AAIB Bulletin No: 10/99 **Ref: EW/C99/1/3** **Category: 1.1**

Aircraft Type and Registration:	Boeing 767-323 ER, N373AA
No & Type of Engines:	2 General Electric CF6-80 C2B6 turbofan engines
Year of Manufacture:	1992
Date & Time (UTC):	15 January 1999 at 0611 hrs
Location:	London Heathrow Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 13 Passengers - 178
Injuries:	Crew - Nil Passengers - Nil
Nature of Damage:	Compression buckling of fuselage crown skin
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	48 years
Commander's Flying Experience:	15,000 hours (of which 1,149 hours were on type) Last 90 days – 92 hours Last 28 days - 16 hours
Information Source:	AAIB Field Investigation

History of flight

On entering UK airspace after a flight from Chicago International Airport the commander, as handling pilot, briefed his flight crew for an approach and landing on Runway 27L at London Heathrow Airport (LHR). During the descent, the landing runway was changed to 27R and the commander rebriefed his crew. Additionally, he was advised by ATC that there would be no delays for his approach and he reduced his airspeed to ensure a landing after 0600 hrs.

For his approach, the commander had selected manual braking and manual spoilers. The crew were visual with the runway at about 3,000 feet amsl and the commander disconnected the autopilot between 3,000 and 2,000 feet amsl. There was some slight 'Chop' on the approach and the aircraft was stabilised with landing flap (Flap 30) by 1,000 feet amsl; at 500 feet amsl, the commander disconnected the autothrottle. Vref had been checked as 140 kt and, with the reported surface wind of 220°/11 kt, 146 kt was used as the approach speed. At approximately 30 feet agl, the commander flared N373AA and then retarded the throttles as the aircraft approached the runway surface. The maingear touched gently and the commander was aware of the aircraft skipping slightly. The throttles were maintained at idle and the commander felt that the aircraft began 'porpoising' over the next few seconds and, at one stage was aware that the nosewheel came down firmly on the runway. Then, with N373AA on the runway on all three gears, the commander selected reverse thrust and commenced manual wheel braking. There were no apparent problems with the aircraft while taxiing to the allocated stand except that a 'Cabin door open' light illuminated for a short period. On stand, shutdown was normal and the commander made an entry in the technical log for a 'heavy landing' check; he was then advised by a ground engineer that there appeared to be some damage to the outside of the fuselage.

There were two other flight crews on the flight deck. One was the allocated first officer and he was in his normal seat position; the other was another first officer who was the nominated 'International Relief Officer' and he was seated in the centre jump seat positioned directly behind the throttle quadrant. Both these pilots considered that the approach was accurately and smoothly flown culminating in a normal flare at the computed speed. The normal height calls were made by the aircraft automatic system and the operating first officer also made a call of "50 feet". Both first officers agreed that initial runway contact was on the main gears and that the aircraft then skipped. The operating first officer was aware that the control wheel moved forward and thought that the next ground contact was firm but nosewheel first; the jump seat pilot also considered the contact to be firm but that the main and nose gears touched together. There was then some lateral movement of the aircraft before the operating first officer thought that the aircraft skipped twice more with intermediate ground contact on either all three gears simultaneously or possibly nosewheel first. Towards the end of this sequence, the operating first officer was aware of applying some back pressure on the control wheel to restrict its forward movement. On the subsequent retardation on the runway, the jump seat pilot noted that the 'Left Aft Entry Door' status message illuminated on the EICAS for a short period.

The purser was sitting near the forward left door and described the first landing he detected as "Firm". He thought that the aircraft might have skipped twice culminating in a final firm contact. The purser could see all of the interior of the First Class cabin and part of the Business Class cabin and noted that about 12 overhead bins popped open, one oxygen panel opened and the panel of the centre video monitor in the Business Class cabin came down. After landing, the purser confirmed with his flight attendants that no other panels had opened and that there were no apparent or reported injuries.

All crew members confirmed that the aircraft had no significant unserviceabilities prior to departure from Chicago and appeared fully serviceable during the flight to LHR.

Damage to the aircraft

The technician assigned to oversee the arrival and perform the walk-round check saw the aircraft taxi down the centreline of the stand. He noticed that the left overwing emergency lights were illuminated but were extinguished by the time the aircraft had parked. As he commenced his check, he quickly noticed the presence of severe circumferential wrinkling of the fuselage crown skin situated above the aft edge of the forward freight bay door and running from one window belt line to the other. He went straight up to the flight deck and asked the crew to inspect the damage outside with him. He reported that there was some considerable surprise when he mentioned that damage was visible and even more so when the crew saw for themselves its extent.

