AIRCRAFT ACCIDENT REPORT 4/89

Air Accidents Investigation Branch

Department of Transport

Report on the incident to Boeing 747, N605PE, at Gatwick Airport, Sussex on 1 February 1988

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2/88	Boeing Vertol BV 234 LR G-BWFC 2.5 miles east of Sumburgh, Shetland Isles, November 1986.	April 1989
7/88	Fokker F27 Friendship G-BMAU 2nm West of East Midlands Airport, January 1987	January 1989
8/88	Boeing 737 G-BGJL at Manchester International Airport, August 1985	March 1989
9/88	Aerospatiale AS 332L Super Puma G-BKZH 35 nm east-north-east of Unst, Shetland Isles, May 1987	February 1989
10/88	Cessna 441 G-MOXY at Blackbushe Airport, April 1987	February 1989
1/89	Airmiss between Tristar G-BBAH and Tupolev 154 LZ-BTE near Lydd, February 1988	February 1989
2/89	Incident involving BAC 1-11 G-AYWB and Boeing 737 EI-BTZ at Gatwick Airport, April 1988	May 1989
3/89	Sikorsky S61N helicopter G-BDII near Handa Island off the north-west coast of Scotland, October 1988	June 1989
4/89	Boeing 747 N605PE at Gatwick Airport, Sussex, February 1988	

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Department of Transport
Air Accidents Investigation Branch
Royal Aerospace Establishment
Farnborough
Hants GU14 6TD

2 August 1989

The Right Honourable Cecil Parkinson
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr R C McKinlay, an Inspector of Accidents, on the circumstances of the incident to Boeing 747, N605PE, that occurred at Gatwick Airport, Sussex on 1 February 1988.

I have the honour to be
Sir
Your obedient servant

D A COOPER
Chief Inspector of Accidents

Contents

GLOSSARY OF ABBREVIATIONS

AAIB	Air Accidents Investigation Branch
ADI	Attitude Direction Indicator
AFM	Aircraft Flight Manual
ASI	Airspeed Indicator
ATIS	Automatic Terminal Informatin Service
ATC	Air Traffic Control
CAA	Civil Aviation Authority
CAS	Calibrated Airspeed
CVR	Cockpit Voice Recorder
COA	Continental Airlines
DALE	Digital Anemometer Logging Equipment
DFDR	Digital Flight Data Recorder
EGT	Exhaust Gas Temperature
EPR(S)	Engine Pressure Ratio(s)
FAA	Federal Aviation Administration
FDAU	Flight Data Acquisition Unit
HP	High Pressure
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organisation
INS	Inertial Navigation System
LP	Low Pressure
MRTOW	Maximum Regulated Take-off Weight
NATS	National Air Traffic Services
RABS	Reverse Actuator Bleed System
TORA	Take-off Run Available
TODA	Take-off Distance Available
V_1	Take-off decision speed
V_2	Take-off safety speed
V_R	Rotation Speed
V_{mca}	Minimum control speed take-off climb

Air Accidents Investigation Branch

Aircraft Accident Report No. 4/89
(EW/C1059)

Owner and operator:	Continental Airlines
Aircraft: Type and Model	Boeing 747-243B
Nationality:	United States
Registration:	N605PE
Place of accident:	Gatwick Airport, Crawley, Sussex
	Latitude: 51° 09' North Longitude: 000°11' West Elevation: 202 feet
Date and Time:	1 February 1988 at 1058 hrs
	All times in this report are UTC

Synopsis

The incident was notified to the Air Accidents Investigation Branch (AAIB) at 1215 hrs on 1 February 1988 and an investigation began the same day. The AAIB team consisted of Mr R C McKinlay (Investigator in Charge), Mr R St J Whidborne (Operations), Mr C I Coghill (Engineering), Mr P F Sheppard, Mr R J Vance and Miss A Evans (Flight Recorders) The incident occurred during take-off from runway 26 Left at Gatwick Airport in conditions of squally cross winds. As the main wheels of the aircraft left the runway the compressor of the No.4 engine surged, resulting in a loss of thrust from that engine. The aircraft banked to the right and pitched up to an attitude of 22°,which was some 11° greater than that recommended after an engine failure. With the stick shaker operating, the aircraft descended towards the high ground that lies due west of the airport until the commander, using maximum thrust from the three remaining engines, was able to establish a climb profile and the aircraft then achieved a safe height.

Fuel dumping began shortly after the engine failure and continued for some 40 minutes until the required landing weight had been achieved. The aircraft returned to Gatwick where it landed at 1150 hrs. The report concludes that the incident was caused by the following:

(1) A surge induced loss of thrust from the No 4 engine just after rotation.

(2) The commander delaying input of down elevator until the pitch had reached 22° which was well above that recommended and consequently the scheduled three engine climb performance not being achieved.

(3) The unusual combination of circumstances of an engine failure shortly after leaving the ground and in adverse wind conditions.

(4) The strong gusting cross wind which may have backed at the moment of rotation so as to reduce the headwind component.

Six safety recommendations are made.

1 Factual Information

1.1 History of the flight

The aircraft was prepared for a transatlantic flight to Miami and initial fuel and load calculations were based upon a destination of Washington/Dulles with a probable en route re-dispatch to the original destination. With 425 passengers and 10 tonnes of cargo loaded, the aircraft was pushed back from Stand 36 at 1040 hours and taxied to the runway holding point Alpha North. Whilst waiting for one landing and one departing aircraft, the crew queried their final dispatch figures with the handling agent who confirmed that the correct number of passengers had boarded. Since this was at variance with the original passenger manifest, a small adjustment was made to the pilot weight manifest worksheet resulting in a calculated take-off weight some 1043 lb (474 kg) below the Maximum Regulated Take-off Weight (MRTOW). Take-off performance was planned using a flap setting of 20° with all air conditioning packs off and no ice or rain protection selected. Maximum permitted thrust was to be used which required engine pressure ratios (EPRs) of 1.45.

The aircraft turned onto Runway 26 Left and the crew received take-off clearance together with a reported wind of 210°/10 kt. The take-off roll began at 1057 hrs. Acceleration was normal, although the crew remarked on a apparent 'hang up' of airspeed shortly before V_1. They also noted some small fluctuations in ASI readings which they attributed to gusty conditions. The commander, who was the handling pilot, began to rotate the aircraft at 156 kt indicated airspeed. As the main wheels left the runway a loud bang was heard and the second officer (flight engineer) announced a loss of power from No.4 engine. The landing gear was retracted and the throttles of 1,2 & 3 engines were pushed fully forward. It was noted that the Exhaust Gas Temperature (EGT) of No 4 engine was off the scale of its gauge with the amber warning light illuminated. The second officer then initiated fuel dumping by opening all the valves and selecting the appropriate pumps. He later completed the shut down actions on No 4 engine.

The commander was aware that the flight profile was flat and that the aircraft was approaching rising ground. He tried to minimise the loss of height whilst attempting to increase airspeed and reported that the stick shaker, giving warning of an imminent stall, was in intermittent operation for some 30 seconds. When sufficient speed had built up to permit flap retraction, the aircraft achieved an apparently normal three engine climb to 4000 feet where the dumping of fuel continued over an area near the south coast. The air (tower) controller, who had witnessed the loss of height together with unusual pitch up and right roll to a bank angle of 20°, sounded the crash alarm since it appeared to him that the aircraft had disappeared below the horizon and was about to crash.

Other eye witnesses had seen the aircraft make a normal rotation some two thirds along the runway and then flames were seen to issue from the tail pipe of No 4 engine. The aircraft was seen to pitch up and roll to the right as it continued on a flat flight path towards rising ground. Some witnesses saw flames issuing from No 1 engine and a cabin attendant, seated by door 2L, saw flames coming from the fan area of No 1 engine. A resident near the brow of Russ Hill, 2500 metres west of the airport saw the aircraft appear from her left at a low height and just clear a neighbouring farm house before disappearing in a cloud of fuel vapour towards the west.

Having dumped about 80 tonnes of fuel in order to achieve the required landing weight the aircraft landed uneventfully at Gatwick at 1150 hrs. Shortly before touch down, the crew restarted No 4 engine and maintained it at a reduced thrust setting in readiness for the application of go-around power should the gusty wind conditions have required it. Reverse thrust after landing was used on No 2 and 3 engines only.

