ACCIDENT

Aircraft Type and Registration:	Boeing 747-443, G-VLIP
No & Type of Engines:	4 General Electric CF6-80C2B1F turbofan engines
Year of Manufacture:	2001
Date & Time (UTC):	20 March 2007 at 0654 hrs
Location:	London Gatwick Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 17 Passengers - 238
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damage to underside of the two right engine nacelles
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	15,925 hours (of which 4,885 were on type) Last 90 days - 127 hours Last 28 days - 34 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was landing on Runway 26L at London Gatwick Airport at the end of a flight from Barbados. After a stable approach, the crew stated that the conditions became 'quite rough' as the aircraft entered the flare. The aircraft was observed to roll markedly in both directions during the touchdown. The surface wind at the time was 350º/15 kt.

Later that morning, when the next flight crew to operate the aircraft were carrying out their pre-flight checks, damage was found on the underside of both engines on the right wing. The evidence indicated that ground contact occurred during the last landing. It had not been suspected by the operating crew at the time and had not been noticed during the intervening maintenance checks.

History of the flight

The aircraft was landing on Runway 26L at the end of an uneventful scheduled passenger flight from Barbados. The commander, who was pilot flying (PF), reported that, having been given a continuous descent by Air Traffic Control (ATC), G-VLIP was radar vectored on to the localiser for a Category I ILS approach.

By 1,500 ft aal the aircraft was fully configured for landing, with 30º of flap, and stabilised on the glideslope at 142 kt IAS, in accordance with the operator's Standard Operating Procedures (SOPs). 142 kt equated to V_{REF}30+7 kt for the aircraft's landing weight of 226,495 kg (max 285,762 kg), V_{REF}30+7 kt being the approach speed when landing manually with 30º of flap extended with an appropriate allowance added for the surface wind. The aircraft's centre of gravity was within limits, approximately a quarter of the range from the aft limit.

The flight crew became visual with the runway at about 800 ft aal and with the aircraft on the runway extended centre line, crabbing to the left to compensate for a crosswind from the right. They stated that the aircraft felt stable, although the commander had to make adjustments to the thrust levers to assist the autothrottle's speed control. He disengaged the autopilot and autothrottle at or just before the Decision Altitude and hand-flew the aircraft for the remainder of the approach. The co-pilot informed the commander at about that time that the crosswind was 20 kt from the right and considered that it would remain constant thereafter. However, the commander stated that below 100 ft aal, he was able to reduce the amount of crab-angle that he was using to compensate for the crosswind. The last wind information the crew received from ATC, one minute before landing, was of a surface wind of 350º/15 kt, well within the 32 kt crosswind limit for the aircraft.

After the commander commenced the flare at about 50 ft aal, he recalled that conditions became "quite rough", requiring aileron control inputs in both directions. He stated that the aircraft's right wing dropped significantly at about the time of touchdown, enough for the co-pilot to join him on the controls to make a roll input to the left. The aircraft then appeared to roll too much to the left and the commander countered with a roll control input to the right. The aircraft stabilised and touched down normally just before passing holding point D1.

The co-pilot's recollection was that the touchdown on the runway centreline was firm to heavy and the aircraft's attitude was "fairly flat", with the aircraft heading slightly to the right of the runway centreline. The right wing then started to lift and, as it continued to do so, the co-pilot became concerned that the engines on the left wing might make contact with the runway. He made an instinctive aileron control input to the right, removing his hands from the control column when he felt a positive input from the commander in the same direction. He thereafter shadowed the control inputs being made by the commander as the aircraft rocking subsided during the landing roll.

During the subsequent taxi to the airport terminal, the flight crew noted YAW DAMPER UPR and YAW DAMPER LWR messages on the Engine Indication and Crew Alerting System (EICAS). They were not aware of having seen these messages prior to the landing.

An ATC controller on duty in the tower's Visual Control Room observed G-VLIP's landing. He commented that the aircraft's final approach was unremarkable until after it had crossed the runway designation marking. It then appeared to oscillate in roll three or four times before touching down firmly, beyond the aiming point but within the touchdown zone. He saw no indication of the wings or engines making contact with the runway surface.