More detailed examination showed the presence of a compression buckle of the fuselage skin and stringers located between the fuselage frames at stations 610 and 632, running between stringers 13L and 14R. In one small area, the buckling was severe enough to have ruptured the skin and daylight could be seen when viewed from inside. There was no apparent damage to the lower fuselage or to any landing gear structure. After a temporary external patch repair, the aircraft was ferried back to the USA where permanent repairs were carried out. A scheme for the temporary repair already existed since this operator had suffered identical damage to another of its B767-300 aircraft during a landing at Sao Paulo, Brazil in October 1992 (see 'Previous accidents' below).

Checks on the Business Class video monitor, 'Door' warning and left overwing emergency lights confirmed their serviceability; it was concluded that their intermittent activation was caused by the force of the landing.

FDR information

The aircraft was equipped with a 25-hour duration, digital flight data recorder (DFDR) and a 30-minute duration cockpit voice recorder (CVR). The only unserviceability noted was that the tape erase facility in the CVR was inoperative. The effect of this was that some recordings made more than 30 minutes previously had been preserved. This additional recording time enabled a CVR record of the approach, landing and taxi onto the stand to be available to the investigation.

Both CVR and DFDR recordings confirm that the flight was uneventful until touchdown. The CVR indicated that the crew were operating in a competent and co-operative way. The earliest recording on the CVR tape was a crew discussion on the use of ground spoilers and reverse thrust. Although subsequent recordings overwrote part of this discussion, it was clear that the commander wanted to accomplish a smooth touchdown; later comments indicated that he was concerned about landing with a forward CG (19%) in the reported gusting crosswind conditions. There was also a discussion about the use of automatic or manual spoilers; the result was that the commander decided to use manual spoilers.

Figure 1 is a graphical time history of relevant DFDR parameters during the final approach and landing. The approach was accurately and smoothly flown. Then, after a normal flare, the aircraft touched down smoothly on the main landing gear at an airspeed of 146 kt and with a positive pitch attitude of 4°. N373AA subsequently bounced three times resulting in 4 touchdowns over a total period of 6 seconds; during this time both thrust levers, which had been retarded at a constant rate between the flare and initial touchdown, remained at idle. Additionally, over the same period, the roll attitude of the aircraft varied between 3° left and 1° right. With no movement in the thrust levers and no major changes in roll attitude during these 'bounces', it was necessary to concentrate on the changes in longitudinal control inputs and pitch attitude changes together with normal acceleration recordings.

The vertical velocity at the Centre of Gravity, derived from recorded accelerations and attitudes as the main landing gear alternately compressed and rebounded during landing, indicated a maximum recorded normal acceleration of 1.5g; this was not excessive but, if coupled with high pitch rates and vertical velocities of the nose gear, could result in high stresses on the airframe.

There were high pitch rates generated during the 'bounces'. However, the recorded time histories of pitch attitude and elevator angle could not be used to analyse accurately the dynamics of the aircraft attitude during this period. Firstly, the DFDR did not sample pitch attitude and elevator angle sufficiently frequently and secondly, control column position was not recorded. Additionally, the recorded elevator angle was not a direct record of the actual elevator angle; on Boeing 757 and 767 aircraft, control position data is filtered within the Engine Instrument Crew Alert System (EICAS). Analysis by the aircraft manufacturer, during the investigation of similar accidents, has shown that the effect of the filter can cause the recorded elevator angle samples to differ from the actual elevator angle by up to 20°. Therefore, it was not possible to accurately interpret the relationship between the longitudinal control inputs and the aircraft pitch attitudes.

Nevertheless, it was possible to assess the pitch attitudes of the aircraft at the point of changeover from air to ground logic and to interpret the rate of change of pitch just prior to these points. On the initial touchdown, the pitch attitude had been relatively constant for two seconds at plus 3.5°. The second touchdown was at plus 1.5° with the pitch decreasing. The third touchdown was at plus 0.5° again with the pitch decreasing. The final landing was at minus 1.0° again with the pitch decreasing. The pitch attitudes were fluctuating as the aircraft was bouncing. The most extreme nose down pitch attitude occurred on the final touchdown. Audio recording from the cockpit area microphone channel also indicated that this final touchdown was the firmest. It was also fortunate that the CVR recording provided a subjective input from the pilots during the taxi to stand.

Operational information

The commander's experience on B767 was mainly achieved as a first officer with the company between 1986 and 1988. He has been a captain for the last ten years and returned to the B767 in November 1998; since then, he has achieved a further 51 hours on type.

