

Boeing 747-236B, G-BDXX

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Aircraft Type and Registration:	Boeing 747-236B, G-BDXX
No & Type of Engines:	4 Rolls Royce RB211-524D4 turbofan engines
Year of Manufacture:	1981
Date & Time (UTC):	2 November 1996 at 2330 hrs
Location:	Near Gatwick, Sussex
Type of Flight:	Public Transport
Persons on Board:	Crew - 18 - Passengers - 306
Injuries:	Crew - None - Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	N/A
Commander's Flying Experience:	
	Last 90 days - N/K
	Last 28 days - N/K
Information Source:	AAIB Field Investigation

History of the flight

When the crew checked in for the flight on the evening of 2 November 1996, they were informed that there was a problem with door 4L, but that the engineers were confident that the aircraft would be declared fit for service at or near the scheduled departure time. This proved to be the case and the flight engineer checked the door for satisfactory operation. However, due to a recent history of problems with this door, the cabin crew responsible for it were briefed to monitor it after take-off and keep the flight deck informed of anything untoward.

Immediately after take-off, the door handle was seen to rotate from its normally closed 3 o'clock position to 1 o'clock. Two cabin crew immediately attended the door but experienced difficulty in keeping the handle in the closed position. The flight crew were informed, and upon completion of the "after take-off" checklist items, the flight engineer went aft to the door, and confirmed that a

considerable amount of force was required to hold the handle in position. He noted that as soon as pressure was relaxed, the handle started to move towards the open position. In addition, there was a loud noise of rushing air, which was apparent at the top and bottom of the door, as opposed to the sides. Two cabin crew were instructed to keep pressure applied to the handle. The flight engineer became concerned not only for the integrity of the door, but also about possible implications for the pressurisation of the aircraft. He therefore called the engineers at Gatwick and discussed the problem with them. They suggested letting go of the handle to see where it would stop. The flight crew declined to do this, and, after further discussion, elected to return to Gatwick. During this time, the aircraft had climbed to 21,000 ft to allow it to enter French airspace. The captain had reassured the cabin crew that the door, being a "plug" type, could not come open. However, the cabin crew were understandably becoming increasingly alarmed, and this was instrumental in the decision to return. The aircraft dumped 46 tonnes of fuel and carried out an uneventful approach and landing. During the latter stages of the flight, the cabin crew looped together some extension seatbelts in an attempt to secure the door handle in the closed position.

Basic description of door

All the main entry doors share the same principles of operation, with doors 2 and 4 having identical latch roller cranks and torque tubes, which constitute the significant components in this incident. A diagram of the door is attached at Figure 1, which shows the principal features. The operating handle is attached to a crank mechanism. Rotation of the handle causes linear motion in the two adjustable control rods emanating from the crank mechanism, and in consequence, rotation of the upper and lower torque tubes. Latch rollers at each end of both tubes engage with cam slot plates attached to the door frame. The "door open" microswitch is located on the lower aft cam slot plate. Additional adjustable control rods on the torque tubes are connected to the upper and lower "gates", which are hinged sections of the door skin, located top and bottom. These fold inwards thereby reducing the door dimensions to less than the door aperture, thus allowing the inward movement of the door. When the door handle is moved towards the fully closed position, the door is pulled into the aperture by the reaction of the latch rollers against the inboard edge of the cam slots. When the door is flush with the fuselage skin, the bellcranks on the upper and lower torque tubes are just about to go into their over-centre positions and the upper gate is resting against a step on the inboard surface of the fuselage skin. The final part of the handle rotation pulls the door into position so that the torque tube bellcranks roll over into an over-centre position. Eighteen door stops (nine either side) are abutted against load bearing lugs on the inside of the door frame. Thus pressurisation forces push the door firmly against the lugs, in accordance with the concept of a "plug" door. When the door is opened, the initial rotation of the handle disengages the latch rollers. The handle mechanism is linked to the door hinge, and further handle rotation moves the door bodily a short distance inwards, into the cabin. The door then turns through approximately 90° so that it can be swung outwards, trailing edge first through the aperture, and forwards against the fuselage side.