1.2 Injuries to persons

There were no injuries to any of the aircraft occupants or any other person.

1.3 Damage to aircraft

There was no damage to the aircraft, its engines or any of its systems.

1.4 Other damage

Aviation turbine fuel was jettisoned at a low level initially and was thought to have caused some damage to vegetation in the area of high ground west of Gatwick Airport but this was not confirmed. There was no other physical damage.

1.5 Personnel information

1.5.1	*Commander:*	Male, aged 38 years	
	Licence:	USA Airline Transport Pilot's Licence with Instrument rating	
	Aircraft ratings:	Multi engine land, Boeing 727, 737, 747	
	Certificate of test:	B747 on 28 July 1987 valid until 28 August 1988	
	Proficiency check	30 November 1987 valid until 30 May 1988	
	Medical examination:	Class 1, renewed 21 August 1987, valid until 20 February 1988	
	Flying experience:	Total flying hours:	7300 hours
		Total hours on type:	850 hours
		Flying hours last 7 days	16 hours
		Flying hours last 28 days	46 hours
	Previous rest period:	24 hours	
1.5.2	*Co-pilot*	Male, aged 40 years	
	Licence:	USA Airline Transport Pilot's Licence with Instrument rating Flight engineer turbojet	
	Aircraft ratings	Multi engine land, Boeing 737, 747	
	Medical examination:	Class 1, renewed 18 February 1987 valid until 17 February 1988	
	Flying experience:	Total flying hours:	4000 hours
		Total hours on type:	1100 hours
		Flying hours last 7 days:	22 hours
		Flying hours last 28 days:	62 hours
	Previous rest period:	24 hours	
1.5.3	*Flight engineer*	Male, aged 35 years	
	Licence:	USA Airline Transport Pilot's Licence Flight engineer-turbojet	
	Aircraft ratings:	Multi engine land, Shorts SD-3 series, Fokker F-27	
	Medical examination:	Class 1, renewed 13 October 1987 valid until 12 October 1988	

Flying experience:	Total flying hours:	8500 hours
	Total hours on type:	1500 hours as flight engineer
Previous rest period:	24 hours	

1.6 Aircraft information

1.6.1 *General information*

Manufacturer:	Boeing Commercial Airplanes
Type:	Boeing 747-243 B
Registration:	N605PE
Serial No:	20520
Date of manufacture:	1978
Registered owner:	Continental Airlines
Total airframe hours:	44465 hours
Certificate of Airworthiness:	FAA standard airworthiness certificate in the transport category. Issued 12 April 1984.
Certificate of Maintenance	Annual check completed on 12 January 1988 including phased elements of A and B checks (35 and 131 day periods respectively)
Type of engines:	4 Pratt and Whitney JT9D-7A turbofans
Engine Serial Nos.	No 1: 662663 No 2: P662541CN No 3: P685817 No 4: P686028

1.6.2 *Aircraft weight and centre of gravity*

The aircraft was loaded within its permitted centre of gravity limits as follows:

Loading:	lb	kg	CG Index
Operating empty weight (1)	359785	163195	64
Additional crew	170	77	
425 passengers (2)	72250	32772	
Baggage (2)	13304	6035	
Cargo (3)	22448	10182	
Fuel (trip)	262800	119204	77

RTOW	730757	331465	39
Structural limit	775000	351534	

Note 1: Determined when the aircraft was last weighed on 24 February 1986.

Note 2: All passengers and baggage were calculated at the standard weight of 205 lb (93 kg) per person in accordance with the operator's procedures. Scrutiny of the passenger manifest did not reveal any unusual aspects which might have caused a significant variation from standard weights.

Note 3: The cargo was checked weighed twice after the incident using certified scales. The actual weight was 242 lb (110 kg) less than the load sheet weight.

1.6.3 *Performance*

Limiting weights, airspeeds and Engine Pressure Ratios (EPR) were derived from the company's Operations Manual which in turn had been extracted from the Aircraft Flight Manual (AFM).

(a) Maximum Regulated Take-off Weight (MRTOW)

Take-off performance was predicated on data published by the operator in a performance fact sheet from the Operations Manual dated 22 November 1987. This indicated that, using runway 26 Left at Gatwick, with engine bleeds OFF and with 20° flap set, the limiting weight for the prevailing conditions was that which would permit clearance of obstacles in the second segment of the climb. To this derived MRTOW of 746300 lb (338516 kg) a reduction of 14500 lb (6577 kg) was made to account for non standard atmospheric pressure (QNH 986 mb). This was based on a reduction of 725 lb (329 kg) for every 1 mb of atmospheric pressure below an arbitrary datum of 1006 mb. Thus the final MRTOW permitted was 731800 lb (331939 kg).

(b) Take-off airspeeds and distances

For the reported conditions and physical characteristics at Gatwick (see paragraphs 1.7 and 1.10) the following airspeeds and distances were derived:

V_1 - 149 kt
V_R - 161 kt
V_2 - 164 kt

V_{mca}-107 kt (one engine out)
Stabiliser trim setting - 7.2°
Climb attitude: 13° *ie* the rotation target pitch attitude for a four engine V_2 +10 climb. For an engine failure, V_2 climb target attitudes are approximately 2° lower. An 18° maximum has been imposed for passenger comfort.

Stall speeds (gear up):	Flap 20° - 136 kt
	Flap 10° - 142 kt
	Flap 5° - 144 kt
Take-off run:	6750 feet (2057 metres) in 47 seconds (Brake release to lift off)
Take-off distance:	7830 feet (2386 metres) in 51 seconds (Brake release to 35 foot screen height)

(c) EPR

The maximum take-off thrust, corrected for all air conditioning packs OFF, was 1.45 EPR.

1.6.4 *Limitations*

The following limitations are contained in the manufacturer's Aircraft Flight Manual (AFM):

Maximum cross wind component for take-off:	The maximum demonstrated crosswind component for take-off and landing is 30 kt reported wind at 50 foot height. This component is not considered to be limiting on a dry runway with all engines operating.
Maximum tail wind for take-off:	10 kt

Fuel jettison: with 6 pumps operating for 32 minutes, 165000 lb (74843 kg) of fuel will be jettisoned (including burn-off).

1.6.5 *Aircraft handling*

In gusty cross wind conditions certain precautionary actions during take-off are recommended. During the ground roll, forward pressure is maintained on the control column to assist directional control via the nose wheels. At V_R the non-handling pilot calls 'ROTATE' and the handling pilot releases forward pressure and moves the control column aft to achieve the target pitch attitude at a rate of 2° to 3° per second. When windshear is suspected the primary reference for attitude is the Attitude Direction Indicator (ADI) but the Flight Director should not be used. If the airspeed should fall below the trim airspeed, unusual control column forces may be required to maintain the desired pitch attitude. The stick shaker must be respected at all times.

The aircraft was fitted with a triple Inertial Navigation System (INS) and, as normal, one display was selected to give a wind readout during take-off. Above 115 kt True Air Speed, as sensed by the Air Data System, all digits in the data display window will flash '8' if wind shear conditions are experienced. During initial debriefing on the incident the crew reported no such warning during the take-off roll but later stated that two of the INS displays had indicated wind shear conditions.

1.6.6 *History of No 4 engine*

The engine fitted in No 4 position on N605PE was JT9D-7A serial No 686028. It had been returned to service in June 1986 following factory refurbishment which "zero timed" the complete engine. It was installed on aircraft N 604 PE and completed 4026 service hours (756 cycles). On 26 August 1987 it was removed from N 604 PE for repair following the detection of diffuser rail cracking. The diffuser case was replaced by an exchange unit and some other refurbishment work was carried out. On rebuild an exchange High Power (HP) turbine was installed (961 hours / 183 cycles) and the Low Pressure (LP) compressor was replaced by a refurbished unit.

