Boeing 747-436, G-BNLF

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Aircraft Type and Registration:	Boeing 747-436, G-BNLF
No & Type of Engines:	4 Rolls Royce RB211-524G turbofan engines
Year of Manufacture:	1989
Date & Time (UTC):	5 April 1997, at 0825 hrs
Location:	Lilongwe Airfield, Malawi
Type of Flight:	Public Transport
Persons on Board:	Crew - 15 - Passengers - 135
Injuries:	Crew - 1 Minor - Passengers - 2 Minor
Nature of Damage:	Extensive but undetected structural damage to lower fuselage skins aft of the wing and distortion of keel beam web
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	16,550 hours (of which 3,550 were on type)
	Last 90 days - 113 hours on type
	Last 28 days - 32 hours on type
First Officer's Flying Experience:	13,010 hours (of which 3,400 were on type)
	Last 90 days - 160 hours on type
	Last 28 days - 56 hours on type
Information Source:	AAIB Field Investigation

History of the Flight

The aircraft was planned to operate a weekly scheduled passengerservice from London (Gatwick) to Lilongwe (Malawi) via Lusaka(Zambia) and the return to Gatwick was also via Lusaka. One crewflew the leg from Gatwick to Lusaka and a separate crew, alreadyat Lusaka, flew the legs to and from Lilongwe. The aircraft wasserviceable for the approach to Lilongwe where the runway in usewas Runway 14. This runway has a high intensity approach lightingsystem including VASIs set at 3_, the landing distance is 11,614feet on an asphalt surface, it is served by an ILS which was serviceableand the touchdown threshold is 4,028 feet amsl. Prior to theapproach, the reported weather conditions for the airfield includeda surface wind of 100_/07 kt, visibility greater than 10 km withno significant cloud and a surface temperature of 21_C; however,showers were reported in the vicinity.

With the First Officer (FO) as the handling pilot the aircraftwas positioned onto the ILS at about 15 miles; the landingreference speed (VRef) was 145 kt. The Captain took control fora visual approach and landing at 1,000 feet at which time he observeda small rain shower crossing the runway threshold but he remainedunconcerned because he could see through it without difficulty. He later described the rain as "sheeting but bright"and he had no problem seeing the runway at 500-600 feet. TheCaptain did not select his windscreen wipers, even when promptedby the FO, because he had previously found the movement and noiseof the wipers to be distracting. He described the rain ripplingover the windscreen but was never in any doubt that he had sufficientvisual cues to continue the landing although he did note thatthe rain appeared to intensify. He heard the FO call '50 Above'and 'Decide' and responded with 'Landing'. The next sound thatthe Captain heard was the GPWS warning "Sink Rate" andthen the aircraft hit the runway hard.

The FO described flying into the rain shower at 500 to 600 feetwhereupon he immediately selected his windscreen wipers to the'High' position, thereafter he maintained sufficient visual referencewith the runway. He offered to select the wipers for the Captainbut this offer was declined. Because of the intensity of therain he decided to revert to the height calls required duringan instrument approach and called '50 Above' and 'Decide'. Heestimated that at about 200 feet the aircraft was stabilised slightlyto the right of the centre line but adequately positioned forthe landing. In the final stages of the approach he was awareof the aircraft sinking so he placed his hands on the controlcolumn, however, before he could intervene the "SinkRate" warning occurred followed immediately by a very hardlanding from which the aircraft bounced. He was not consciousof any check or flare being initiated by the Captain and thisis substantiated by the Flight Data recordings.

The FO realised that the aircraft was now airborne and displacedover the right hand side of the runway; he considered that theywere not in a safe position to attempt to continue with the landingso he called 'Go Around' and applied full power. When they weresafely away from the ground he called for the Autopilot to beengaged; after checking the EICAS for failure indications to theHydraulics system, Landing Gear, Tyres and Doors, he retractedthe gear. The Cabin Services Director came onto the flight deckto tell the crew that there was some damage in the cabin, thecrew responded that they would be landing in 5 minutes. The FOpositioned the aircraft for a visual approach to Runway 32 sincehe noted that the shower was still over the threshold of Runway14, the Captain then took control and continued the visual approachwhich culminated in a normal landing.

Once on the ground and after the shutdown checklist had been actionedthe Captain completed the technical log and an Air Safety Reportand informed the accompanying ground engineer that a "Heavylanding check" would be required. The FO completed his ownwalkround, paying particular attention to the undercarriage, butcould see nothing amiss with the exterior of the aircraft. Inthe cabin approximately 12 Passenger Service Units (PSUs) hadbroken loose as had an over-aisle panel containing the video displayscreen, all of these displaced units were at the rear of the aircraft. One elderly couple had been struck by one of the PSUs but declinedthe offer of medical assistance.

