Runway excursion on landing, Boeing 747-236B, G-BDXP

Micro-summary: **This Boeing 747-236B left the runway on landing.**

Event Date: **2000-12-12 at 1938 UTC**

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

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

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Boeing 747-236B, G-BDXP

AAIB Bulletin No: 5/2002	**Ref: EW/C2000/12/05**	**Category: 1.1**
INCIDENT		
Aircraft Type and Registration:	Boeing 747-236B, G-BDXP	
No & Type of Engines:	4 Rolls-Royce RB211-524D4-19 turbofan engines	
Year of Manufacture:	1988	
Date & Time (UTC):	12 December 2000 at 1938 hrs	
Location:	London Heathrow Airport	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew -18	Passengers - 116
Injuries:	Crew - None	Passengers - None
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	47 years	
Commander's Flying Experience:	11,336 hours (of which 6,344 were on type)	
	Last 90 days - 112 hours	
	Last 28 days - 71 hours	
Information Source:	AAIB Field Investigation	

History of the flight

The flight departed from Boston USA and was inbound to London Heathrow Airport (LHR). The 1800 hrs Terminal Aerodrome Forecast (TAF) for LHR, obtained en-route by the crew, indicated that surface winds could increase to a value in excess of the aircraft crosswind limitation at the expected time of arrival. The crew reviewed the available alternates and decided that London Stansted Airport would be the most suitable in the event of LHR being unavailable.

At 1917 hrs the aircraft was required to hold in the London area awaiting an approach. The crew asked London Area and Terminal Control Centre (LATCC) whether Runway 23 would be available in view of the wind conditions. They were advised that it was but would entail a 20 minute delay for the flight. In light of this information, together with the fact that the surface wind remained within limits for Runway 27R and that an ILS approach would be preferred the commander elected to continue for an approach for Runway 27R, the landing runway scheduled for use until 2359 hrs.

The First Officer (FO) flew the approach with the autopilot engaged. At about 1,000 feet agl the Flight Engineer (FE) advised the others of the Inertial Navigation System (INS) derived wind; 206°/45kt with a drift of 16.1°. ATC advised another aircraft ahead on the approach that severe turbulence could be expected around the area of the hangars on short final. A question was raised amongst the incident crew as to why the airport was using this runway in these conditions as from their own previous experience Runway 27L would be preferable. At 700 feet agl with visual contact established the commander took control, in accordance with company standard operating procedures, and then disengaged the autopilot. Flap 25 with a VREF speed of 135 kt was used for landing. The FE read out a drift angle of 12° at touchdown. The touchdown was made at 150 kt on a heading 8o left of the runway QDM of 273°M, smoothly and close to the centreline. Autospeedbrake deployed normally. After touchdown the aircraft initially tracked towards the left of the runway despite the commander's attempts to maintain the centreline by the use of full right rudder. The left wing of the aircraft lifted to give a right roll attitude of 4° and then returned to level. The FO delayed the selection of reverse thrust until he was confident that the aircraft was under control. The aircraft tracked back towards the runway centreline and thrust reversers were then deployed at a speed of 110 kt. The centreline was regained and the aircraft began to track slightly to the right. An input of 70% left rudder was used for a short time to counter this and the aircraft swung rapidly to the left. Reverse thrust was cancelled and the commander attempted to use the steering tiller to regain control but felt the nosewheel scrubbing across the runway surface. The left wing briefly lifted again. Full right rudder was reapplied but the aircraft continued tracking to the left and came off the paved area into a grass triangle between two taxiways.

The aircraft came to rest on the grass and the flight crew assessed the possible damage. The commander consulted with the attending Heathrow Fire Service and decided that it was not necessary to carry out a passenger evacuation of the aircraft and completed a normal shutdown. The emergency services confirmed that there was no apparent damage to the aircraft. There was some delay before steps could be attached and passengers disembarked because of the difficult ground and wind conditions.

Meteorological conditions

The synoptic situation at 1900 hrs on 12 December 2000 showed a low pressure area centred over north-west Ireland with a cold front lying from South Wales to Western Scotland and a trough lying 40 nm west of London. A very strong southerly airstream covered the Heathrow area.