The engine was installed in N605PE at No 4 position on 17 December 1987 and had completed a further 343 hours / 59 cycles of operation at the time of the incident. On 17 January 1988 the engine was reported in the technical log as suffering a compressor stall (surge) during reverse thrust operation on landing at Los Angeles. The engine had been shut down after the EGT overtemperature light had illuminated. The engine was boroscope inspected, the rigging and operation of the reverser was checked and a ground run was carried out with no fault being found. On 18 January 1988 a take-off from Honolulu for Auckland had been aborted when the No 4 engine surged. An engine "run up" had failed to repeat the problem and the engine performed normally during the subsequent take-off. At Auckland engineers had inspected the intake, jet pipe and bleeds for evidence of internal damage or distress and, having noted the previous occurrence, requested crews to "report further".

This technical log entry (18 January 1988) appears to contain a contradiction in that it is classified as "closed", presumably following the engineering inspection, but the engineering entry contains a request to "report further". Normally flight crews would only be required to observe technical log entries which had an "open" or "deferred" status. Undoubtedly, subsequent surge incidents would have been "reported further".

A search through the engineering flight logs for N605PE and N 604 PE revealed no other recorded cases of engine No 686028 having surged. The search covered the period of operation when the engine was installed in N605PE up to the time of the incident and the last three months of its operation when installed in N 604 PE (June, July, August 1987).

1.7 Meteorological aspects

1.7.1 *Synoptic situation and general weather*

An intense depression, 984 mb, was centered 40 miles west of Malin Head (55°N 007°W) at 1100 hrs with a very strong unstable southwesterly flow over southern England in its circulation. At 1100 hrs there was no significant weather in the vicinity of Gatwick Airport, neither were there any showers. Warnings of windshear were being broadcast on the Automatic Terminal Information Service (ATIS).

Recordings made by the Satellite and Radar Branch of the Meteorological Office, Bracknell showed an area of precipitation, which was elongated northeast-southwest, passing to the east of Gatwick at 1100 hrs. This was associated with a trough in the increasingly unstable airflow. Study of local temperature and precipitation recordings in conjunction with the radar recordings suggested the presence of some large cumulus embedded in layer cloud but centred about 25 km east of Gatwick. Any downdraught from this cumulus would have been directed ahead of the cloud and would not have spilled out to the west (*ie* at Gatwick) especially in view of the strong south southwesterly gradient.

1.7.2 *Actual observations at Gatwick on 1 February 1988*

Observation:	1050 hrs	1118 hrs
Wind/velocity	210°/19	210°/19
Variable between:	160°-240°	160°-240°
Maximum/minimum:	37/10 knots	30/10 knots
Visibility:	30 km	30 km
Cloud:	1/8th 1500 feet	2/8th 1500 feet
Temperature:	+8°C (+47°F)	+8°C (+47°F)
Dew point:	+3°C (+37°F)	+4°C (+39°F)
QNH:	986 mb	986 mb

1.7.3 *Wind velocity and direction*

A single anemometer located 200 metres south of runway 26 Left adjacent to a point 2240 metres along its length measured the direction and strength of the wind at this point. From repeater dials in the Visual Control Tower this information was passed to landing and departing traffic by controllers. No Digital Anemometer Logging Equipment (DALE) was installed but an anemometer trace was maintained. Study of this trace for the relevant period showed a mean wind direction of 210° varying between 160° and 240°. Between 1050 hrs and 1110 hrs the strongest gust recorded was 30 kt. Thus the maximum crosswind on the runway was 30 kt when the wind direction was 168° and 23 kt when the wind direction was 210°. The wind information that was given to pilots by the tower controller is shown in the RTF transcript which is at paragraph 1.9.

The anemometer was subject to annual checks and the last check was on 28 April 1987. It had also been inspected on 2 September 1987 following a lightning strike. These inspections included a check on the head alignment, starting speed, telemetry, the generator and its voltages at 10, 30, 50 and 80 kt. Operational experience, confirmed by pilot reports, tended to suggest that the anemometer was not always fully representative of conditions on the runway. Trees and buildings created some disturbed wind patterns under certain conditions. For these reasons a trial installation of an additional anemometer located near the 'Foxtrot' hold was due to start on 9 May 1988 but no results have so far been produced.

1.7.4 *Observing and reporting of surface wind - ICAO Annex 3 Chapter 4.*

Recommended Standards and Practices relating to surface wind observations are contained in ICAO Annex 3. The relevant recommended practice for take-off and landing reports is given below:

> "4.5.5 Recommendation.- The averaging period for wind observations should be:
>
> a) 10 minutes for reports disseminated beyond the aerodrome;
>
> b) 2 minutes for reports used at the aerodrome for take-off and ıanding and for wind indicators in air traffic services units
>
> "4.5.6 Recommendation In reports for take-off and landing, variations in the wind direction should be given when the total

variation is 60° or more with the mean speeds above 10 km/h (5 kt); such directional variations should be expressed as the two extreme directions between which the wind has varied during the past 10 minutes. Variations from the mean wind speed (gusts) during the past 10 minutes should be reported only when the variation from the mean speed has exceeded 20 km/h (10 kt); such speed variations (gusts) should be expressed as the maximum and minimum speeds attained. In reports for take-off, surface winds of 10 km/h (5 kt) or less should include a range of wind directions whenever possible."

4.5.7 Recommendation.- Where multiple sensors are installed, the 2 minute time averages of and significant variations in the surface wind direction and speed for each sensor used in reports for take-off and landing should be monitored by automatic equipment.

1.8 Aids to navigation

Not relevant.

1.9 Communications

1.9.1 *Air Traffic Control (ATC)*

The aircraft, using the callsign 'Continental 31' (COA 031), was in communication with the control tower at Gatwick on ground (121.8 Mhz), tower (124.22 Mhz) and radar (118.6 Mhz) frequencies and recordings of these were maintained. An extract from the transcript of the tower frequency, including take-off clearance, is reproduced below:

To	From	Text	Time
NET 373	TOWER	WIND CHECK TWO THREE ZERO DEGREES TWENTY KNOTS	1053
	TOWER	TWO ONE ZERO DEGREES TWENTY KNOTS	
	TOWER	TWO ONE ZERO DEGREES TWENTYKNOTS	
	TOWER	FINAL WIND CHECK TWO ONE ZERO DEGREES TWENTY KNOTS GATWICK OUT	1054
COA 031	TOWER	CONTINENTAL THREE ONE AFTER THE DEPARTING ONE ELEVEN LINE UP TWO SIX LEFT	

TOWER	COA 031	LINE UP TWO SIX LEFT CONTINENTAL THIRTY ONE	1056
COA 031	TOWER	CONTINENTAL THREE ONE IS CLEARED FOR TAKE-OFF STANDARD CLIMB OUT THE WIND IS TWO ONE ZERO DEGREES AT TEN KNOTS	
TOWER	COA 031	- FOR TAKE-OFF CONTINENTAL THIRTY ONE 'BYE 'BYE	
TOWER	COA 031	GATWICK CONTINENTAL THIRTY ONE	1059
COA 031	TOWER	YES I HAVE YOU IN SIGHT AND PRESUMABLY RETURNING TO GATWICK STRAIGHT AWAY	
TOWER	COA 031	AFFIRMATIVE WERE GOING TO HAVE TO COME BACK	1100
COA 031	TOWER	THATS OK THIRTY ONE THE WIND AT THE MOMENT IS TWO ONE ZERO DEGREES AT THIRTY THREE ZERO KNOTS IF YOU WISH TO TURN BACK AT EIGHT RIGHT YOU MAY DO SO OTHERWISE A LEFTHAND CIRCUIT FOR TWO SIX LEFT ADVISE ME AS SOON AS YOU KNOW	

1.9.2 *Transponder*

The aircraft was equipped with dual ATC transponders. At 1115 hrs, some 17 minutes into the flight, the radar controller reported to the crew of N605PE that their secondary radar return was garbled. The fault cleared when the crew selected the other transponder. Notwithstanding this, a recording of the aircraft's track and secondary radar height information throughout the flight was obtained from the radar head at Pease Pottage (51°04'N 001°12'W). This information, which accorded with that derived from the flight recorder, was incorporated into the data which was used to produce the track and height plots which are at Appendix 1.

