Boeing 747-236B, G-BDXK

AAIB Bulletin No: 5/97 Ref: EW/C96/11/2Category: 1.1

Aircraft Type and Registration:	Boeing 747-236B, G-BDXK
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 November1996, they were informed that there was a problem with door 4L,but that the engineers were confident that the aircraft wouldbe declared fit for service at or near the scheduled departuretime. This proved to be the case and the flight engineer checkedthe door for satisfactory operation. However, due to a recenthistory of problems with this door, the cabin crew responsiblefor it were briefed to monitor it after take-off and keep theflight deck informed of anything untoward.

Immediately after take-off, the door handle was seen to rotatefrom its normally closed 3 o'clock position to 1 o'clock. Twocabin crew immediately attended the door but experienced difficultyin keeping the handle in the closed position. The flight crewwere informed, and upon completion of the "after take-off"checklist items, the flight engineer went aft to the door, andconfirmed that a considerable amount of force was required tohold the handle in position. He noted that as soon as pressurewas relaxed, the handle started to move towards the open position. In addition, there was a loud noise of rushing air, which wasapparent at the top and bottom of the door, as opposed to thesides. Two cabin crew were instructed to keep pressure appliedto the handle. The flight engineer became concerned not onlyfor the integrity of the door, but also about possible implicationsfor the pressurisation of the aircraft. He therefore called theengineers at Gatwick and discussed the problem with them. Theysuggested 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 aircrafthad climbed to 21,000 ft to allow it to enter French airspace. The captain had reassured the cabin crew that the door, beinga "plug" type, could not come open. However, the cabincrew were understandably becoming increasingly alarmed, and thiswas instrumental in the decision to return. The aircraft dumped46 tonnes of fuel and carried out an uneventful approach and landing. During the latter stages of the flight, the cabin crew loopedtogether some extension seatbelts in an attempt to secure thedoor 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 torquetubes, which constitute the significant components in this incident. A diagram of the door is attached at Figure 1, which shows theprincipal features. The operating handle is attached to a crankmechanism. Rotation of the handle causes linear motion in thetwo 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 slotplates attached to the door frame. The "door open" microswitchis located on the lower aft cam slot plate. Additional adjustablecontrol rods on the torque tubes are connected to the upper andlower "gates', which are hinged sections of the door skin,located top and bottom. These fold inwards thereby reducing thedoor dimensions to less than the door aperture, thus allowingthe inward movement of the door. When the door handle is movedtowards the fully closed position, the door is pulled into theaperture by the reaction of the latch rollers against the inboardedge of the cam slots. When the door is flush with the fuselageskin, the bellcranks on the upper and lower torque tubes arejust about to go into their over-centre positions and the uppergate is resting against a step on the inboard surface of the fuselageskin. The final part of the handle rotation pulls the door intoposition so that the torque tube bellcranks roll over into anovercentre position. Eighteen door stops (nine either side) areabutted against load bearing lugs on the inside of the door frame. Thus pressurisation forces push thedoor firmly against the lugs, in accordance with the concept ofa "plug" door. When the door is opened, the initialrotation of the handle disengages the latch rollers. The handlemechanism is linked to the door hinge, and further handle rotationmoves the door bodily a short distance inwards, into the cabin. The door then turns through approximately 90° so that itcan 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 flightdeck shortly after take-off, and with approximately 1.5 psi pressuredifferential applied. The cabin pressure remained normal, butthe door handle was not fully closed. The handle was pushed tothe 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 uppertorque tube had failed, thus releasing the forward latch crank. The aircraft was taken out of service and a new torque tube andlatch crank were fitted by the night shift team. The door wasrigged during the following day but difficulties were encounteredin that the pull-off load on the door handle (i.e. the force requiredto move the handle away from its closed position) was too low. A number of adjustments were made which brought the release loadinto limits and the aircraft was released for service on the eveningof 27 October.