The flight crew of a Boeing 747-400 which landed ahead of G-VLIP, in a similar surface wind of 350º/14 kt, experienced minimal turbulence. They observed G-VLIP land as they taxied back towards the terminal and although it appeared to roll to its right before touching down, they saw no indications that G-VLIP's engines had made contact with the runway surface.

After G-VLIP arrived on stand and the passengers disembarked, the crew boarded a bus and returned to their crew room before going off duty. The commander made an entry in the aircraft's technical log, regarding the yaw damper EICAS messages but no mention was made to an engineer, who was standing near the engines on the left wing as the crew disembarked the aircraft, of any other fault.

Later that morning, the next crew to operate the aircraft were carrying out their pre-flight checks when the co-pilot noticed that the drain mast underneath the No 4 engine was shorter than it should be. On further investigation he saw evidence of ground contact on the underside of the engine cowling and advised an engineer and the aircraft commander. Similar damage was found on the underside of the No 3 engine cowling. Subsequently, the co-pilot of the previous crew confirmed that there had been no sign of any such damage when he carried out the pre-flight external aircraft checks in Barbados prior to the aircraft's preceding flight.

G-VLIP had received an ATC delay before departing Barbados and during the flight the crew calculated that their Flight Duty Period (FDP) would extend beyond the nominal maximum FDP into the extended period available to the commander, as advised under the Flight and Duty Times Limitation Scheme in the company's Operations Manual. (The FDP is that period between an operating crew reporting for duty for a flight and the aircraft arriving 'on chocks' on the last sector of that duty.) In this case the duty only involved one sector and the 'maximum' FDP was 9 hours 45 minutes. To reduce this extended period, the commander increased the aircraft's speed. In the event, the crew's FDP was 10 hours, which represented 15 minutes into 'discretion'. Neither of the flight crew recalled feeling more fatigued than would be expected at the end of such a duty.

Meteorology

During their pre-flight briefing, the flight crew noted that the weather forecast for Gatwick Airport at their scheduled time of arrival included a possibility of visibility reducing to 800 m in snow and crosswinds gusting to 35 kt. Gatwick Airport's Aeronautical Terminal Information Service (ATIS), timed at 0647 hrs, gave a surface wind of 350º/14 kt, visibility, 7 km in slight rain and snow, few clouds at 700 ft aal, scattered clouds at 1,000 ft aal and broken clouds at 1,600 ft aal. The temperature was +2ºC, the dew point was +1ºC, the QNH pressure setting was 1008 millibar and the runway surface was described as wet throughout its length.

Aircraft damage

Aircraft damage was restricted to the two right engine nacelles. In one case, this constituted a light score on the underside of each of the two composite engine bay doors either side of their junction, together with light damage to the lower end of the protruding drain mast. In the second case, greater disruption of the drain mast had distorted part of the box structure within the nacelle profile forming the structure of an internal fire-wall. In addition, a main engine oil pipe passing through the fire-wall area was severely dented by the distortion of the box structure. Deeper scoring of the engine bay doors, together with distortion of the nose cowl, was evident on this nacelle.

Aircraft turn-round

Another 747-400 aircraft from the same operator landed and arrived on stand within minutes of G-VLIP, although the scheduled arrival times were approximately 30 minutes apart. G-VLIP positioned on the southern side of an east-west taxiway whilst the other aircraft positioned directly opposite on the north side. G-VLIP was thus parked in a position fully exposed to the northerly wind whilst the other aircraft was isolated from G-VLIP by the presence of an active taxiway between the two machines. No mention of an abnormal landing was reported by the incoming flight crew to the ground crew during headset communications at the time of arrival of G-VLIP. The flight crew had departed by the time the relevant engineer reached the flight-deck.

G-VLIP was scheduled to depart 3 hrs 50 minutes after its arrival. The other aircraft which arrived at the same time was scheduled to leave 2 hours 40 minutes after arrival. According to the Operator's work plan, one team, consisting of three airframe/engine technicians, was allocated to carry out Daily and Transit checks on the two arriving 747 aircraft. Only one member of that team was qualified to sign the Certificate of Release to Service (CRS) on the type. He concentrated exclusively on G-VLIP, directing the other two individuals to share the tasks on the other aircraft. (For the purpose of this report the person qualified to sign the CRS on the 747-400 type is referred to as the Engineer; other participants are referred to as Technicians.)