1.10 Aerodrome information

The relevant part of the aerodrome obstruction chart relating to runway 08R-26L at London/Gatwick Airport is also shown at Appendix 1. The ground track of N605PE has been superimposed both in plan and profile.

Runway 26 left is aligned on a true bearing of 258° with a Take-Off Run Available (TORA) of 3098 metres. The Take-Off Distance Available (TODA) is 3250 metres with an upslope of 0.07% on the final 400 metres.

The following description of obstacles which are within 4 nm of the airport reference point is contained in the UK Aeronautical Information Publication (AGA 2-23-4 paragraph 39):

> "Trees on high ground lying across approach to Runway 08L/R, 1.5 to 3 nm west of airport up to 285 ft aal and trees on or near the extended centre-line of Runway 08R, 1.25 nm to 1.85 nm up to 207 ft aal. A hazard beacon showing 29 red flashes a minute, is situated on the extended centre-line of Runway 08R on tree covered high ground where a number of trees within 0.3 nm of the beacon rise up to 27 ft above it. Another, showing 36 red flashes a minute, is situated 0.66 nm NNW of the first. Together, they mark the line of the high ground."

1.11 Flight recorders

The aircraft was equipped with a Sundstrand Model AV 557B Cockpit Voice Recorder (CVR) and a Sundstrand Model Digital Flight Data Recorder (DFDR). Both recorders were removed from the aircraft undamaged and taken to AAIB Farnborough for replay.

1.11.1 *Cockpit Voice Recorder (CVR)*

The CVR installation was to FAA standard. The track allocation was as follows:-

Track 1 - P1 (Commander's) RTF
Track 2 - P2 (Co-pilot's) RTF
Track 3 - P3 (Flight engineer's) RTF
Track 4 - Cockpit area microphone

The incident flight lasted for 53 minutes and the recorder had been allowed to continue recording after the aircraft had landed. As a result the 30 minute duration CVR tape contained no record of the incident. A section of the tape contained a record of some of the crew's discussion and analysis of the incident. This record provided some insight into the problems faced by the crew, their actions and performance during the incident and on what they believed to be the causes of the incident. It was possible to confirm that the commander had handled the aircraft throughout the incident; the co-pilot had called out heights; the stick shaker had operated for over 30 seconds after lift-off and the airspeed indicator was fluctuating markedly between V_1 and V_R so that the commander considered he had no accurate indication of airspeed. The commander commented that he considered the airspeed to have been about V_2 throughout. A full transcript of this discussion could not be made because of high background noise level on the area microphone track from external ground servicing equipment and cross talk from adjacent tracks on the tape.

1.11.2 *Digital flight data recorder*

The aircraft was equipped with with a flight recorder installation to ARINC 573B standard with a Teledyne Systems Flight Data Acquisition Unit (FDAU) and a Sundstrand DFDR. There was also a separate and additional ARINC 542 recorder (5 parameter scratch foil or digital equivalent) installation. No recorder was fitted in the ARINC 542 installation.

A full replay of the incident flight was obtained. However, the unusual dual recorder installation and the extensive but apparently undocumented alterations made to the parameter list during the aircraft's life delayed conversion of the raw DFDR data to engineering units. The problems that gave rise to this delay are summarised as follows:-

(a) No document listing the recorded parameters and associated equations was available for the aircraft.

(b) Since the operator and manufacturer were unaware of the data frame layout, the validity of many parameters was suspect, particularly those identified as flying control inputs and engine performance parameters. Calibration of the recorded engine parameters was carried out at Gatwick Airport during post incident ground runs. Additional calibrations and parameter validation checks were made at the operator's engineering base in Los Angeles.

(c) A number of recorded parameters, including R12 spoiler, R0 aileron, No 3 EGT, Nos 2 and 4 N_1 were found to be deficient.

(d) In addition to physical checks on the aircraft, considerable efforts had to be made to cross check mathematically the recorded data with performance data as well as using data frame layouts from similar aircraft to identify possible recorded parameters.

1.11.3 *DFDR parameter information*

It was apparent that N605PE had one of the most extensive recorded parameter tables available on a 747-200 series aircraft. In addition to information on basic flight instrumentation, control inputs and control surface movements were recorded. Comprehensive data on the behaviour of each engine was recorded. The value of the recorded engine data in identifying the exact time of the No 4 engine failure was limited by the low sampling rate of engine data (each engine parameter sampled every 4 seconds), and because the N_1 parameter was not operational on No 4 engine. Despite the amount of time spent on investigation of parameters, it is still considered that some of the data recorded on the aircraft has not been identified. The accuracy of the recorded data is set out in ARINC 573 Appendix 2. This includes tolerances of +/- 2% for control positions and engine parameters.

1.11.4 *DFDR readout information*

The recording of Calibrated Airspeed (CAS) fluctuated throughout the take-off and is evidence of the gusty conditions. Indications quoted from the DFDR record are therefore mean ones. Take-off EPRS were stabilised by 80 kt CAS and right rudder was applied to maintain heading. At 109 kt CAS 13° of nose down elevator was applied and held until rotation. As shown in Appendix 2 , wheel and rudder inputs were applied to maintain runway heading during the take-off roll. The table below list the significant events in sequence:-

Time	Elapsed	Event
1056:13	0:00	N605PE lined up for take-off runway 26L
1057:10	+0:57	Take-off roll began
1057:58	+1:45	7° nose up elevator applied
1058:03	+1:50	Main landing gear left the ground
1058:06	+1:53	Significant decrease in longitudinal acceleration No 4 engine indicated abnormal performance Stick shaker activated
1058:12	+1:59	Aircraft at pitch attitude of 22° Airspeed 147 kt, altitude 150 feet agl No 4 engine thrust lever retarded by 12%
1058:15	+2:02	No 4 engine EGT 1000°C Thrust levers of remaining engines fully advanced
1058:36	+2:23	IAS 161 kt
1058:39	+2:25	Minimum height of 105 feet agl
10:59:01	+2:47	V2 was achieved for the first time.
10:59:32	+3:18	Flap retraction began, aircraft pitch was reduced to 10 nose up, height was 600 feet agl and airspeed was 168 kt IAS.
11:01:02	+3:48	Flaps were fully retracted. Altitude was 2100 feet and airspeed 250 kt IAS.

After lift-off the elevator angle was progressively increased to about 16° (see Appendix 2) and the aircraft exceeded its target pitch attitude of 13°. Full left control wheel was applied, however a right roll built up reaching a maximum of 20°. It was calculated that the stick shaker would have activated 3 seconds after lift- off and was operating intermittently thereafter. Roll attitude was corrected using full wheel and 30° of left rudder. By this time (9 seconds after lift-off) the aircraft was at a pitch attitude of 22° when the nose up elevator demand was reduced, but the recorded airspeed, which fluctuated wildly throughout the incident, had reduced to about 141 kt IAS. Pitch attitude was reduced to 16° and roll attitude stabilised at 4° with the left wing low.

1.11.5 *The ground roll*

Thrust was calculated from recorded EPRs and Mach No and this was used to calculate longitudinal acceleration using the equations in the B747 performance engineers' manual. This was compared with the recorded longitudinal acceleration. The calculations were performed for both the incident take-off and for a previously recorded take-off from Newark, USA on 31 January 1988. Both calculations showed close agreement between the calculated and achieved acceleration. The distance covered during the take-off roll was calculated and compared with predicated values; again close agreement between actual and calculated distances was obtained (see paragraph 1.6.3). From this work it was concluded that the ground roll had been normal. Recorded CAS and ground speed, which were derived from recorded longitudinal acceleration, were used to derive a headwind component for the incident take-off. The calculation was repeated using recordings from two DC 10 aircraft that took-off from Gatwick Airport at 1049 hrs and 1118 hrs on 1 February 1988. All three showed a varying headwind component with a mean value of 20 kt.