On 27 October (the first flight following the rectification),the 4L door light again illuminated during the climb. Pushingdown on the door handle extinguished the light. The door waschecked when the aircraft landed, whereupon it was confirmed thatit was difficult to close unless it was pushed on "the topright hand corner" An acceptable deferred defect (ADD) wasraised to re-rig the door during the next maintenance input.During the next sector, on 28 October, the door warning lightagain illuminated, together with associated movement of the doorhandle. When the aircraft returned to Gatwick, the door was riggedin accordance with Maintenance Manual requirements. and the doorwarning microswitch was also adjusted. These actions clearedthe ADD.

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

The entire sequence of events subsequently formed the subjectof 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 removedfrom 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 theunlock position. After comparison with another door, the engineersdiscovered that the upper torque tube that had been installedon 26 October had been drilled such that there was an incorrectangular relationship between two sets of holes. Each latch rollercrank 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 forthe purpose of attaching the operating bellcrank. A tooling holeis drilled at either end of the tube, inboard of the latch crankbolt holes. When the replacement torque tube was compared withthe failed one, it was found that the axes of the bellcrank boltholes had been drilled with approximately 18° of circumferentialdisplacement from their correct position. As a result it wouldhave been impossible to rig the door correctly, although the angularerror could be largely compensated by extreme adjustment of thecontrol rods attaching to the torque tube. Figure 2 shows a sketchof the tube, together with the relative positions of the variousholes.

Metallurgical examination of the torque tubes

Both the failed tube and the wrongly drilled replacement, togetherwith the failed latch crank, were subjected to metallurgical examinations. The latch crank fitting, which had been machined from an aluminiumalloy forging, had suffered a single torsional overload as a resultof a segment breaking out of the tube. The fracture in the tuberesulted from a low cycle, high stress tension fatigue mechanismwhich split the tube at its end and progressed in a longitudinaldirection. After approximately 1inch the crack branched intotwo, with one arm running diagonally back to the end of the tubeby way of one of the outer latch crank bolt holes, thereby releasingthe segment of tube noted above. The other branch went to oneof the inner bolt holes. An additional crack extended from thesebranches, following a helical line, to the adjacent tooling hole. The tube was also longitudinally cracked in the diametricallyopposite position, with the crack running into an inner latchcrank bolt hole.

The tube was sectioned and it was apparent that some of the fracturesurfaces were stained, suggesting that the cracks had existedfor some time. There was no plastic deformation associated withthe fractures, indicating that the material was of low ductility. The overall conclusion was that the failure had resulted froma low cycle fatigue mechanism, with crack development being acceleratedby stress corrosion under the static loads imposed when the doorwas in a closed and latched position.

Hardness and flattening tests were conducted on both the failedtube and its replacement, which revealed marked differences inthe material properties. The hardness values indicated that thetensile strengths of the failed and the new tube materials were208,000 and 155,000 lbf/in2 respectively. The end of the new tube could be flattened to half-diameter withoutcracking, whereas the failed tube cracked longitudinally withoutplastic deformation.

The manufacturer is aware of a history of cracking of the latchtorque tubes, and has addressed the problem by means of BoeingService Letter 747-SL-52-25, with Revision 'B' dated November1984. The document emphasises that there has been no operationaldifficulty associated with cracked or failed torque tubes, butsuggested that operators take action by reworking or replacingthe 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 onan "as and when" basis, with the stores inventory recordsshowing that four units have been drawn up to the time of thisincident. The tests indicated that the incorrectly drilled itemwas made from the improved material.

Effect of mis-drillled holes on door operation

The design of the door is such that unlike the upper gate, thelower gate is not in a "hard" contact with the sillduring the final part of the latching sequence thus giving riseto a non-symmetrical distribution of loads in the upper and lowertorque tube linkages. The aircraft manufacture stated that 80%of the overcentre lock loads are generated by the correct relationshipof the upper torque tube, its associated door gate and controlrods. The remaining 20% is created by the lower latching mechanismand the latch rollers locating overcentre. Unless all the componentsare installed in the correct relationship to each other, the latchingsequence will not operate correctly. The angular position ofthe centre bellcrank on the torque tube, with the 18° error,meant that it would not have been possible for the linkage toachieve the correct overcentre lock required to keep the doorlatched, even by utilising the full extent of the adjustment availablein the control rods. The manufacturer additionally stated thatwithout the overcentre lock, but with the correct rigging adjustments,it is possible that the door would remain latched during normaloperations. However the latching mechanism would have been susceptibleto movement with the slightest disturbance. It is possible thatsuch a disturbance could result from a small amount of door movementarising from increasing pressurisation loads as the aircraft leftthe ground.