Recent door problems

On 26 October, the 4L door warning light illuminated on the flight deck shortly after take-off, and with approximately 1.5 psi pressure differential applied. The cabin pressure remained normal, but the door handle was not fully closed. The handle was pushed to the fully closed position, but popped up again immediately. However, a further attempt at reselecting fully closed appeared to be successful.

After landing, it was found that the forward end of the upper torque tube had failed, thus releasing the forward latch crank. The aircraft was taken out of service and a new torque tube and latch crank

were fitted by the night shift team. The door was rigged during the following day but difficulties were encountered in that the pull-off load on the door handle (i.e. the force required to move the handle away from its closed position) was too low. A number of adjustments were made which brought the release load into limits and the aircraft was released for service on the evening of 27 October.

On 27 October (the first flight following the rectification), the 4L door light again illuminated during the climb. Pushing down on the door handle extinguished the light. The door was checked when the aircraft landed, whereupon it was confirmed that it was difficult to close unless it was pushed on "the top right hand corner". An acceptable deferred defect (ADD) was raised to re-rig the door during the next maintenance input. During the next sector, on 28 October, the door warning light again illuminated, together with associated movement of the door handle. When the aircraft returned to Gatwick, the door was rigged in accordance with Maintenance Manual requirements and the door warning microswitch was also adjusted. These actions cleared the ADD.

On 30 October the same symptoms, i.e. warning light and handle movement recurred, this time in the cruise. On arrival, a "vast quantity of water was found around the floor/girt bar..." but no other defects were noted. Another ADD was raised for further investigation. The same problems with door 4L latching continued to occur during the three sectors flown on 31 October. The maintenance activity on that day included a further check of the door handle release loads, plus lubrication of the microswitch. A further occurrence on the 1st November resulted in the door handle being tied down for the rest of the flight. An "inoperative" label was subsequently attached to the door and a further ADD raised. This resulted in the additional maintenance at Gatwick, and preceded the subject incident on 2 November which was notified to AAIB.

The entire sequence of events subsequently formed the subject of a Quality Assurance investigation by the airline. In addition, the aircraft manufacturer contributed to the technical investigation.

Examination of door components

General

On arrival back at Gatwick on 2 November, the aircraft was removed from service for investigation. Following removal of trim components, the aircraft was pressurised in an attempt to reproduce the defect. At 0.6 psi it was found that the door handle moved towards the unlock position. After comparison with another door, the engineers discovered that the upper torque tube that had been installed on 26 October had been drilled such that there was an incorrect angular relationship between two sets of holes. Each latch roller crank is retained in the end of the torque tube by a pair of bolts, one at 90° to the other, located across the tube diameter. Another pair of holes is drilled in the centre of the tube for the purpose of attaching the operating bellcrank. A tooling hole is drilled at either end of the tube, inboard of the latch crank bolt holes. When the replacement torque tube was compared with the failed one, it was found that the axes of the bellcrank bolt holes had been drilled with approximately 18° of circumferential displacement from their correct position. As a result it would have been impossible to rig the door correctly, although the angular error could be largely compensated by extreme adjustment of the control rods attaching to the torque tube. Figure 2 shows a sketch of the tube, together with the relative positions of the various holes.

Metallurgical examination of the torque tubes

Both the failed tube and the wrongly drilled replacement, together with the failed latch crank, were subjected to metallurgical examinations. The latch crank fitting, which had been machined from an aluminium alloy forging, had suffered a single torsional overload as a result of a segment breaking out of the tube. The fracture in the tube resulted from a low cycle, high stress tension fatigue mechanism which split the tube at its end and progressed in a longitudinal direction. After approximately 1 inch the crack branched into two, with one arm running diagonally back to the end of the tube by way of one of the outer latch crank bolt holes, thereby releasing the segment of tube noted above. The other branch went to one of the inner bolt holes. An additional crack extended from these branches, following a helical line, to the adjacent tooling hole. The tube was also longitudinally cracked in the diametrically opposite position, with the crack running into an inner latch crank bolt hole.