The 1920 hrs ATIS report for LHR included the following; "landing Runway 27R, surface wind 190°/21 kt gusting to 32 kt, varying between 160° and 220°, visibility 10 km, moderate rain, cloud broken at 1,300 feet and overcast at 1,800 feet, temperature 13°C, dewpoint 11°C and QNH 998 mb pilots be advised turbulence may be experienced during the last mile of final approach to Runway 27R and windshear has been forecast". This information was included as a result of an instruction in the Manual of Air Traffic Services (MATS) Part 2 for LHR requiring a message to be broadcast if the surface wind is between 170° and 230° in direction and exceeds 15 kt. There was no similar requirement for Runway 27L.

A Meteorological Office anemograph trace was available for the investigation. The anemometer was located in a position near to the threshold of Runway 09R, some 1 to 2 nm from the relevant section of Runway 27R. These traces recorded a minimum wind speed of 12 kt and a maximum of 36 kt in a two-minute period around the time of the incident.

Data was also available from a touchdown sensor for Runway 27R. This data gives a 2-minute mean wind speed and the maximum and minimum values over a 10-minute period. The values recorded at 1938 hrs were as follows; mean wind speed 25 kt, maximum 33 kt and minimum 15 kt, mean wind direction 198°M, maximum 220°M and minimum 180°M. The tower reported wind passed to the aircraft with the landing clearance was 200°M/31 kt.

The runway condition was wet. Subsequent to the incident a grip test on Runway 27R was carried out by the airport operator and a braking condition 'good' reading was obtained.

The aircraft

The aircraft centre of gravity was calculated to have been in the middle of the allowable range. The landing weight of the aircraft was 216 tonnes, the maximum allowable was 285 tonnes.

The aircraft had one significant outstanding technical defect, an unserviceable autothrottle system. This defect caused the orange reference speed 'bug' to remain fixed at 290 kt throughout the flight. A manually positioned 'bug' was used instead by the crew for setting the appropriate reference speed and the thrust levers were operated manually.

The maximum demonstrated crosswind for the aircraft type on initial certification was 28 kt. The crosswind demonstration was conducted on a dry runway, and this level of crosswind was not considered to be the limiting crosswind condition. In 1995, a need to better understand the aircraft's crosswind capability was identified following a number of crosswind related diversions among operators. The manufacturer carried out a program of simulator trials and engineering analysis that resulted in revised crosswind guidelines. The simulator trials were based on steady wind conditions. The landing crosswind guideline for the 747-200 aircraft was revised to 32 kt on a wet runway and the operator adopted this in September 1996.

The recommended technique for landing in a crosswind on a wet surface was to fly the aircraft onto the runway while maintaining the runway centreline track. The Boeing 747 Flight Crew Training Manual states: *"It is not necessary to eliminate the crosswind crab angle prior to touchdown on wet runways. Allowing the airplane to touch down without removing the crab angle will reduce drift toward the downwind side of the runway"*. It was recommended in the operators own flight crew manual that selection of reverse thrust be delayed until directional control was assured because of the possible adverse effect of the reverse thrust vector.

The aircraft's rudder fine steering system had been de-activated by the operator to ensure commonality amongst its Boeing 747 'Classic' fleet. Should full rudder be insufficient to keep the aircraft straight then both the manufacturer and the operator recommended the use of differential braking. This technique was rarely required and not routinely practised in the simulator. The operator's Boeing 747 flying manual also stated that tiller operated steering could be used at speeds of up to 100 kt but would not normally be required until 40 kt.

The aircraft was also equipped with a body gear steering system selected by a switch on the overhead panel. This system was used solely for taxiing and the switch was not selected on at any time during this incident.

Flight recorders

Information retrieved from the Cockpit Voice Recorder (CVR), the Flight Data Recorder (FDR) and the Quick Access Recorder (QAR) was used to reconstruct a time history of the aircraft's approach and landing. Appendix A and Appendix B contain extracts of the FDR data. Rudder pedal position was recorded but rudder deflection was not. No data on the tiller input was available from the data recorders therefore it was not possible to calculate the nose wheel angle during the landing roll. The FDR and QAR recordings also provided the data to enable the aircraft's track along the runway to be derived.