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

Effect on flight safety

The door is essentially a "plug" design, such that loadsholding the door in the fuselage frame are a function of cabindifferential pressure. Boeing have indicated that with the aircraftat an altitude of 1,500 ft, the cabin differential pressure istypically 0.3 psi, leading to a closing force on the door of 900lbs. They additionally indicated that the handle mechanism isnot capable of moving the door when the differential pressureexceeds 0.18 psi. Above this value, there is no possibility ofthe door moving from its position in the fuselage regardless ofthe handle position. Thus any risk of the door moving is confinedto such times as when the differential pressure is close to zero. Boeing stated that aerodynamic studies showed that in the eventthat the latches became disengaged, thereby making the door susceptibleto moving inwards to the "cocked" position under theaction of vibration, then airflow forces would <u>not</u> causethe door to fully open.

<u>Note</u>: The standard take-off configuration for the Boeing747 is with the air conditioning packs to be turned OFF. Thisresults in a slight negative pressure in the cabin until approximately700 ft, when the first pack comes on line. For landing, the standardprocedure is to keep the packs ON. This maintains a slight butdecreasing positive pressure in the cabin until touchdown.

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

Quality assurance investigation

During the airline's investigation, all the personnel involvedwere interviewed with the aim of detailing the events that ledup to the fitment of the wrongly drilled torque tube and the subsequentrelease to service of the aircraft. The first report of problemswith the door was on October 26, and resulted in the discovery,at Gatwick of the broken torque tube and latch crank. A new tubeand crank assembly were ordered from Heathrow. The rectificationrequirements were considered outside the scope of ramp maintenance,with the result that at 1900 hrs (i.e. the start of the nightshift), the aircraft was handed over to the Gatwick Support Unitfor investigation and repair. A verbal handover was given tothe shift Fleet Technical Liaison Engineer (FTLE). There wasa shortage of certifying staff and a Licensed Aircraft Engineer(LAE) had to be called in on overtime. Pending his arrival, twohangar engineers were given the task of removing the door trim.

The LAE arrived at 2100 hrs and was briefed by the FTLE. He hadreplaced a door torque tube on a previous occasion, at Heathrow,and was happy to accept the task. He was also asked to investigatean 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 thedoor, after the door-to-tube relationship had been marked on theadjacent door frame. An inspection of the door was also carriedout at this time and it was noted that there were witness markson the external surface of the forward upper cam slot plate, indicatingthat 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 Manualcalled up a drill jig, which is designed to be attached to thetube via the tooling holes, thus allowing the latch crank andthe central bellcrank holes to be drilled off. However, the drilljig was not available and the main workshops were closed for thenight. The decision was made by the LAE and the FTLE to drillthe tube in the area workshop. Consideration was given to callingout the workshop engineer and to leaving the task until the morning,but these options were discounted due to time constraints andthe operational requirement for the aircraft.

Note: Once the non-availability of the drill jig becameapparent, it would not have been possible to comply with the MaintenanceManual requirements. The correct action would have been to callthe Fleet Technical Office who have the necessary CAA approvalto issue Engineering Orders covering work that falls outside theMaintenance Manual. It was subsequently established that theairline had never held the drill jig. The LAE had of course faceda similar situation on the previous occasion he had replaced atorque tube. However, at that time he had had the facilitiesof the main workshops available to him.