The tube was sectioned and it was apparent that some of the fracture surfaces were stained, suggesting that the cracks had existed for some time. There was no plastic deformation associated with the fractures, indicating that the material was of low ductility. The overall conclusion was that the failure had resulted from a low cycle fatigue mechanism, with crack development being accelerated by stress corrosion under the static loads imposed when the door was in a closed and latched position.

Hardness and flattening tests were conducted on both the failed tube and its replacement, which revealed marked differences in the material properties. The hardness values indicated that the tensile strengths of the failed and the new tube materials were 208,000 and 155,000 lbf/in² respectively. The end of the new tube could be flattened to half-diameter without cracking, whereas the failed tube cracked longitudinally without plastic deformation.

The manufacturer is aware of a history of cracking of the latch torque tubes, and has addressed the problem by means of Boeing Service Letter 747-SL-52-25, with Revision 'B' dated November 1984. The document emphasises that there has been no operational difficulty associated with cracked or failed torque tubes, but suggested that operators take action by reworking or replacing the tubes with components made from improved ductility material, which is achieved by a lower temperature heat treatment process. The airline has stated that torque tubes are being replaced on an "as and when" basis, with the stores inventory records showing that four units have been drawn up to the time of this incident. The tests indicated that the incorrectly drilled item was made from the improved material.

Effect of mis-drilled holes on door operation

The design of the door is such that unlike the upper gate, the lower gate is not in a "hard" contact with the sill during the final part of the latching sequence thus giving rise to a non-symmetrical distribution of loads in the upper and lower torque tube linkages. The aircraft manufacturer stated that 80% of the overcentre lock loads are generated by the correct relationship of the upper torque tube, its associated door gate and control rods. The remaining 20% is created by the lower latching mechanism and the latch rollers locating overcentre. Unless all the components are installed in the correct relationship to each other, the latching sequence will not operate correctly. The angular position of the centre bellcrank on the torque tube, with the 18° error, meant that it would not have been possible for the linkage to achieve the correct overcentre lock required to keep the door latched, even by utilising the full extent of the adjustment available in the control rods. The manufacturer additionally stated that without the overcentre lock, but with the correct rigging adjustments, it is possible that the door would remain latched during normal operations. However the latching mechanism would have been susceptible to movement with the slightest disturbance. It is possible

that such a disturbance could result from a small amount of door movement arising from increasing pressurisation loads as the aircraft left the ground.

In the event that there was some movement of the top of the door relative to the frame (and hence the cam slot plate), it would result in a small amount of rotation of the latch cranks and the torque tube. This would back-drive the door operating linkage, overcoming any marginal over-centre condition, thus causing the handle to move. Remembering that the torque tubes are connected to the gates, it is apparent that the latter would also have moved, thus accounting for the wind noise at the top and bottom of the door.

Effect on flight safety

The door is essentially a "plug" design, such that load holding the door in the fuselage frame are a function of cabin differential pressure. Boeing have indicated that with the aircraft at an altitude of 1,500 ft, the cabin differential pressure is typically 0.3 psi, leading to a closing force on the door of 900 lbs. They additionally indicated that the handle mechanism is not capable of moving the door when the differential pressure exceeds 0.18 psi. Above this value, there is no possibility of the door moving from its position in the fuselage regardless of the handle position. Thus any risk of the door moving is confined to such times as when the differential pressure is close to zero. Boeing stated that aerodynamic studies showed that in the event that the latches became disengaged, thereby making the door susceptible to moving inwards to the "cocked" position under the action of vibration, then airflow forces would not cause the door to fully open.

Note: The standard take-off configuration for the Boeing 747 is with the air conditioning packs to be turned OFF. This results in a slight negative pressure in the cabin until approximately 700 ft, when the first pack comes on line. For landing, the standard procedure is to keep the packs ON. This maintains a slight but decreasing positive pressure in the cabin until touchdown.