1.11.6 *Rotation and lift-off*

Rotation began at a recorded airspeed of 156 kt CAS (V_R was 161 kt CAS.) Derived headwind data indicated that there was a reduction in headwind component from 20 kt to 12 kt immediately after rotation. Ignoring angular rate inputs to the Angle of Attack vane, the stick shaker would have activated 3 seconds after lift-off and elevator control input to reduce pitch was not made for a further 9 seconds. The stick shaker operated intermittently for about 30 seconds. Due to the complex interaction of pitch, roll and yaw movements during this period it was not considered possible to carry out an exhaustive analysis of the aircraft's performance using the recorded data in the period immediately after rotation. The main obstacles to these calculations were the wildly fluctuating pitot / static parameters and insufficient resolution of the recorded normal acceleration parameter which prevented accurate positional information being derived from the 3 body axis accelerometers

1.11.7 *The subsequent climb performance*

Using three engine climb gradient capability and the effects of spoiler deployment on C_L supplied by the manufacturer, the theoretical climb performance of the aircraft was calculated. The actual climb performance of the aircraft was then calculated from recorded data. It was necessary to base actual performance on integrated accelerometer data due to the previously mentioned problems with recorded pitot static data.

1.11.8 *DFDR Engine Parameters*

Data based on EPRs, EGTs, Fuel Flow, N_1, N_2, and thrust levers was recorded on this aircraft. The practice of recording this data only every 4 seconds and using the same second to record all data relating to a particular engine results in a dilution of the value of the data. The recorded data for No 4 engine showed no abnormalities during the ground roll. During the 4 second recording period in which lift-off occurred, EPR had dropped from 1.43 to 1.02, EGT had risen from 862°C to 932°C, N_2 reduced from 91% to 74% and fuel flow was down to 30%. The thrust lever remained unaltered. In the next 4 second recording cycle the thrust lever was backed off by approximately 12%. 10 seconds after lift-off, as roll attitude was stabilised, the thrust levers were advanced on Nos 1,2, and 3 engines. EPRS of approximately 1.6 were recorded for these three engines. No 4 engine EGT continued to rise until it went off the scale of its gauge 35 seconds after lift-off. The turbulent weather conditions were confirmed by the fluctuations of the recorded No 4 EPR whilst the engine was windmilling following its shutdown.

During the take-off roll nothing unusual was noted on the recorded data of all engines and there was no evidence of any loss of thrust or abnormality from No 1 engine. No 4 EGT and fuel flow were slightly higher than the other engines (No 3 engine EGT recording was unserviceable). The EPR of No 3 engine reduced by 0.013 during the period that No 4 engine failed although all other recorded parameters on No 3 engine did not change.

On the incident take-off and the preceding one, in the time frame straddling 80 kts, the engine parameters recorded on the DFDR were as follows:-

Preceding Flight

Engine	EPR	EGT (a) °C	EGT (b) C deg	Fuel Flow (a) lb/hr	Fuel Flow (b) %
1	1.372	784	+22	15992	+2.9
2	1.385	762	Datum	15545	Datum
3	1.377	-	-	15623	+0.5
4	1.376	818	+34	15895	+2.2

Incident Flight

Engine	EPR	EGT (a) °C	EGT (b) C deg	Fuel Flow (a) lb/hr	Fuel Flow (b) %
1	1.428	808	+12	16845	+ 2.0
2	1.451	796	Datum	16515	Datum
3	1.446	-	-	16826	+ 1.9
4	1.445	856	+60	17272	+ 4.6

Notes: (a) Absolute Value
(b) Relative to No 2 engine

The DFDR values displayed were calibrated against the flight deck instruments. Those for No 4 engine were calibrated with the replacement engine installed on N605PE.

The relative values tabulated here, using No.2 engine as an arbitrary datum, are intended to illustrate the anomalous indication from No.4 engine, referred to in 1.12.2.1, which would have been displayed during the incident take-off and the preceding one. The total discrepancies in No.4's performance, as referred to in 1.12.2.1, are not apparent here since those were related to No.4 engine's own basic level of performance; a datum which was not available to the flight crew.

The EGT and Fuel Flow for Engine No.4 recorded on the incident flight were high but because EGT's from one engine failed to record on the incident flight it is not clear by what margin No.4 would be seen to be hotter than the other engines. On the preceding flight No.4's EGT again appears high but because one EGT indication is missing on the DFDR its prominence relevant to the other engines cannot be assessed. Fuel flow on the No.4 was within the scatter exhibited by the other engines. Furthermore, the No 4 Fuel Flow gauge had been placarded as unserviceable, following a history of erratic and fluctuating indication.

During take-off crew operating procedures require take-off EPR to be set and EGT, N_1 and N_2 to be monitored relative to their limits. There is no limit specified for fuel flow. The EGT's recorded on the DFDR for engine No.4 during these take-offs were not in excess of their limit (915°C). Of the N_1 and N2 indications, not shown here, N_1 was not successfully recorded for Engine No.4 and N_2 was low compared to the other engines. Though it would appear that the No 4 engine indications were revealing an anomaly, in particular on the incident flight, there is nothing in current operating practices or requirements that would equip flight crews to recognise the significance of these indications.

1.12 Wreckage and impact information

1.12.1 *Examination of aircraft*

The exterior of the aircraft was examined, particularly the landing gear, intake lips and undersurfaces. No evidence was found of any collision with trees or buildings.During the incident take-off and flight the handling pilot had selected the Flight Director system ON. The crew did not report any defect in the system. The flight log record for the aircraft was checked for the two preceding months and no unserviceabilities in the system had been recorded. In operations subsequent to the incident no defective behaviour by the system was recorded by flight crews.

Following the incident, the system warning of incorrect deployment of the high lift leading and trailing edge devices was checked and was found to indicate correctly.

1.12.2 *Examination of engines*

Although No 4 engine had been successfully restarted in flight and ran at a part power condition before and during the landing, it was not run subsequently whilst installed on the aircraft. It was removed for testing and strip examination by the manufacturer since it had exceeded its overtemperature limit and it was suspected that it might have suffered some defect relating to its surge and flame–out behaviour. The other three engines were subjected to power assurance ground runs and their airflow scheduling controls checked. The data from the power assurance runs showed No 1,2, and 3 engines to be essentially normal in their operation and confirmed that they had been producing the EPR levels recorded on the DFDR and, considering all the parameters together, the correct levels of thrust. Although eye-witnesses reported flame emanating from No.1 engine during the incident the engine responded to throttle demand and there were no indications of any deficiency in thrust.

1.12.2.1 *Strip examination and testing of No 4 engine*

No 4 engine, serial No P686028, was run in a test cell by the manufacturer and its operating characteristics and performance was recorded "as received". It was then stripped, its control systems rig checked and its gas-path components, such as blades, stators and seals, subjected to detailed dimensional assessment. No single, obvious defect was found. The detailed dimensional checking indicated a normal level of wear consistent with the engine's service history. Analysis of test-bed performance data confirmed moderate deterioration in the HP compressor and HP turbine. The variable stator vanes were found to be scheduling high within the setting band and were slightly above the limits at high power. The vane scheduling adjuster was found still to be factory wire locked and so had not been re-adjusted in service.

Performance information obtained from No 4 engine on the test bed and as recorded during the incident on the DFDR was compared with data obtained from No 2 engine which was judged to give consistent indications. A performance comparison was also made with No 4 engine on the previous flight and with the replacement engine in that position for the subsequent flight. From these comparisons it was concluded that, during the incident take-off the engine was running with an EGT which was 80°C higher than normal and a fuel flow 9.25% higher than test cell data. Analysis indicated that this performance was consistent with there having been a major gas leak from the HP compressor, either through two or three "3.5" bleed valves[1] being open inappropriately at the high power setting or through a leak through the aircraft services bleed system. On subsequent test and examination, no defect, apart from a minor exceedance on leakage in the lower 3.5 bleed control, was found which would confirm a malfunction of the 3.5 bleed system. Neither did the performance of the replacement engine show any indication of a service bleed problem. It was concluded that, though there had been an inappropriate and unscheduled air leakage, it had been transitory.

The engine manufacturer calculated that the combined effects of the service deterioration, high Variable Stator Vane scheduling and inappropriate air bleeds would have reduced the surge margin by an amount greater than 11%, the largest debit (7%) being from the air bleed effects. This represents a reduction of more than half of the normal surge margin.