After bolting the new tube to the damaged tube through the toolingholes, and using the existing latch crank holes in the damagedtube as guides, it was possible to drill two of the latch crankholes in the new tube with the aid of a pillar drill. The secondset of holes were at 90° to the first, and these were drilled,after their positions had been marked, by means of a rechargeablehand drill. This part of the operation was witnessed by the FTLEand other engineers, but was not overseen by the LAE, who wasaway 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 angularrelationships from the Maintenance Manual, and also by comparisonwith the old tube. Once satisfied, the new tube was installedin the door and the latch cranks bolted into position. Afteralignment with the marks made on the door frame during disassembly,the LAE instructed the engineers to drill the centre bellcrankholes. It must be presumed that the angular error arose at somepoint in the marking/alignment process, possibly as a result ofmis-reading the drawings in the Maintenance Manual.

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

Rigging of the door commenced at approximately 0230 hrs and continuedfor three hours. By 0530 hrs, the door was fairing correctlybut the "pull-off" load on the door handle (i.e. theforce 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 tohand the task over to the incoming day shift. The work that hadbeen carried out so far, together with the outstanding tasks,was documented in the aircraft Technical Log. No stage sheetswere raised (see the Note below) as the job was considered straightforwardenough to be contained within the Technical Log. However, theLAE did produce a written handover for the next team, althoughthis was never actually seen by anyone.

Note: In some maintenance situations, operators use pre-plannedstage sheets which briefly describe each action required, givingthe appropriate Maintenance Manual reference and providing boxesfor the authorising signatures. Whilst these documents shouldnot be used in place of the Maintenance Manual, they neverthelessserve as an aide-memoir and provide confirmation that all criticaltasks have been completed. Thus stage sheets can be of considerablebenefit in the non-scheduled maintenance environment.

A day shift LAE was not available, and so a verbal handover wasmade to one of the two hangar engineers assigned to complete thetask. This engineer was unaware of any written information otherthan that in the Technical Log and did not see the handover noteswritten by the night shift LAE. Later on, another LAE was taskedwith co-ordinating the activity on the door in addition to hisother work. He therefore made frequent visits to the aircraftas work progressed. The work was mainly directed to obtainingthe correct pull-off load on the door handle, and included adjustmentof the operating rods, the torque tube and the forward latch guide. A considerable amount of free play was also identified withinthe handle mechanism, and was eliminated by re-tightening thecentral mounting bolt. Eventually, a pull-off load of 20 lbswas achieved, which was considered satisfactory. The door wasinspected by the LAE, who considered that all the MaintenanceManual requirements had been met, and was then reassembled. Theaircraft was released for service at 1700 hrs on October 27.

The aircraft continued to experience problems with the door, asdescribed earlier, culminating in the incident on November 2. When the drilling error became apparent, another torque tubewas obtained and drilled off in the main workshops using a verticalmilling machine incorporating a dividing head and a digital dialtest indicator. The door was subsequently reassembled and riggedwith no problems, the handle pull-off load now being 25 lbs, asrequired by the Maintenance Manual. The aircraft was returnedto 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 inrespect of; a) Not using a drill jig when drilling the torquetube; b) Failure to call the Fleet Technical Office when it wasapparent that the work now fell outside the Maintenance Manual, c) Failing to protect the tube with primer and to "wetassemble" during installation.

2. The work should not have proceeded without the jig, workshopor 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 workwhen 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 couldbe wrong when the handle pull-off load requirement could not bemet, or when the door could not be rigged easily.

6. When the aircraft returned from its first trip the full extentof the problem was not appreciated by the engineering organisation. Also, the problem was not detected by the appropriate Reliabilitysection after the subsequent flights and the numerous failed attemptsto rectify the defect.

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

Measures adopted since the incident have included ordering a torquetube drill jig as specified in the Maintenance Manual. However,in order to minimise dependency on the jig, it is intended toorder pre-drilled torque tubes from the manufacturer. It is alsointended to establish a more effective control over the shifthandover files. In addition, stage sheets are to be used wheneverwork is carried out in the hangar which is considered to be beyondthe scope of ramp maintenance. Furthermore, the airline intendto publish the findings of the investigation, together with astatement, in an in-house publication, of the requirement to contactthe Fleet Technical Office in the event that specialised equipmentis unavailable.