At the time of the accident, the company instructions pertaining to the use of auto spoilers was as follows: 'The auto spoilers, if operative, must be armed for: All CAT 11 and CAT 111 Autolandings; Whenever auto brakes are used; Whenever a tailwind exists. When use of auto spoilers is not required by one or more of the above, the auto spoilers may be used at the Captain's discretion.'

Following the accident and, after review by the company, the following instruction was issued to crews on 14 May 99: 'The auto spoilers, if operative, will be armed for all landings.'

Boeing Commercial Airplane Group was asked about its views on the use of auto spoilers; in particular would their use in this accident have prevented the initial bounce and what effect spoiler deployment has on aircraft pitch attitude. The company confirmed that it recommended the use of auto spoilers but did not require it and stated that one of the advantages of the system was to minimise the possibility of a bounce on landing. Their simulation work on the N373AA accident suggested that the bounce may not have occurred had auto spoilers been used. However, Boeing added that the use of auto spoilers may not have prevented the damage to the aircraft. The company also confirmed that spoiler deployment results in a small nose up pitching moment but that this is easily controlled by the pilot.

Previous accidents

Three previous landing accidents to Boeing 767-300 aircraft resulted in damage to the fuselage upper crown in a similar location to that seen on N373AA. These occurred on 16 Jan 92 in Korea, 27 Oct 92 in Brazil and 31 Dec 93 in Poland. The first accident caused more severe damage in that the skin and stringer buckling extended to the lower fuselage and also caused structural damage in the region of the nose gear landing bay.

Following the first two accidents, the National Transportation Safety Board (NTSB) convened a special investigations group to review B767 hard landings and the potential for crown skin distortions. Boeing Commercial Airplane Group stated to this group that the Boeing 767-300 structure was designed to withstand maximum nose down pitch rates after mainwheel touchdown of 8° per second or maximum sink rates of 10 feet per second on all three landing gears. In the case where the mainwheels are still airborne and the nosewheel strikes first, the structure may experience a combination of the two components which fall outside the design requirements. The Boeing 767-300 has sufficient elevator authority to exceed the 8° per second pitch rate at touchdown. The company concluded that the damage to both aircraft was a result of the pilot applying full nose down elevator after main wheel touchdown and a subsequent bounce resulting in excessive pitch rate at nose gear contact and thus transferring excessive loads to the fuselage crown. For the first accident, auto spoilers were used but manual spoilers were selected for the second accident. During the meeting, the use of auto spoilers was discussed. There was concern that the use of auto spoilers during landing often resulted in a pitch-up of the nose gear after main gear touchdown thus leading to the pilot to compensate with excessive nose down pitch command. The special investigations group agreed with the Boeing conclusions.

The third accident was also attributed to excessive nose down elevator being applied after initial main gear touchdown; the aircraft also bounced on landing. Auto spoilers had been pre-selected but did not deploy because the throttles had not been retarded to the idle position.

In summary, it was concluded that all three accidents had the following common characteristics:

1. Excessive nose down elevator commanded
2. Bounce after initial main gear touchdown
3. Operating in moderate to high crosswinds

Figures were also presented by Boeing Commercial Airplane Group to the NTSB investigation which showed that, in the area in which the damage had occurred in the three accidents, the structural capability matched the design envelope with no reserve in respect of the ultimate vertical bending moment. Thus, with such a moment imparted by a nose landing gear impact beyond the design envelope, damage in the area in which it occurred in all recorded cases would be expected. The same presentation also mentioned two product-improvement modifications which had been introduced on later aircraft. The first, PRR 12601, increased the fuselage stringer metal gauge by 0.008" between stations 434 and 654 and stringers 7L to 7R. This was applied at production from aircraft S/No 563, was only applicable to B767-300 passenger aircraft and no retro-fit was planned. This change gave a 20% margin in structural capability beyond the design envelope at the critical point.

The second modification, PRR 12618, changed the metering pin in the NLG shock-strut to "reduce the peak vertical gear load at the maximum stroke of the nose gear". Introduced on production from aircraft S/No. 547, this modification was applicable to all B767-300 aircraft and was available for retrofit. Since disassembly of the strut is required, the modification was best accomplished at overhaul.

The serial number of N737AA was 200; neither modification had been incorporated on the aircraft.