The turnround period of G-VLIP was the only time when the team was required to turn round two aircraft at the same time. At the time of arrival of G-VLIP, the Line Maintenance Supervisor was occupied resolving a problem on another operator's aircraft.

During the period G-VLIP was on the stand, the wind was northerly at approximately 14 kt accompanied by sleet showers and the temperature was reported to be +2ºC. G-VLIP had no shelter from these conditions and the ground was wet.

As well as the normal specified checks, the Engineer working on G-VLIP identified a yaw damper problem and one main-wheel tyre worn below limits which he subsequently changed. The baggage loaders found that both forward and aft baggage hold doors would not open and required assistance from the Engineer to resolve the problem on both occasions. A series of special checks was required to be carried out on each of the aircraft lavatories during the turn round period which, given the large number on the aircraft, also occupied the Engineer for a considerable period.

It was noted that the damage to the undersides of nacelles on the type could readily pass undetected unless the displaced drain-mast was observed, or a technician deliberately spent time lying on the ground beneath the nacelle.

Significance of damage

Had the aircraft been dispatched in the condition as found, it would have done so with the integrity of a fire-wall compromised. This condition would be regarded as a dormant fault. The damage to the oil pipe, whilst not directly compromising engine operation, could have lead to pipe failure and the loss of engine oil contents.

Pod scrapes can create structural damage to pylon attachments which can be difficult to detect. In this instance, later non-destructive testing inspection did not reveal any such damage.

Turn-round manning

Shortly before this incident, the operator had contracted to provide technical support to a number of other operators passing through the Gatwick base. Although total manning levels were increased to cover this change, the work pattern also changed from coverage of just the daytime period to coverage of the full 24-hour period. This change in workload reduced the number of personnel available for the task on this occasion. When subsequently interviewed by the operator, both the Engineer and his Supervisor commented that the high workload experienced was not uncommon. The initiation of the contract with another operator had, in their opinion, stretched the minimal manpower available at the station.

Procedures

Landing technique

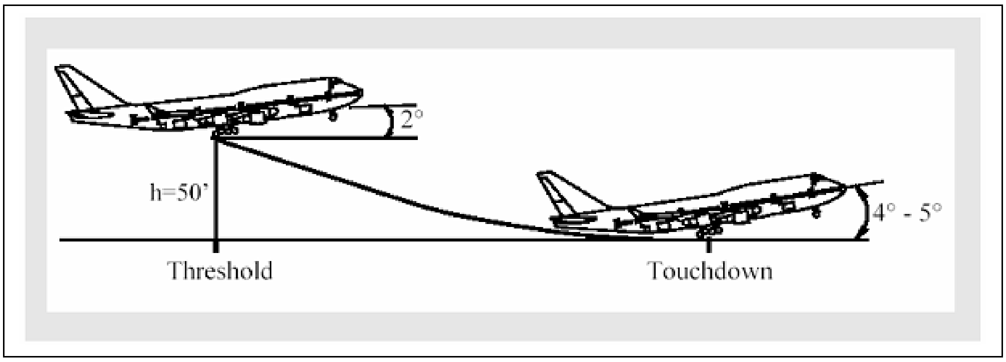
The flare and touchdown techniques applicable to all Boeing 747-400 landings are described in the Boeing 747-400 Flight Crew Training Manual (B747-400 FCTM). It states:

> *'Initiate the flare when the main gear is approximately 30 feet above the runway by increasing pitch attitude approximately 2° - 3°……. A touchdown attitude as depicted in the figure below is normal with an airspeed of approximately VREF plus any gust correction. ……*
>
> *• airplane body attitudes are based upon typical landing weights, flaps 30, VREF 30 + 5 (approach) and VREF 30 + 0 (landing), and should be reduced by 1° for each 5 knots above this speed.*
>
> *…… A smooth power reduction to idle also assists in controlling the natural nose down pitch change associated with thrust reduction. Hold sufficient back pressure on the control column to keep the pitch attitude constant.'*

Crosswind landing technique

The commander stated that he used the de-crab technique for the crosswind landing. This method is also described in the B747-400 FCTM. It states:

> *'The objective of this technique is to maintain wings level throughout the approach, flare and touchdown. On final approach a crab angle is established with wings level to maintain the desired track. Just prior to touchdown while flaring the airplane, downwind rudder is applied to eliminate the crab and align the airplane with the runway centreline.*
>
> *As rudder is applied the upwind wing sweeps forward developing roll. Hold wings level with simultaneous application of aileron control into the wind. The touchdown is made with cross controls and both gear touching down simultaneously. Throughout the touchdown phase upwind aileron application is utilised to keep the wings level.'*



Ground contact during landing

The aircraft attitude required for contact between the engine nacelles and the ground surface during a landing, as advised in the B747-400 FCTM, is shown in Figure 1. The diagram caters for the different makes of engine fitted to the aircraft type ie General Electric (GE), Pratt & Whitney (PW) and Rolls Royce (RR) and is based on a rigid wing, as opposed to one that flexes.

Flight Recorders

The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR) capable of recording a minimum duration of 25-hours of data and 120 minutes of audio respectively. In addition, the aircraft was also equipped with a comprehensive quick access recorder (QAR) system. Parameters included the position of the control column and wheel, rudder surface

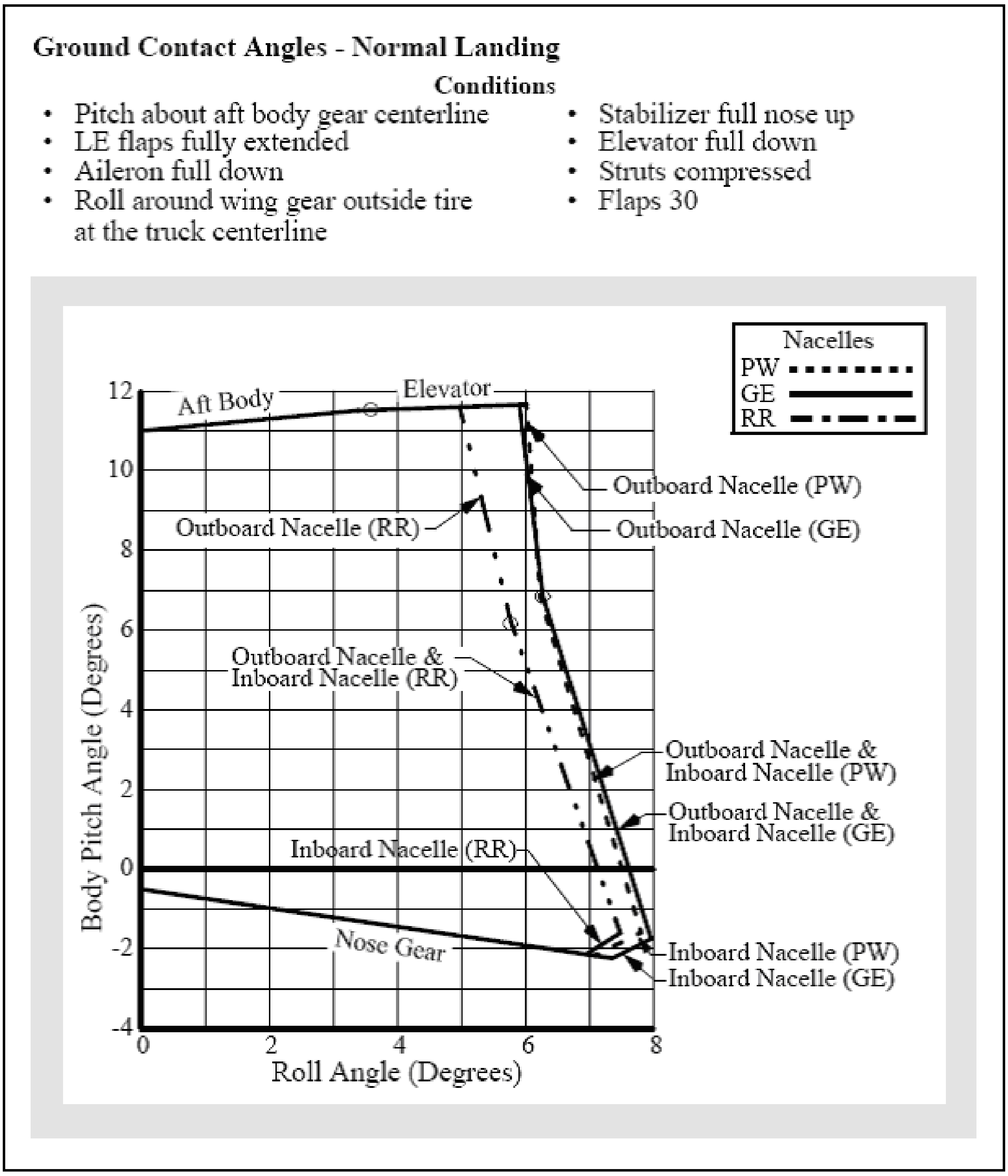


Figure 1

and pedals, pitch and roll attitude, wind speed and direction and landing gear. A plot of the FDR parameters during the landing is provided in Figure 2.