The CVR recording contained three ATC transmissions warning approaching aircraft about turbulence on short finals to Runway 27R. Of these one was specifically transmitted to the accident aircraft whilst it was 8.5 nm, (4 minutes), from touchdown. The surface wind at this time was reported as 200 o/ 25 kt gusting 30 kt.

The aircraft remained accurately aligned on the localiser signal throughout the approach although it was slightly below the glideslope on final approach. Thirty six seconds before touchdown ATC reported the surface wind as 200o/31 kt. The commander commented "that's on our limits". Ten seconds before touchdown ATC reported the wind as 200o/28 kt occasionally gusting 30 kt.

Throughout the approach the FE called the INS derived headwind and drift. The numbers called were consistent with the wind data recorded on the QAR. The winds recorded on the QAR were 216o/27 kt four seconds before touchdown and 191o/27 kt at touchdown.

The FDR data and the CVR recording confirm that the commander had difficulty controlling the aircraft after landing. During the first 10 seconds on the landing roll first the left and then the right wing lifted. Full right rudder pedal was used in an attempt to regain and maintain the runway centre line.

The comments on the CVR together with the reductions in the amplitude and frequency of the control inputs and the deployment of reverse thrust indicated that the crew considered the aircraft was under control as it decelerated through 110 kt.

As the airspeed reduced through 100 kt the relationship between airspeed and groundspeed changed consistent with the aircraft encountering a 8 kt relative increase in headwind component. The aircraft began to turn right and full left rudder pedal and 80% left control wheel were applied. Two seconds later the increased headwind component disappeared.

A further 3 seconds later the airspeed and groundspeed difference was consistent with a relative headwind component increase of 16 kt. The left wing of the aircraft began to lift and the aircraft began to turn left. Full right rudder pedal and full left control wheel were applied. The aircraft continued to turn to the left. The maximum roll angle reached was approximately 4° to the right. The aircraft left the runway on a heading of 242o at a speed of 50 kt. After leaving the paved surface the aircraft heading increased and it came to rest on a heading of about 258o.

Radar recording

Ground movement radar was recorded for the duration of the incident. The replay showed the aircraft initially tracking the runway centreline when still airborne. It was not possible to locate the exact moment of touchdown but the replay then showed a deviation to the left of the centreline

followed by a return to the centreline and then a slight deviation to the right. The aircraft then rapidly turned to the left and off the side of the runway. This gave a good correlation with the data from the FDR and the reports of the flight crew.

Examination of the aircraft and runway

The aircraft had run onto a grassed area (designated block 8) adjoining the left side of Block 11 on Runway 27R, approximately mid way down its length. It came to rest aligned approximately 16° to the left of runway heading, with its right main gear 7 metres from the edge of the paved surface, having travelled a total distance of approximately 80 metres on the grass. The wheels sank to approximately axle depth in the soft ground, but the aircraft sustained no significant damage during the incident. Examination of the paved surface revealed a set of faint but clearly distinguishable scrub marks from each of the tyres, made by the aircraft as it crossed the 22.5 metre wide paved shoulder on the left margin of the runway; it was not possible to identify any marks on the darker surface of the runway proper.

The visible tyre tracks indicated that the aircraft had departed the runway at an angle of approximately 30° to the left of the runway axis, and the nose tyre tracks diverged to the left, relative to the main tyre tracks, as they approached the edge of the paved surface consistent with a yaw rate to the left. As they crossed onto the grass, the nose tracks merged with those from the left body gear, and remained so up to the point where the aircraft came to rest, indicating that the yaw rate to the left had been contained by the time the aircraft ran onto the grass, albeit with a residual yaw angle to the left of approximately 12°. The fact that the (normally free-rolling) nosewheel tyres left visible marks showed that they were developing side forces at, or approaching, their limits of adhesion as the aircraft departed the runway, consistent with the nosewheels being actively steered in an attempt to regain the correct heading.