Following the three investigations, NTSB investigators highlighted the difficulty of interpreting the flight control position. They stated that the action of the filter within the EICAS, which is not reversible, introduces a time shift and an amplitude distortion in the recorded data. Furthermore the data sampling rate was inadequate. Tests undertaken by Boeing Commercial Airplane Group showed that rapid movements of the B767 elevator may result in the recorded elevator position differing from the actual elevator position by greater than 20°. Eurocae ED 55 at Table A1-1 and FAR 14 CFR 121 at Appendix B require that flight control position data be recorded to an accuracy of ±2°. The NTSB recommended that the FAA:

1. "Require design modifications to the Boeing 757/767 so that flight control position data to the DFDR is accurate and not filtered by the EICAS. The sample rate should also be increased to an appropriate value." (NTSB Safety Recommendation A-94-120).

2. "Review other airplane designs to ensure that flight control position data to the DFDR is accurately recorded and that flight control position data filtered by systems such as EICAS is not substituted for accurate data." (NTSB Safety Recommendation A-94-121).

In July 1997 the FAA published a final rule (14 CFR 121, et al) accepting these recommendations and extending their scope to cover all recorded parameters. To satisfy this rule Boeing issued a service letter (767-SL-31-036-A) in August 1998, mandated by FAA airworthiness directive (AD) 96-07-09, requiring that a modified EICAS computer be fitted by May 2000. This modification enables the EICAS computer to make raw control surface data available to the flight data recorder. Furthermore recording of control surface position must to be increased in frequency by August 2001. These modifications had yet to be embodied on N373AA.

Analysis

The aircraft was fully serviceable during the flight and the approach was accurately and smoothly flown. The accident sequence started when the aircraft bounced on the first touchdown and the FDR evidence, together with CVR and crew information, indicate that the damage to the aircraft resulted from a subsequent Pilot Induced Oscillation (PIO). This PIO was initiated as the aircraft bounced on the first touchdown and the damage probably occurred on the final touchdown. Investigations into similar previous accidents concluded that the common characteristics were an excessive down elevator demand, a bounce after initial main gear touchdown and operation in moderate to strong crosswinds. In the accident involving N373AA, the bounce occurred but the crosswind was light. The extent of the nose down elevator demand could not be accurately determined because of the recording system and so this aspect became more subjective. Without the evidence from the CVR and comprehensive and honest crew recollection, it would have been very difficult to ascertain the sequence of events. Accordingly, it would be appropriate to hasten the recommendations initiated by the NTSB and to ensure that similar deficiencies do not occur in other aircraft. Therefore, it is recommended that:

99-43 The Civil Aviation Authority initiate action to change Joint Aviation Authority requirements in JAR OPS 1.715 (d), 1.720 (d) & 1.725 (d), which currently read:

"Data must be obtained from aircraft sources which enable accurate correlation with information displayed to the flight crew".

and which should be rewritten to read:

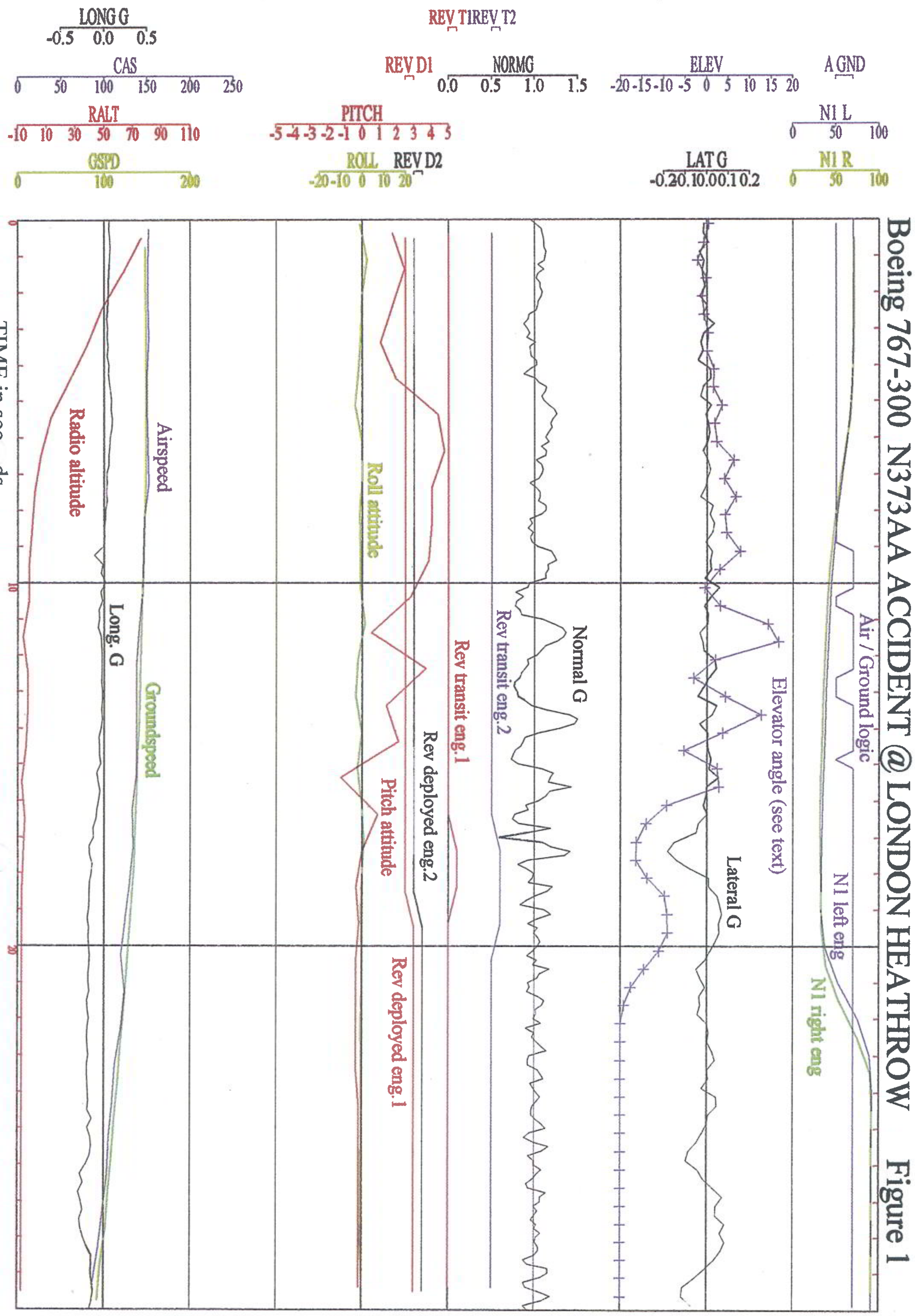
" Ensure that accurate data is recorded on the DFDR and that data filtered by systems for display to the flight crew is not substituted for accurate data."