There is in fact an Emergency Procedure in both the Flight and Operations Manuals for "Upper and Main Deck Smoke Evacuation", which details the procedures for opening the main entry doors in flight for the purpose of clearing smoke from the cabin. Airflow forces will cause the door to be retained in the "cocked" position, such that a gap of approximately 2 inches can be expected around the periphery of the door. The door can be left unattended in this position, with no danger of persons falling from the aircraft through such a small opening.

Quality assurance investigation

During the airline's investigation, all the personnel involved were interviewed with the aim of detailing the events that led up to the fitment of the wrongly drilled torque tube and the subsequent release to service of the aircraft. The first report of problems with the door was on October 26, and resulted in the discovery, at Gatwick of the broken torque tube and latch crank. A new tube and crank assembly were ordered from Heathrow. The rectification requirements were considered outside the scope of ramp maintenance, with the result that at 1900 hrs (i.e. the start of the night shift), the aircraft was handed over to the Gatwick Support Unit for investigation and repair. A verbal handover was given to the shift Fleet Technical Liaison Engineer (FTLE). There was a shortage of certifying staff and a Licensed Aircraft Engineer (LAE) had to be called in on overtime. Pending his arrival, two hangar engineers were given the task of removing the door trim.

The LAE arrived at 2100 hrs and was briefed by the FTLE. He had replaced a door torque tube on a previous occasion, at Heathrow, and was happy to accept the task. He was also asked to investigate an APU fault and a toilet problem on the aircraft.

Whilst awaiting the arrival of the parts ordered from Heathrow, the unserviceable tube and latch assembly was removed from the door, after the door-to-tube relationship had been marked on the adjacent door frame. An inspection of the door was also carried out at this time and it was noted that there were witness marks on the external surface of the forward upper cam slot plate, indicating that the associated latch roller had not been correctly located. This in turn suggested that the door had not been rigged correctly.

The new torque tube arrived at 0030 hrs and was found to be undrilled, apart from the tooling hole at each end. The Maintenance Manual called up a drill jig, which is designed to be attached to the tube via the tooling holes, thus allowing the latch crank and the central bellcrank holes to be drilled off. However, the drill jig was not available and the main workshops were closed for the night. The decision was made by the LAE and the FTLE to drill the tube in the area workshop. Consideration was given to calling out the workshop engineer and to leaving the task until the morning, but these options were discounted due to time constraints and the operational requirement for the aircraft.

Note: Once the non-availability of the drill jig became apparent, it would not have been possible to comply with the Maintenance Manual requirements. The correct action would have been to call the Fleet Technical Office who have the necessary CAA approval to issue Engineering Orders covering work that falls outside the Maintenance Manual. It was subsequently established that the airline had never held the drill jig. The LAE had of course faced a similar situation on the previous occasion he had replaced a torque tube. However, at that time he had had the facilities of the main workshops available to him.

After bolting the new tube to the damaged tube through the tooling holes, and using the existing latch crank holes in the damaged tube as guides, it was possible to drill two of the latch crank holes in the new tube with the aid of a pillar drill. The second set of holes were at 90° to the first, and these were drilled, after their positions had been marked, by means of a rechargeable hand drill. This part of the operation was witnessed by the FTLE and other engineers, but was not overseen by the LAE, who was away investigating the other two defects on the aircraft.

To drill the centre bellcrank mounting holes in the torque tube, the LAE marked their positions after obtaining the necessary angular relationships from the Maintenance Manual, and also by comparison with the old tube. Once satisfied, the new tube was installed in the door and the latch cranks bolted into position. After alignment with the marks made on the door frame during disassembly, the LAE instructed the engineers to drill the centre bellcrank holes. It must be presumed that the angular error arose at some point in the marking/alignment process, possibly as a result of mis-reading the drawings in the Maintenance Manual.

The Maintenance Manual required the tube to be painted with primer prior to assembly, and also called up a corrosion preventive compound. However, the tube is an interference fit through three bearings and unless the primer was allowed to dry, it would have been scraped off on assembly. The components were not wet-assembled as it was intended to apply a corrosion inhibitor to the area on completion of the work. However, this instruction was omitted from the subsequent handover to the day shift.