Runway allocation

There are two main runways at LHR, 27L/09R, 27R/09L, and one subsidiary, Runway 23. The main runways all have Category III ILS approach aids installed. The sole approach aid for Runway 23 was a Surveillance Radar Approach terminating at 2 nm with a minimum descent altitude of 730 feet.

Runway alternation at Heathrow was introduced for daytime landings (7.00 am to 11.00 pm) in 1972[1]. It applies during westerly operations only and provides communities east of the airport under the final approach tracks with predictable periods of relief from the noise of landing aircraft. During daytime westerly operations, landing aircraft use one runway from 7.00 am until 3.00 pm (local time) and switch to the parallel runway from 3.00 pm until 1100 pm. In order to achieve a fair and equitable balance in the use of the two runways, the runway assigned to landing aircraft after 3.00 pm also alternates on a weekly basis so that communities in west London situated under the final approach tracks may benefit from quieter periods in the mornings, or the afternoons and evenings as the case may be. The programme for runway alternation at the time of the incident had been agreed with The Department of the Environment Transport and the Regions (DETR)[2] in December 2000 and then published as a Temporary Operational Instruction to National Air Traffic Services (NATS). The DETR instructions with regard to preferential runway use included the following:

> *"When the associated cross wind component on these main runways exceeds 20 knots, runway 5/23[3] will normally be made available if there is a lesser cross wind component affecting it."*
>
> *"Pilots who ask for permission to use the runway into the wind when, in accordance with these procedures, Runway 27R or 27L are in use, should understand that their arrival or departure may be delayed."*

Status of the runway alternation scheme

The runway alternation scheme is a non-statutory noise amelioration measure but it has long been widely accepted that any proposal to change the scheme would come within the category of actions that require the approval of the Secretary of State. Nevertheless, since the introduction of the runway alternation scheme, NATS has always had the discretion to suspend its operation temporarily in order to reduce delays to arriving aircraft. Moreover, during the Terminal 5 Planning Inquiry, it was stated in evidence that: *"Landings out of alternation may also be necessary due to equipment failure, debris on the runway, or due to turbulence over the last mile of the final approach to Runway 27R (arising from the effect of southerly cross-winds and the positions of the large hangers in the maintenance area)."*

Runway selection

In accordance with MATS Part 2 (Heathrow ATC instructions), runway selection is the responsibility of the ATC watch manager. The instructions state: *"Runway 23 is not to be used with a tail wind component and should normally be selected for use only when the mean crosswind component on the main runways exceeds 25 kts."* The section of MATS Part 2 which describes the procedure for activating Runway 23 states: *"The Met Office will issue an appropriate severe weather warning whenever winds necessitating the use of Runway 23 are forecast. Prior to the anticipated use of the runway, the ADC Supervisor[4] is to consult with the Met Office Forecaster at Bracknell in order to ascertain a more accurate timing of the severe weather . Based on this forecast, the following procedure is to be adopted 3 hours prior to the planned runway promulgation."*

The detail of the procedure is not reiterated in this report but it involves notification action and the removal of aircraft from areas adjacent to Runway 23. The relocation of aircraft usually results in a shortage of aircraft stands and aircraft may have to be parked in overflow areas remote from the terminals. This factor is one reason why three hours advance notice is required. Subsequently, the change to Runway 23 may or may not take place depending on the actual crosswind component, but the preparations enable ATC to effect the change in 20 minutes. When Runway 23 is used for landing, Runway 27R is normally used for departures.

Turbulence in strong wind conditions

The UK Aeronautical Information Publication (AIP) contains the following warnings for LHR:

> *"Pilots are warned, when landing on Runway 27R in strong southerly/south westerly winds, of the possibility of building-induced turbulence and large windshear effects."*

Also:

"Similarly, R27L arrivals may be affected by winds with a strong Northerly component. Building-induced turbulence may be experienced at the mid sections of each runway from winds with a strong Southerly, or strong Northerly component."

A study of wind effects was carried out on Runway 27L in 1995 prior to the construction of a new building 450 metres from the runway. No study has been undertaken for the environment around Runway 27R and so no data comparison was possible.