Analysis of the Landing

Although the aircraft was initially stabilised on the approach,a series of pitch inputs, which were initiated by the pilot below250 feet, caused the aircraft to strike the ground with a highrate of descent. There was no attempt to flare the aircraft. It is probable that the visual references used by the Captainduring the landing phase were distorted by the presence of wateron the windscreen. The distortion would have been significantlyreduced by the use of the windscreen wipers, as was demonstratedby the perceptions and actions of the FO.

Flight Recorders

The Flight Data Recorder (FDR) and OpticalQuick Access Recorder (OQAR) fitted to the aircraft were replayedby the Operator once the aircraft had returned to Gatwick. Thevoice recording of the accident landing had been over-written.

The FDR and OQAR recordings contained theaccident and subsequent landings and, as the OQAR data was morecomprehensive and at a higher sample rate, this was the data usedfor the investigation.

The data showed that the first approach intoLilongwe was stable on a glideslope of approximately 2.8oand was flown manually with an aircraft pitch of approximately3onose up on a magnetic heading of approximately 131oM. Flap 25 had been selected and the landing gear was down.

Fourteen seconds before the landing, at aheight of 240 feet agl and a speed of 153 kt (Vref+8 kt), theaircraft was slightly high on the glideslope. Corrective nosedown elevator was applied and the pitch attitude of the aircraftreduced to 2.5onose up as the sink rate increased from 700 feet/min to 1,400 feet/minover a period of seven seconds. As the nose down elevator wasapplied the heading increased to 132.5oM. With the aircraft now at 120 feet agl, the nose was briefly raisedto 2.8o,temporarily reducing the descent rate to 900 feet/min, beforeit was lowered to 2.2o,allowing the descent rate to increase to 1,488 feet/min.

In the four seconds before touchdown, froma height of 70 feet agl, the handling pilot raised the pitch toa maximum of 3.7obefore lowering it to a minimum of 1.3onose up. As the descent rate increased the GPWS Sink Rate warningwas activated for the last two seconds.

At 0823 hrs the aircraft struck the ground,with a roll of 2.1oleft wing down, at a speed of 149 kt (Vref+4 kt), a last recordeddescent rate of 1,344 feet/min and a peak vertical accelerationof 2.86g. The air/ground sensor was active for a period of twoseconds and the localiser reading indicated that the aircraftwas slightly right of the runway centreline. There was no recordedactivation of the windshear alert nor was there any evidence ofwindshear from the correlation of the airspeed and groundspeedof the aircraft during this landing.

Having struck the ground the aircraft waspitched up, became airborne and maintained a height of approximately15 feet agl for six and a half seconds before full engine powerwas achieved. Flap 20 and gear up were selected and the aircraftclimbed away with a pitch attitude of between 13oand 15onose up. At 0829 hrs the aircraft made an uneventful, flap 25landing on a heading of 314° magnetic, 6 minutes after theinitial incident.

Engineering aspects

Because this operator only flies one scheduledservice into Lilongwe each week, engineering coverage is suppliedby the operator's Station Maintenance Manager (SMM) travellingwith the service from Lusaka, Zambia, and using local airlineengineering resources as necessary at Lilongwe. The SMM hadoriginally received his technical training and experience in theRAF and then worked for this operator for some 30 years.

At the time of the heavy landing, the SMM was, therefore, seatedin the forward passenger cabin, having joined the aircraft atLusaka. As the aircraft was taxying to the stand the cabin crewadvised him of the damage in the aft cabins and, after the aircraftwas parked, he made his way to the flight deck where the Captainrequested that he perform a "Heavy landing check". The SMM then recorded the cabin damage before going to the engineeringoffice and printing a 'hard' copy of the relevant MaintenanceManual pages of the required Hard Landing Inspection.

The Hard Landing Inspection in the manufacturer's MaintenanceManual is distinct from the Overweight Landing Inspection andis divided into two parts: Phase I and Phase II. The inspectionis at the discretion of the commander and the Manual states thatif Phase I does not show that damage has occurred, no more inspectionsare necessary: if the Phase I Inspection **does** show thatdamage has occurred, then the more extensive Phase II is required. The Phase I Inspection covers four sheets from the MaintenanceManual and directs attention primarily at the landing gears, atthe engine nacelles and at the engine attachments to the wing. In addition, items are included for the wing leading edge fairings,the trailing edge flap mechanisms, the horizontal stabiliser fueltank and the APU supports. The only reference to fuselage inspectionis "aft of body station 2000 for signs that the runway wastouched". The Phase I Inspection is qualitative and no measurementsare specified.