The operator monitored engine performance in cruising flight as routinely reported by flight crews according to a procedure set out in the Continental Airlines General Maintenance Manual. "Performance monitoring" information for

1 "3.5" bleed valves (3) are used to control the stability of the HP compressor and are situated aproximately half way along the array of HP compressor stages

engine No P686028 was examined for the period between its installation in N605PE and the incident but any useful analysis was prevented by a lack of continuity in the data and a high scatter in the fuel flow readings which appeared to be due to an instrumentation problem rather than an engine defect.

On examination of the engine's control system the manufacturer found there to be an intermittent short circuit in the "Bleed Override" solenoid valve (Part No 729728) in the Reverse Actuated Bleed System (RABS). This fault could have resulted in the appropriate 3.5 bleed valve not opening when reverse thrust was selected and it could have been a factor in the surge experienced at Los Angeles on 17 January 1988 during thrust reverse operation. A further fault was found in the RABS solenoid valve (Part No 655005). One of the pins in the valve's electrical connector was found to have been bent and was not properly engaged. This defect, again, could possibly have resulted in non-operation of the appropriate bleed valves during reverser operation and could have contributed to the surging in reverse thrust at Los Angeles. Neither of these two defects could have been a factor in a surge at high take-off power.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

Although flames were seen to issue from the tail pipes of the No.1 and 4 engines and sparks were seen in the area of the No.1 engine fan, there was no visible fire damage. This was confirmed by the airport Fire Rescue Services who examined the aircraft immediately after it had landed and vacated the runway.

1.15 Survival aspects

Not relevant.

1.16 Tests and research

Arrangements were made with a major operator of a number of B 747 aircraft to introduce a scenario, which was similar to the Gatwick incident, into routine simulator training for line crews. The purpose of the research was not to replicate the incident but to see if there was any discernible pattern in the handling of such an emergency by ordinary crews with particular reference to pitch and roll attitudes following an engine failure shortly after V_R and in strong gusting cross winds. It must be understood that the crews taking part in the trial were in an advantageous position compared with the crew of N605PE. They would have some prior knowledge of the incident at Gatwick, their awareness was increased because they were flying a simulator on a check during which engine failures could be expected and the wind model may well have caused less severe problems than that existing at Gatwick on the day of the incident. No attempt was made to verify aircraft performance by means of the simulator but recorded plots of several parameters were available for analysis.

Data from 11 take-offs, with an engine failure just after rotation, was studied. The mean time from rotation to engine failure was 3.5 seconds but, due to programming difficulties with the simulator being used, there was a wide variation from 0.75 seconds to 6.1 seconds The average maximum pitch attitude reached was 15.1°, but in one case a maximum value of 18.1° was recorded. In this case the altitude levelled for a short time at around 530 feet, but in all other cases the climb rate did not decrease below zero. The average maximum pitch rate was 3.57°/sec, the maximum value recorded was 4.74°/sec. The average peak alpha reached was 12.6°, the maximum value was 13.6°. The mean right roll after take-off was 12.7°, but there was a wide variation. In one case a maximum of 29.7° was recorded after an initial right roll of 7.7° and then a left roll of 12°. In another case an initial right roll of 15.2° was followed by a left roll of 16.7° with a further right roll of 23° The mean left roll was 12.6° but with much less variation. The average maximum rudder angle was 21° with a mean heading change of 9.3°.

1.17 Additional information

1.17.1 The operator's training programme for conversion and proficiency checks was examined with particular reference to the handling of engine failures after take–off. Appendix 3 contains extracts from the guidance on training and checking that is given to operators by FAA. A copy of the guidance that is similarly issued by the CAA to UK operators is also shown, although the operator in this incident was not obliged to conform to these guidelines. An extract from the operator's syllabus for Boeing 747 initial, transition and upgrade training is shown and the appendix also contains a copy of FAA Air Carrier Operations Bulletin No.8-88-3.

1.18 New investigation techniques

None.

2 Analysis

2.1 General

It was apparent that the aircraft had suffered a loss of power from No.4 engine at a crucial stage of take-off. The difficulty of handling a heavily laden aircraft in this situation was compounded by the gusty and turbulent conditions that existed at low level. Although eye witnesses reported flames coming from No 1 engine, there was no recorded evidence of any abnormal function from that engine and subsequent inspection showed it to be in good condition. It was however possible that there had been an unquantifiable loss of thrust from No 1 engine for a period of less than 4 seconds. The investigation concluded that any loss of thrust had been attributable to No 4 engine alone. Furthermore, the crew had no indication of any loss of thrust from No 1 engine and it was only later that they learned of reports of flames emanating from this engine. Following the loss of thrust, N605PE did not maintain a constant rate of climb as predicated on the normal performance calculations. The investigation concentrated on the determination of possible reasons for this. Apart from the evidence of the flight crew and eye witnesses, the most accurate record of the aircraft's performance was available from the DFDR. Less accurate information was available concerning the actual wind strength and direction which had been experienced throughout the take-off roll and early part of the climb out. The CVR was of limited value since, due to its duration of only 30 minutes, it did not contain that part of the flight when the incident had occurred. The investigation would have been helped considerably if it had had available a record of the flight crew conversation and instructions issued by the commander. It is therefore recommended that airworthiness authorities should actively encourage manufacturers to produce a CVR capable of retaining the information recorded during at least the last two hours of its operation in accordance with the recommendations in para 6.3.8.2 of Annex 6, Part 1, to the Convention on International Civil Aviation.

2.2 Flight recorder data

The evaluation of the recorded flight data was made using B747 performance data supplied by the manufacturer. The problems encountered in identifying the parameters have been listed in paragraph 1.11.2. It is recommended that ICAO should encourage contracting states to ensure that operators maintain accurate records of DFDR data frame layouts and to calibrate recorded parameters.

Radar and meteorological data were incorporated into the calculations to produce an aircraft track plot and to derive data. The track of the aircraft relative to grid north and the aircraft pitch attitude over the same period is shown in Appendix 1.

For the purpose of analysis it was convenient to consider the incident during rotation and lift-off followed by the subsequent climb performance. The calculation of wind effects are dealt with separately.

2.2.1 *Rotation and lift-off*

Rotation began at a recorded airspeed of 156 kt CAS although V_R was 161 kt CAS. Derived headwind data indicated that there was a reduction in headwind component from 20 kt to 12 kt immediately after rotation. Ignoring angular rate inputs to the angle of attack vane, the stick shaker would have activated 3 seconds after lift-off. The stick shaker operated intermittently for about 30 seconds and elevator control input to reduce pitch was not made for a further 9 seconds. Due to the complex interaction of pitch, roll and yaw movements during this period it was not considered possible to carry out an exhaustive analysis of the aircraft's performance using the recorded data in the period immediately after rotation. The main obstacles to these calculations were the fluctuating pitot / static parameters and insufficient resolution of the recorded normal acceleration parameter which prevented accurate positional information being derived from the 3 body axis accelerometers.

2.2.3 *The subsequent climb performance*

From a comparison of the theoretical 3 engine climb performance with the recorded data, which has been described in paragraph 1.11.7, it was considered that the climb performance during this period was close to the theoretical performance data supplied by the manufacturer. It was also concluded that in view of this the aircraft was unlikely to have been overweight at take-off.

2.2.4 *Calculation of wind components*

Continuing the evaluation of the headwind through the rotation phase showed that there was an apparent reduction of headwind component of between 7 and 12 kt. Confirmation of the extent of this reduction is difficult due to the absence of accurate short term airfield wind data. It was not possible to say whether this drop in headwind component was due to a reduction in wind speed or a change in wind direction. A subjective judgement based on drift calculations would tend to favour a change in wind direction. There is insufficient recorded data to determine if there was a vertical component in the predominant wind. The best approximation, which indicated that there was no vertical wind component, was based on an evaluation of the initial climb performance of the aircraft. The validity of this technique was again hampered by the limited resolution of the recorded normal acceleration parameter.

2.3 The surface wind

Throughout the morning of 1 February 1988 Gatwick Airport experienced a succession of squally showers associated with the strong southwesterly flow which affected southern England. The surface wind was at a mean angle of 50° to the runway in use, but on occasions it backed to give a 90° cross wind from the left with gusts up to 30 kt.