There were no specific procedures or guidelines outlined in MATS Part 2 for the ATC Watch Manager to implement a change to Runway 27L for landing traffic in adverse wind conditions for Runway 27R. On some occasions in the past, under similar conditions, changes had been effected at the discretion of the Watch Manager, sometimes following requests from pilots. MATS instructions required these occasions to be logged by the Watch Manager. However, final responsibility for acceptance of the allocated runway rests with the aircraft commander.

Data analysis

The plot of FDR data covering the final part of the approach and landing given at Appendix A *(jpg 103kb)* provides an overview of events, and the more detailed plot at Appendix B *(jpg 102kb)* covers the touchdown and subsequent landing roll.

The heading data during the final 400 feet of the approach shows an angle to the left of runway heading varying between 7° and 13°, with approximately 8° remaining at the instant of touchdown. The lateral acceleration trace displays considerable activity throughout the approach with excursions to both left and right. Immediately after touchdown, the data indicates a rapidly increased acceleration to the left, consistent with the tyre side-forces which would have developed as the mainwheels touched down with 8° of yaw to the left. The associated translation towards the left side of the runway peaked about 3 seconds after touchdown, and thereafter reduced, passing through zero some 3 seconds later.

Right rudder pedal was applied immediately at touchdown: initially at about 30% deflection, held for approximately three seconds; then at about 45%, held for a further two seconds; then at maximum deflection. These applications of rudder pedal progressively reduced the left heading deviation, and the lateral acceleration trace shows a corresponding reduction, passing through zero as the heading trace reduces through 5°. By this stage the aircraft's heading would have been more closely aligned with its direction of travel, and the tyre side forces effectively reduced to zero.

Full right rudder pedal was then maintained (with a series of brief partial reductions) for a further 4 seconds, during which period the data shows the heading deviation reducing to zero, before increasing in the opposite direction, to the right of runway heading, with a corresponding lateral acceleration to the right. These data are consistent with the aircraft moving back towards the runway centre, after its initial excursion to the left immediately after touchdown. Over the next 8 seconds the amount of right rudder pedal applied was effectively reduced back to zero, in a series of reductions and partial re-applications, with a commensurate reduction in heading deviation and lateral acceleration.

During the landing roll to the point when the heading deviation, lateral acceleration, and rudder pedal deflection were all reduced to insignificant levels and the aircraft had apparently regained its correct position on the runway, the data imply a clear relationship between rudder pedal deflection and aircraft response. Progressively large rudder pedal deflections contained the aircraft's initial

excursion towards the left side of the runway, and then restored its correct position on the runway. The roll angle trend also followed the lateral acceleration in a manner which suggests that the roll angle was the result of inertial forces arising from accelerations of the aircraft's centre of mass in relation to the side forces being developed by the tyres: roll angle increasing to the right in response to a lateral accelerations to the left, and vice versa. Subsequent events, however, do not show such a clear relationship.

With the initial excursion to the left apparently having been contained and corrected, the data then shows a significant lateral acceleration to the right and, fractionally afterwards, there was the start of a rapid application of rudder pedal to the left, which reached a maximum of approximately 65% and was held for some 5 seconds. The acceleration to the right, however, reversed after about 2 - 3 seconds and ramped up sharply to the left, reaching a maximum of approximately twice the acceleration associated with the initial movement to the left after touchdown. As this acceleration to the left was building rapidly, the rudder pedal was reversed: initially to about 50% deflection to the right, which was held briefly before being reduced over the next 4 seconds; then being increased rapidly to 100% right rudder pedal, which was held until the lateral acceleration reduced back through zero some 6 seconds later. During the initial phase of this period, starting with the lateral acceleration to the right and extending throughout the period of left rudder pedal application, the heading swung initially to the right before reducing back to regain the runway heading at about the stage when the rudder pedal deflection was reversed from left to right; thereafter, the heading deviated rapidly to the left, reaching a maximum of approximately 30° left of runway heading before being contained, and reduced to 15° by the time the aircraft came to rest.