During his initial 'walk around' the exterior of the aircraft,the SMM looked, from experience, for signs of bursting or over-pressuringof tyres, integrity of the main and body landing gears, the airframein general and engine alignment marks: there were no signs ofstructural damage. He then started the formal Phase I Inspection,which he performed over a period of about 6 hours. Although theSMM performed the inspections himself, he was assisted in accessingthe various areas (for example, the engine struts) by personnelassigned from the national airline. In addition to the PhaseI items specified, he performed a number of checks based on hisexperience, such as opening and closing all the exterior cabinand baggage doors on the aircraft, looking for any signs of misalignmentor mismatch. From previous experience of heavy landing checkshe also looked at the condition of the water tanks and re-tighteneda number of leaking joints around the potable water tanks.

The only item from the Phase I check not included in the SMM'sinspection was the horizontal stabiliser tank, which was not requiredas the tank did not contain fuel. For the inspection of the APUsupport intercostal, the SMM was concerned as to whether the equipmentavailable was adequate for full access within the compartmentitself, although he did open the APU doors and inspected the area,ascertaining that there was no visible damage. At the end ofthe Phase I Inspection, having found no evidence of structuraldamage from the heavy landing, the SMM raised an ADD form (AcceptableDeferred Defect) for a precautionary repeat Phase I Inspection,with a 'Cat Q 2' limitation for two landings to cover the aircraft'ssectors returning to London Gatwick. The aircraft manufacturerhas since confirmed that the SMM's inspection of the APU intercostal,viewing from a distance of some 6 feet, met the requirement ofthe Phase 1 Inspection.

During his inspection the SMM was conscious of a number of Telexmessages between Lilongwe and the operator's Maintenance Control('Maintrol') at London Heathrow. These were handled directlyby local Customer Service Manager as the SMM stayed with the aircraftand he states that he was not conscious of any particular interestfrom Maintrol in the level of vertical G recorded in the ACMS(Airplane Condition Monitoring System). This figure was not availablethrough the ACARS (Aircraft Communications Addressing and ReportingSystem) as the ACARS printer had previously been disabled fleet-wideand an early attempt to interrogate the ACMS directly had beenunsuccessful. The SMM also comments that the Maintenance Manualinstructions for the Phase I Inspection, which he was following,do not refer to any recorded data.

By about 1730 hrs local (UTC+2), with his exterior work completed,the SMM was back in the aircraft cabin, tidying the remainingcabin problems caused by the heavy landing but without extra timeto address Cabin Log deferred defects. At about 1800 hrs localthe flight crew came back on board and the SMM reported that therewas "no damage other than in the cabin" and that thePhase I Inspection had been negative. With the Transit checkcompleted and signed by the SMM, the Captain accepted the aircraftand at 1840 hrs local the aircraft departed for Lusaka, on time,with the SMM aboard.

At Lusaka no further defects were entered in the aircraft TechnicalLog. There was a complete crew change and the 'heavy crew' acceptingthe aircraft each did normal external inspections. The SMM againattempted to interrogate the ACMS and managed to acquire a formof the report of the exceedance event but this report did notinclude values either for sink rate or vertical G. After theaircraft had departed for London Gatwick, approximately on time,the SMM received a Telex message from Maintrol enquiring aboutthe ACMS information and he transmitted the very limited ACMSdata to Maintrol by Telex.

Aircraft damage

During the repeat Phase I Inspection at London Gatwick signs offuselage skin damage were noted, just aft of the wing (stations1480 to 2181), with substantial areas of 'quilting' and 'rippling'of the skin panels. It was determined that the level of verticalG deceleration had been recorded as 2.86G in the ACMS, with arelated sink rate of 1070 ft/min. The aircraft was ferried tothe maintenance facilities at London Heathrow and the full PhaseII Inspection was conducted, with extensive support from the manufacturer. It was determined that there was further structural damage tothe left-hand web of the fuselage keel beam, in the area of thelanding gears, and slight 'out-of-round' damage to some of thewheel hubs which was discovered only during detailed workshopinspection. There had been no discernible damage in the areascovered by the Phase I Inspection, including the APU support intercostal. The aircraft underwent extensive structural repair at LondonHeathrow with support from the manufacturer and was returned toservice on 1 June.

AAIB investigation

The AAIB investigation included interviews with the SMM who hadperformed the Phase I Inspection at Lilongwe, the flight crewfor that sector and the operator's technical and quality staff. Examination of G-BNLF and other aircraft at London Heathrow confirmedthat, as most B747 lower fuselage panels show some degree of skinwaviness, it can be difficult to determine what constitutes adamaged condition.