The siting of any anemometer must be to an extent a compromise consistent with the requirement to avoid creating an obstacle whilst finding the optimum position to measure the wind direction and speed accurately. It was known by the CAA and National Air Traffic Services (NATS) that the single anemometer at Gatwick was suspected of under-reading in certain conditions; a suspicion that had been born out of reports that had been submitted by pilots and controllers. Trials of a new anemometer installation at a site near the eastern end of the runway which had been planned before the incident are not yet complete. The CAA have stated that decisions concerning the future use of the existing and trial anemometers and the correlation of information derived from them will depend on the results of the trial.

The installation of Digital Anemometer Logging Equipment (DALE) or any other type of automatic analysis and display is not required under existing regulations, although a recommendation for automatic equipment to monitor multiple sensors is contained in ICAO Annex 3 Chapter 4. In terms of a report for take-off or landing the data is only as valid as the basic accuracy of the anemometer and the interpretation of the repeater dials by the controller at the moment he reads them. Daily checks are made to ensure that all repeater dials and the anemograph are in agreement. In this incident it would have proved helpful to the crew if the wind information given to them with their take-oft clearance had been derived from the 2 minute average.

Although the take-off clearance given to the crew of N605PE included wind information of 210°/10 kt it would have had to be of the order of 170°/40 kt before the aircraft's maximum demonstrated cross-wind of 30 kt was exceeded. This was unlikely to have been the case in view of the pattern of wind reports that the controller had been making earlier, unless the anemometer was under-reading significantly. Moreover, the crew were aware of the potentially hazardous surface wind conditions, particularly from the windshear warning that was broadcast on the ATIS. However, a final wind check which included variations just prior to take-off would have been prudent. Additionally, aircraft such as N605PE had the facility to provide wind read-outs (above 115 kt airspeed as sensed by the air data unit) from their INS display and crews can verify the wind information that is given to them. Thus, in the absence of automatic analysis and display equipment, which could have provided a more accurate record, it was concluded that the wind information at the time of the incident was probably substantially correct although tending towards an under assessment of the speed.

2.4 Aircraft handling

The take-off roll was unremarkable except that the crew were aware of a 'hang up' in the airspeed shortly before V_1. They were aware of the possibility of windshear under the prevailing conditions and accepted this likely explanation although it is not possible to be certain that the INS wind readout had put up an alert.

Rotation appears to have been normal, albeit slightly early perhaps explained by the gusty conditions which were noted as fluctuations on the airspeed indicators, until the point at which the No.4 engine surged and lost thrust as the aircraft achieved its target pitch attitude of 13°. The question of an aborted take-off did not arise since the commander knew that his aircraft had achieved V_1 before the noise and indications of the No.4 engine surge. It is also possible that there was some momentary loss of thrust from No 1 engine, evidenced by the observation of flames emanating from the fan area, although it was not recorded on the DFDR or observed on the flight deck. The amount of runway remaining was no longer relevant, but the proximity of obstacles in the climb out segment were of significance. Control of heading was adequately maintained by the commander (handling pilot) despite the fact that he was obliged to apply almost full left rudder to counteract the asymmetric thrust immediately after he had been maintaining a considerable amount of right rudder to counteract the effect of cross wind during the take-off roll. Roll control was less effective despite the application of full left control wheel and this may have been due partially to the effect of a quartering wind lifting the upwind wing at the moment of rotation but more probably to the sideslip induced roll caused by the loss of thrust from No 4 engine.

The aircraft was rotated straight through its four engine target pitch attitude of 13° to an attitude of 22°. It is reasonable to conclude that the commander was momentarily distracted by the engine failure so that he did not stabilise the aircraft at the required pitch attitude. In this condition climb performance would have been severely degraded. The commander has since stated that he deliberately exceeded the target pitch attitude in view of the obvious wind shear and he believed that, irrespective of the loss of thrust from No 4 engine, this was the correct action to take. The combined cues of a poor rate of climb and the stick shaker at the approach to the stall prompted the commander the begin to lower the nose of the aircraft after some 9 seconds. By this time he was in a dilemma whereby a decreased pitch attitude was required to maintain or gain airspeed but any reduction of pitch would cause a loss of height as the aircraft flew towards rising ground. Fortunately, he was able to maintain the aircraft between these alternatives until the combined effects of fuel dumping and gradual speed increase allowed the aircraft to climb.

The root cause of the loss of performance must be judged to be the excessive pitch attitude. However, it must be understood that, at the time just after the engine surge, the commander was confronted by a highly unusual situation. With all engines operating, the commander's expectation would be for the aircraft to 'weathercock' into wind (i.e.yaw to the left) but in this case the left yawing moment was almost exactly opposed by the right yawing moment resulting from the No 4 engine failure. In these circumstances the aircraft must have been side-slipping to the left which resulted in the roll to the right. The commander's instinctive reaction to correct the roll by use of full left wheel was to be expected in the prevailing circumstances since no yaw was immediately apparent. In the situation confronting the commander his use of rudder was timely and effective. With hindsight it could be argued that application of left rudder at an earlier stage would have been beneficial but the normal cues available to him were masked by the crosswind. Thus the sequence and rate of control application can be explained. By the time he had applied correct control inputs to deal with the yaw and roll caused by the loss of thrust, the aircraft was not stabilised at the correct pitch attitude. The pitch rate during rotation and lift-off was close to the recommended rate but the commander did not apply the required small down elevator input as the aircraft approached the target pitch attitude. The stabiliser trim setting had been correctly calculated and applied. From the simulator trial referred to in paragraph 1.16 it can be seen that the average pitch attitude recorded was 15° with a single case maximum of 18.1°. These achieved pitch attitudes were all considerably in excess of that recommended in the AFM. Crews training in a simulator have heightened awareness of the possibility of engine failure. In line operations the expectation of all engines remaining operating during take-off is very high and consequently response to an engine failure will usually require a longer reaction time. It is probable that the commander's high workload in dealing with this emergency so close to the ground and in gusty conditions played an important part in the achievement of a high pitch attitude during the initial climb.

2.5 Pilot training

Under ideal training conditions, a variety of likely scenarios can be explored in order to teach and verify the handling of emergency situations. However, for the purposes of fulfilling mandatory checks of proficiency it is normal that the pilot on check will be presented with a scenario laid down in the operator's Training Manual or Proficiency Check syllabus. Examination of the operator's syllabi showed that the two situations which were perceived to be the most likely were taught and tested *ie* "V_1 cut" or "engine failure on take-off". In the former case the pilot must make a rapid assessment and decision as to whether to continue or abandon the take-off. In the latter case the pilot must concentrate on maintaining control of his aeroplane and adopting a safe flight profile before securing the failed engine. This incident demonstrated the need for training in the handling of engine failures throughout the ground roll, take-off and climb out, not just the most critical in terms of decision making or handling. It must be acknowledged that only the latest simulators are capable of accurately reproducing aircraft handling and performance characteristics whilst the aircraft is in ground effect. Furthermore, training in a real aircraft at representative weights would be hazardous.

It is noteworthy that training guidance given by the CAA and FAA to operators specifies training for "take-off with engine failure between V_1 and V_2". Enlightened training will try to create situations where an engine failure occurs during periods of maximum distraction or high cockpit workload so that the genuine surprise of a performance loss is met with a controlled and orderly response. This requires a more flexible approach than that apparent in the operator's syllabi from which a literal interpretation would result in the practicing of engine failures at V_1 or after V_2. The NTSB recommendation referred to in Air Carriers Operations Bulletin N 8-88-3 which is reproduced at Appendix 3 is therefore endorsed.