Recorded information

The takeoff, cruise and initial approach phases were uneventful. At about 1,000 ft aal the flight crew had completed the landing checks, with the commander confirming "manual landing four hundred feet". The aircraft was stabilised on both the localiser and glideslope, with airspeed at 156 KCAS and flap 30º selected. The selected speed set on the Mode Control Panel (MCP) was 147 kt. At 1,000 ft aal, the wind speed and direction, as recorded from the flight management system (FMS), indicated the wind was from the right at 346º/30 kt.

As the aircraft passed through 400 ft aal, ATC cleared the aircraft to land and advised that the wind was 350º/15 kt. At 400 ft aal and 149 KCAS the commander confirmed "automatics coming out" and both the autopilot and autothrust were disengaged. Almost immediately the co-pilot advised the commander that the wind was from the right at 20 kt, which the commander acknowledged. The decision height warning occurred at 200 ft aal, at which time the commander confirmed they were to land. The aircraft had just started to descend below the glideslope at this time. The aircraft continued to descend below the glideslope, until it was stabilised at about 2 dots below the glideslope. The pitch attitude remained in a relatively nose level attitude until the flare.

As the aircraft continued its approach, the commanded roll and actual roll were occasionally out of phase with each other. The drift angle was about 6° during the approach. At about 40 ft aal, left rudder was gradually applied as the 'de-crab during flare' technique was used to align the nose of the aircraft with the runway and right roll was also commanded. At about 25 ft aal the commander started to flare the aircraft. Pitch attitude was increased from 0º to about 2º over two seconds, before gradually reducing to nearly 0º just before the main gear touched down.

As the aircraft neared the ground, right rudder was quickly applied, from 25º left to 16º right in one second and the aircraft coincidentally rolled to 5º right wing down (see Figure 2, point A). Corrective left control wheel and left rudder inputs were made and the aircraft responded by rolling to the left. Countering the left roll, right control wheel was progressively introduced, reaching 83º just before the aircraft touched down (see Figure 2, point B). The control wheel has stops at +/- 90º.

The aircraft touched down with a small amount of left bank (1.5º) and at an almost nose level pitch attitude; airspeed was 145 KCAS and the normal acceleration at touchdown was at 1.43 g. The aircraft started to roll quickly to the right and about two seconds after touchdown the bank angle reached 6.7º right wing down (see Figure 2, point C). The pitch attitude was 1° nose down. A left roll was commanded and the aircraft rolled to the left quickly, before another almost full travel deflection of the control wheel to the right (see Figure 2, point D) was made. The aircraft continued in a rocking motion for a few more seconds before the roll attitude stabilised at about 2º left wing down, with right (into wind) control wheel applied.

As the aircraft was taxied to the terminal, the flight crew had mentioned that the winds were unusual, with the commander adding "the way it lifted the wing like that…the other way". There was no reference to possible contact of the nacelles.