It was established that the requests from Maintrol to the SMMfor the record of vertical G from the ACMS had been at the suggestionof the Fleet Technical Manager. With no limitations or stricutreswithin the Maintenance Manual's Phase I Hard Landing Inspection,there was no question of this G recording being used as a criterionfor determining the aircraft serviceability nor of requiring thatthis parameter be read from the ACMS prior to the aircraft's returnto service at Lilongwe.

Regarding the SMM's concern about access for inspection of theAPU support intercostal, the operator's engineering organisationconcluded that the normal procedure would have been for the SMMto contact the Fleet Technical Engineer at Maintrol, who would,in turn, have contacted the relevant Fleet Technical Design Engineer(FTDE). In this case, any additional inspection of the APU supportintercostal arising from such an exchange would have found nodamage. It is highly unlikely that any extra activity in thearea of the APU would have resulted in detection of the damageto the fuselage skin panels.

Manaus incident

On 22 March 1997 N707CK, a B747-200 cargo aircraft, suffered aheavy landing on arrival at Manaus, Brasil, and the incident waslater investigated by the National Transportation Safety Board(NTSB).

The crew stated that the heavy landing had occurred because ofa lack of flare: playback of the FDR confirmed that the flarehad only been initiated about two seconds before the impact. The FDR also indicated a maximum recorded vertical G level of2.77 with a descent rate greater than 1100 feet/min. The crewreported the landing weight as 629,500 lbs, close to the maximumlanding weight.

In the subsequent Phase I Inspection at Manaus, the engineer notedskin waviness in the fuselage, aft of the wing, and eight 'popped'fasteners. Following exchanges between the operating companyand the manufacturer, and further inspections inside the fuselage,the aircraft was ferried to Miami and then to Oscoda, Michigan,where it was surveyed and repaired. During the manufacturer'ssurvey at Oscoda skin panel wrinkling was detected up to a depthof .250", considerably more severe than in GBNLF, anddamage in the keel beam area of N707CK was also more severe. Some minor contact damage was noted around the main landing gears.

The significance of this incident to N707CK, in relation to G-BNLF,was that substantial structural damage in the fuselage was notaccompanied by significant damage within the Phase I Hard LandingInspection.

Manufacturer's response

In response to a number of questions put by the AAIB, the airframemanufacturer confirmed that the fuselage damage would have hadno discernible effect on the structural strength of the aircrafton its two return sectors and that, after the repairs, full structuraldurability was restored to G-BNLF.

Concerning the significance of the maximum recorded values ofvertical G deceleration, the Maintenance Manuals consistentlystate that the pilot must make the decision as to whether a structuralinspection is necessary. The manufacturer has concluded fromflight tests and analysis that definition of a particular verticalG exceedance level is not a reliable method to define a Hard Landing. This is partly due to the variations of time and magnitude ofdeceleration due to such factors as aircraft attitude and rates,structural dynamics, weight and CG, and partly due to the filteringcharacteristic and sampling rate of the accelerometer itself. In response to appeals from several customers the manufacturerhas, however, developed a limited procedure for touchdowns withless than 2° roll. The roll attitude of G-BNLF at touchdownwas 2.1°.

The manufacturer also responded that it is unusual, but not unknown,for fuselage structural damage such as that on G-BNLF to havebeen found whilst not exhibiting damage in those areas specifiedin the Phase I Hard Landing inspection. Further, if the SMM hadspotted the damage to the fuselage or keel beam, the manufacturersuggests that the correct course would have been contact withthe manufacturer for guidance on limits to wrinkle depth and containment. The manufacturer states that, as a result of the two recent occurrences,the 747 Maintenance Manual Phase I and Phase II Hard Landing Inspectionswill be reviewed and updated; it is planned that inspection andacceptance criteria for panel wrinkling will be included.

Operator's response

The operator of G-BNLF notes that the ACARS printers are beingreinstated and a figure of 1.8g or above will initiate a print-out. In addition, a development programme has been initiated to linkthe printer automatically to ACARS for transmission to the mainEngineering base.

Recommendations

During the investigation, the AAIB noted that significant structuraldamage had occurred to G-BNLF as the result of a heavy landingand this damage was not reflected in the Phase I Inspection. It was also noted that, had the SMM, an experienced engineer,noted the possible skin damage, there was no ready means of distinguishingthis from normal skin waviness. The AAIB therefore makes thefollowing recommendations:

Recommendation 97-42

It is recommended that the CAA and FAA monitor the manufacturer'sreview of the Hard Landing Inspections and any subsequent amendmentto the 747 Maintenance Manual to ensure that there is a high levelof confidence in detecting structural damage which follows a heavylanding.

Recommendation 97-43

It is recommended that, to aid flight crew in determining theneed for inspections, the CAA and FAA consider methods for quantifyingthe severity of landings, based on aircraft parameters recordedat touchdown.