2.6 No.4 engine surge

2.6.1 *Loss of surge margin*

Stable operation of the fan and core compressors of the JT9D engine is achieved by appropriate fuel scheduling and by a system of bleeds and variable stator vanes. Early models had a surge recovery bleed at the HP compressor delivery but this system was deleted from later models and engine No 686028 was not so equipped. Compressor stall or surge can occur in a variety of modes in the LP and HP compressors and the fan. The stability margin of these components varies with changing engine or flight conditions and may decrease with deterioration in service of blade profiles or gas path quality but normally the residual margin is sufficient to absorb transient disturbances The engine is also vulnerable to any mechanical defect in its surge protection systems and intake airflow distortion can initiate surging, particularly at low airspeeds or when the aircraft is static. This latter hazard should diminish with increasing forward speed during the take-off roll. Analysis of the recorded parameters during the incident flight suggested a loss of surge margin of at least 11% and this has been ascribed to a transitory but major air leak in the HP compressor section of the engine, combined with a high stator vane schedule and moderate engine deterioration. Whilst this must be judged highly unusual, it does appear credible as a factor in the engine failure that occurred at the point of rotation. At V_R intake flow conditions would be approaching the optimum, with reducing sensitivity to cross winds, but the process of rotation does produce a change in the angle of incidence of the engine intake.

2.6.2 *Previous incidents*

There had been two previous surges on this engine. The case on 17 January 1988 during reverse thrust operation most probably had causes which, given the two defects found in the RABS system, were completely unrelated to the two subsequent surges experienced during take-off. At the time it must have appeared that the two incidents could be related and the entry for 18 January 1988 recording a surge at take-off does make reference to the previous occurrence. The technical log entry describing the surge on 18 January 1988 can be criticized for the sparseness of information relating to that event. Nothing was recorded of the environmental conditions, aircraft speed, engine condition (acceleration or stabilized setting) or parameter indications. Further, the engineering response appears barely adequate for what may have been a second occurrence of a hazardous condition. The recorded engineering actions comprise only a visual inspection of engine condition and there appears to have been no development of the troubleshooting process which had been initiated following the previous surge in reverse thrust. The "performance monitoring" information, taken in cruise flight, may not have shown any evidence of the impending problem at take-off conditions but, given the deficiencies in the data when examined after the event, it is considered that the operator should review the efficacy of his performance monitoring procedures.

The Boeing 747 Maintenance Manual gives comprehensive guidance on troubleshooting procedures following surging in different regimes and the engine manufacturer offers advice in his JT9D Line Maintenance Training Manual as to the cockpit indications which could be of use in the troubleshooting process and which should be acquired by the line maintenance personnel. This information is incorporated in Continental Airlines General Maintenance Manual and in their engineering training. Since the incident this has been reinforced by the distribution of two training videos for study by maintenance personnel.

Following the take-off incident on 18 January 1988 the aircraft then operated for 14 days with no recorded surge events and no further investigative action. If consideration had been given to these problems then it must have appeared that a transitory problem had occurred but had cleared. Indeed, the surge problems probably were transitory but had the potential for recurrence. Considering that the eventual test running and full strip examination failed to identify a physical defect to associate with the surge event at Gatwick on 1 February 1988 it is highly unlikely that the normal troubleshooting procedures would have exposed any such intermittent or transitory defect. Nevertheless, the actions following the previous incidents, whether they were related to the final incident or not, did not represent an entirely satisfactory effort to identify the problem. Other reports and actions recorded in the technical log appeared exemplary but it is recommended that, in view of the occurrence preceding the incident at Gatwick and which was possibly related to it, the operator should review his education of flightcrews in effective reporting of defects and occurrences.

In retrospect, from all the evidence available, it can be seen that there were indications to flightcrew and maintenance personnel, of defective behaviour in engine No 4 on N605PE. It is concluded (see 1.11.5) that the indications of anomalous operation of No 4 engine during the ground roll portion of the incident take-off at Gatwick were within operational limits and were not such as to signify to the flightcrew the possibility of a surge and power loss.

3. Conclusions

3(a) Findings

(i) A valid Certificate of Airworthiness had been issued for the aircraft, which had been maintained in accordance with an approved maintenance schedule.

(ii) The flight crew were properly licensed, experienced, medically fit and rested to conduct the flight.

(iii) The maximum permitted take-off weight had been correctly calculated and adjusted for climatic conditions to ensure obstacle clearance in the second segment of climb out from Gatwick Airport.

(iv) The aircraft had been correctly loaded within its permitted centre of gravity limits. The stabiliser trim setting had been properly established. The eventual climb performance of the aircraft indicated that it was unlikely to have been overweight at take-off.

(v) At the time of take-off, the runway in use was subjected to strong gusting cross winds from the left and a broadcast warning of wind shear was in force. Analysis of the aircraft's performance as recorded on the DFDR, did not indicate the presence of a vertical wind component. It was calculated that the head wind component reduced by some 8 knots immediately after rotation. This was the only indication of unfavourable wind conditions during take-off.

(vi) Prior to the incident reports by ATC controllers, including a Mandatory Occurrence Report, had raised doubts about the accuracy of the anemometer at Gatwick Airport. It was considered to be unrepresentative of actual conditions under certain circumstances. The trace recorded the mean wind at the time of take-off as 210°/20 kt with variations between 160° and 240° gusting to 30 kt. Such wind speeds and directions were within the aircraft's maximum demonstrated cross-wind capability.

(vii) The initial take-off run and acceleration was normal both in terms of recorded and predicted data.

(viii) The incident was initiated when No.4 engine surged and lost power about 2 seconds after the main landing gear left the ground.

(ix) A transitory but major air leak in the HP compressor section of the engine, combined with a high stator vane schedule and moderate engine deterioration was responsible for the surge.

(x) It is highly unlikely that the normal troubleshooting procedures would have exposed any such intermittent or transitory defect.

(xi) It is probable that the unusual combination of circumstances of an engine failure shortly after leaving the ground and in adverse wind conditions played an important part in the commander's rotation of the aircraft some 11° beyond the 3 engine target pitch attitude. Although the excessive pitch attitude was reduced within 10 seconds, it had by then resulted in an airspeed considerably lower than the take-off safety speed (V_2) and caused a loss of performance during the first two minutes of flight.

(xii) The nature of the emergency was such that routine simulator training could not reproduce the several adverse factors of the incident.

(xiii) Although flames were seen to issue from No.1 engine there was no recorded evidence or flight deck indications of any loss of thrust or abnormality from that engine.

(xiv) Correct emergency drills by the flight crew including rapid initiation of fuel dumping and skilful handling by the commander eventually restored a rate of climb.

(xv) A record of the incident was not obtainable from the CVR since the flight and subsequent ground power phase had exceeded the 30 minute duration of the CVR recording equipment.

(xvi) The operator's check procedures were designed to familiarise the crew with an engine failure that occurred either at V_1 or at some later stage in the flight. Engine failures at or near V_R were not specified.

(b) Cause

The incident was caused by the following:

(1) A surge induced loss of thrust from the No.4 engine just after rotation.

(2) The commander delaying input of down elevator until the pitch had reached 22° which was well above that recommended and consequently the scheduled three engine climb performance not being achieved.

(3) The unusual combination of circumstances of an engine failure shortly after leaving the ground and in adverse wind conditions

(4) The strong gusting cross wind which may have backed at the moment of rotation so as to reduce the headwind component.

4. Safety Recommendations

THE FOLLOWING SAFETY RECOMMENDATIONS WERE MADE DURING THE COURSE OF THE INVESTIGATION :

(1) Airworthiness authorities should actively encourage manufacturers to produce a CVR capable of retaining the information recorded during at least the last two hours of its operation in accordance with the recommendations in para 6.3.8.2 of Annex 6, Part 1, to the Convention on International Civil Aviation.

(2) ICAO should encourage contracting states to ensure that operators maintain accurate records of DFDR data frame layouts and to calibrate recorded parameters.

(3) Consideration be given to the installation, at major international airports, of suitable equipment to monitor automatically and display to ATC the surface wind in accordance with para 4.5.5 (b) and 4.5.7 of ICAO Annex 3 thus enabling controllers to pass the appropriate 2 minute average wind velocity to aircraft which are landing and taking-off.

(4) Continental Airlines review the operation of their engine condition monitoring procedures to determine whether the quality of data obtained is satisfactory.

(5) Continental Airlines review how their maintenance personnel use published troubleshooting procedures and the existing avenue of communication with flight crews through the Technical Log to pursue and identify defects.

(6) Continental Airlines review their briefing to flight crews on the need for comprehensive reporting of defects and occurrences and on the correct identification of the relevant information in particular situations.

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