Neither the initial brief acceleration to the right, nor the heading deviation to the right, appeared to have been initiated by control inputs, and the roll to the right appeared to have started to increase slightly in advance of the lateral acceleration, unlike the preceding stages of the landing when the roll angle appeared to have followed lateral acceleration with a small lag.

Conclusion

On the available evidence, it would appear that whilst carrying out a landing on the margins of permitted cross wind limits, and after the crew had contained successfully an initial veer to the left on touchdown and were in the process of correcting an apparent subsequent swing to the right, the aircraft was caught by a sudden gust which effectively reinforced the corrective rudder pedal being applied at that time, resulting in a violent over-swing to the left. Despite reversal of the rudder pedal, ultimately to 100%, the yaw rate to the left could not be contained, directional control was lost, and the aircraft departed the paved surface.

Discussion

In this incident despite turbulent conditions, a safe touchdown was made. The crosswind component of the reported wind remained within the aircraft limits endorsed by the manufacturer and used by the operator. However, there may be a significant difference between a reported wind and an actual wind as a result of short-duration gusts and local effects.

The loss of control occurred after touchdown. It seems likely that a critical wind change occurred just as the aircraft was transitioning from the speed at which full rudder would be effective to that at which some input from the tiller or possibly differential braking would be required. As the aircraft swung to the left, the nosewheel was at its limit of adhesion and the only further corrective input available would have been differential braking. The crew had not practised this technique and

as the swing to the left was very rapid, it may not have been effective in any case. After the incident, the operator revised the crosswind limits to 25 kt on a wet runway and reviewed the training of crosswind landing technique on the type specifically to raise awareness of the use of differential braking. Moreover, since September 2001, the operator has withdrawn its Boeing 747 'Classic' variants from service and all its remaining Boeing 747 aircraft have rudder fine steering enabled.

Although Runway 23 was available for the aircraft, albeit with a 20 minute delay, there was no precision approach aid available on Runway 23 and weather conditions were such that the commander considered it desirable to use a precision approach aid. That entailed the use of either Runway 27L or 27R. The crew would have preferred to use Runway 27L because they knew the approach path to Runway 27R would be especially turbulent but they were under the impression that it was not available because of the strictures of the runway alternation scheme.

Minimising approach turbulence

In strong south and south-westerly wind conditions, turbulence from buildings upwind of the final approach path to Runway 27R can add considerably to a flight crew's workload. Whilst a change of landing runway from 27R to 27L would be unlikely to have any effect on reducing the crosswind component, such a change would significantly reduce flight crew workload during a critical stage of the approach because it would reduce the turbulence encountered.

When Runway 27R is the landing runway and the mean southerly crosswind component reaches 25kt, a change to landing on Runway 23 will automatically invoke a change of use for Runway 27R. (Having been the landing runway, it has to become the departure runway in order to allow Runway 23 to be used for landings). Consequently, at times when Runway 27R is the landing runway, runway alternation is one step in the process of changing to landing on Runway 23. 'Out of phase' alternation has the advantage that approaches would then be made primarily to Runway 27L which does not suffer the same turbulence problems on final approach as Runway 27R. This change can be achieved in 30 minutes and so an early change during preparations for landing on Runway 23 would be beneficial. Consequently, the following safety recommendation was made to HAL and Heathrow ATC.

Recommendation 2002-07

It was recommended to Heathrow Airport Limited and to Heathrow Air Traffic Control that Runway 27 Left should be the nominated landing runway from the commencement of the promulgation of Runway 23 (three hours prior to start of Runway 23 operations). This will serve to minimise the use of Runway 27 Right during periods of strong south-westerly winds.

Response to safety recommendation 2002-07

In March and April 2002 respectively, Heathrow Air Traffic Control and Heathrow Airport Limited notified the AAIB that they would accept the safety recommendation.

1. This was correct at the time of the incident but has since been modified to include night rotation.
2. The DETR responsibilities have now been assumed by the Department for Transport, Local Government and the Regions (DTLR).
3. Runway 5 is no longer in use as an operational runway at Heathrow
4. Aerodrome Control Room Supervisor (a supervisory function usually performed by the ATC Watch Manager)