Note: Changes to 1.720 and 1.725 are required to cater for the situation where modern, novel and/or unique avionics are fitted into old airframes. The revised paragraph should be added to 1.715 to cater for DFDR designs in new aircraft.

99-44 The Civil Aviation Authority alert Eurocae WG50 to the problems posed by filtered data so as to ensure that the latest revision of ED55 contains suitable advice on the need to avoid substituting filtered data for accurate data in recording systems.

99-45 The Civil Aviation Authority should review aircraft designs to ensure that data on the DFDR is accurately recorded and require that B757/767 on the UK register be modified either to record accurate surface position data or require that the surface position data filtered by the EICAS be supplemented by control input data sampled at an acceptable rate.

It is also possible that the accident may not have occurred if the auto spoilers had been armed and prevented the aircraft bouncing on landing; the manufacturer acknowledged, from their simulation work on the accident landing that the bounce may not have occurred if the auto spoilers had been used. While accepting that excessive forward control column movement after touchdown is inappropriate, it is difficult to imagine an experienced airline pilot inputting such a movement during a normal touchdown. However, a bounce requires some correction and excessive forward movement of the control column in that situation is more understandable. If auto spoilers are always used, pilots will become accustomed to the effects of spoiler deployment; Boeing Commercial Airplane Group acknowledge that the pitch up resulting from spoiler deployment is easily controlled by the pilot. Therefore, there seems to be no advantage in allowing pilots the option of when they use auto spoilers; indeed, there is an advantage in standardising the landing configuration as much as possible. Following the accident and a subsequent internal review, the operating company established a requirement to always use auto spoilers, if operative.


Boeing 767-300 N373AA ACCIDENT @ LONDON HEATHROW
Figure 1
LONG G
-0.5 0.0 0.5
CAS
0 50 100 150 200 250
RALT
-10 10 30 50 70 90 110
GSPD
0 100 200
REV T1REV T2
REV D1
NORMG
0.0 0.5 1.0 1.5
PITCH
-5 -4 -3 -2 -1 0 1 2 3 4 5
ROLL
-20 -10 0 10 20
REV D2
ELEV
-20 -15 -10 -5 0 5 10 15 20
LAT G
-0.2 0.1 0.0 0.1 0.2
A GND
N1 L
0 50 100
N1 R
0 50 100
Radio altitude
Airspeed
Long. G
Groundspeed
Roll attitude
Pitch attitude
Rev deployed eng.2
Rev deployed eng.1
Rev transit eng.1
Rev transit eng.2
Normal G
Elevator angle (see text)
Lateral G
Air / Ground logic
N1 left eng
N1 right eng
TIME in seconds