Rigging of the door commenced at approximately 0230 hrs and continued for three hours. By 0530 hrs, the door was fairing correctly but the "pull-off" load on the door handle (i.e. the force required to move the handle away from its closed position) was below the 20 to 25 lbs required by the Maintenance Manual. The team were very tired by this time and so it was decided to hand the task over to the incoming day shift. The work that had been carried out so far, together with the outstanding tasks, was documented in the aircraft Technical Log. No stage sheets were raised (see the Note below) as the job was considered straightforward enough to be contained within the Technical Log. However, the LAE did produce a written handover for the next team, although this was never actually seen by anyone.

Note: In some maintenance situations, operators use pre-planned stage sheets which briefly describe each action required, giving the appropriate Maintenance Manual reference and providing boxes for the authorising signatures. Whilst these documents should not be used in place of the Maintenance Manual, they nevertheless serve as an aide-memoir and provide confirmation that all critical tasks have been completed. Thus stage sheets can be of considerable benefit in the non-scheduled maintenance environment.

A day shift LAE was not available, and so a verbal handover was made to one of the two hangar engineers assigned to complete the task. This engineer was unaware of any written information other than that in the Technical Log and did not see the handover notes written by the night shift LAE. Later on, another LAE was tasked with co-ordinating the activity on the door in addition to his other work. He therefore made frequent visits to the aircraft as work progressed. The work was mainly directed to obtaining the correct pull-off load on the door handle, and included adjustment of the operating rods, the torque tube and the forward latch guide. A considerable amount of free play was also identified within the handle mechanism, and was eliminated by re-tightening the central mounting bolt. Eventually, a pull-off load of 20 lbs was achieved, which was considered satisfactory. The door was inspected by the LAE, who considered that all the Maintenance Manual requirements had been met, and was then reassembled. The aircraft was released for service at 1700 hrs on October 27.

The aircraft continued to experience problems with the door, as described earlier, culminating in the incident on November 2. When the drilling error became apparent, another torque tube was obtained and drilled off in the main workshops using a vertical milling machine incorporating a dividing head and a digital dial test indicator. The door was subsequently reassembled and rigged with no problems, the handle pull-off load now being 25 lbs, as required by the Maintenance Manual. The aircraft was returned to service with no further door problems since being reported.

Conclusions and follow-up action

Following its investigation, the airline made the following observations:

1. The Maintenance Manual requirements were not followed in respect of; a) Not using a drill jig when drilling the torque tube; b) Failure to call the Fleet Technical Office when it was apparent that the work now fell outside the Maintenance Manual, c) Failing to protect the tube with primer and to "wet assemble" during installation.
2. The work should not have proceeded without the jig, workshop or technical support.

3. The LAE in charge was on overtime and working three defects. He made the decision to proceed with the work without the jig, due to commercial pressures, and was not supervising the work when the tube was being drilled.

4. No stage sheets were used following the initial tube replacement, and no written handover could be found.

5. No consideration was given at the time that something could be wrong when the handle pull-off load requirement could not be met, or when the door could not be rigged easily.

6. When the aircraft returned from its first trip the full extent of the problem was not appreciated by the engineering organisation. Also, the problem was not detected by the appropriate Reliability section after the subsequent flights and the numerous failed attempts to rectify the defect.

7. No entries were made in the Technical Log by the flight crew to emphasise the magnitude of the problem.

Measures adopted since the incident have included ordering a torque tube drill jig as specified in the Maintenance Manual. However, in order to minimise dependency on the jig, it is intended to order pre-drilled torque tubes from the manufacturer. It is also intended to establish a more effective control over the shift handover files. In addition, stage sheets are to be used whenever work is carried out in the hangar which is considered to be beyond the scope of ramp maintenance. Furthermore, the airline intends to publish the findings of the investigation, together with a statement, in an in-house publication, of the requirement to contact the Fleet Technical Office in the event that specialised equipment is unavailable.