expedited.

4.18 Consideration be given to a revision, where applicable, of states' airworthiness requirements, so as to take into account wet runway conditions during the take-off, rejected take-off (accelerate-stop) and landing manoeuvres.

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Department of Trade
June 1982

Produced in England by Her Majesty's Stationery Office, Reprographic Centre, Basildon

Bas 91637/R151 C8 7/82 TP