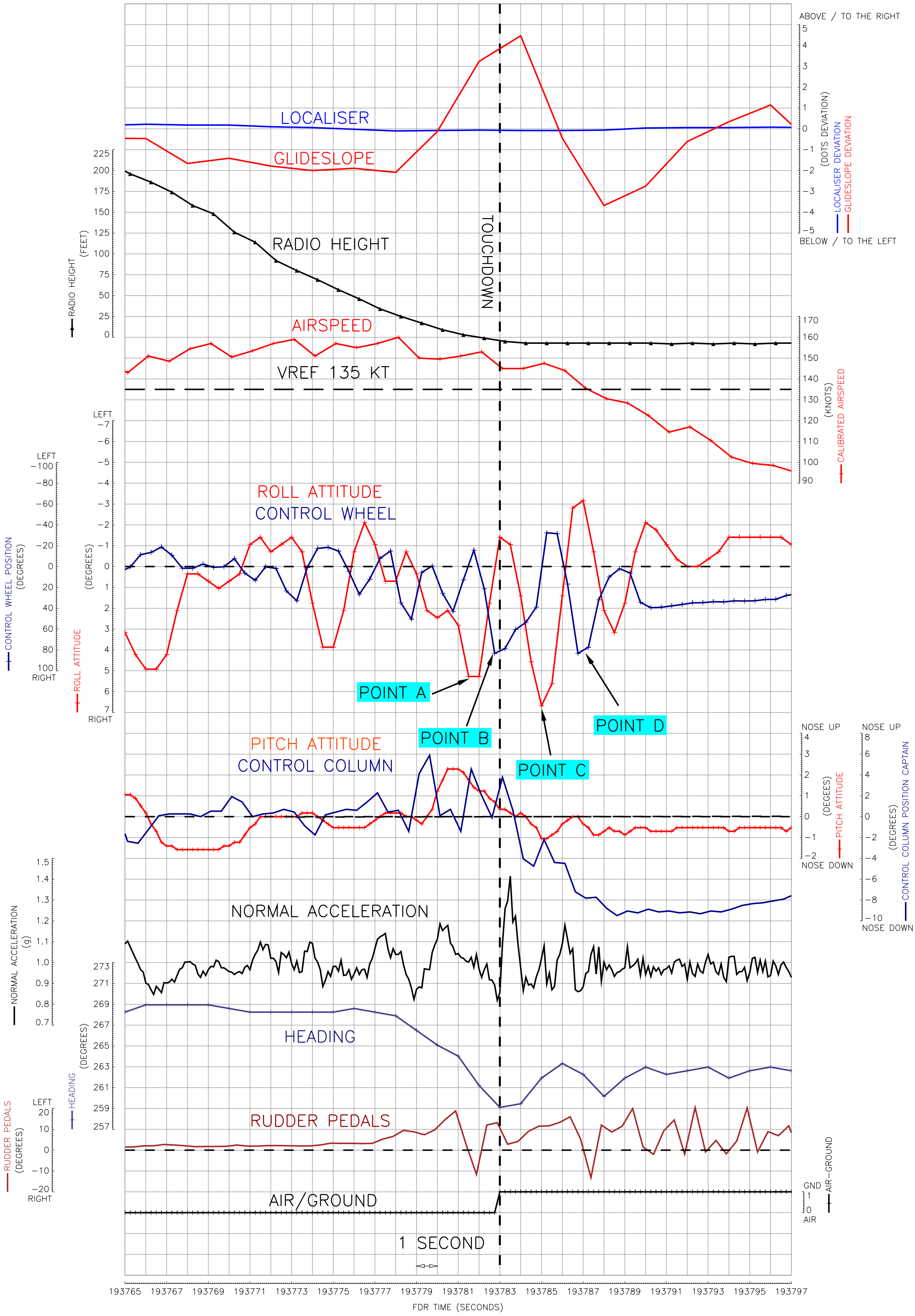


Figure 2

Salient FDR Parameters

Follow-up action

Personnel

The commander was an experienced pilot on the Boeing 747-400 and could not recall having encountered such a problem before. He was also well acquainted with Gatwick Airport, having operated into and out of the aerodrome since 1978. Following the incident, he received further aircraft training in the simulator. Initial assessment of his crosswind technique indicated a tendency to over-control both rudder and aileron during touchdown. By the end of the training session he was achieving smooth and consistent landings in strong crosswinds using the correct technique. The commander returned to line flying duties, with his first duty under the supervision of a training captain.

The co-pilot was also given additional training in crosswind landing techniques. After two hours he was achieving well handled crosswind landings in crosswinds of up to 40 kt, which is twice the co-pilot's limit. The subject of making control inputs during the other pilot's landing was also discussed.

Discussion

G-VLIP landed in wind conditions that were within the limits for the aircraft type and the crew. They were also similar to the conditions experienced by the preceding aircraft, which was the same type, operated by the same company and landed without incident.

G-VLIP's pitch attitude at touchdown was lower than the 4º - 5º nose up attitude recommended in the B747-400 FCTM. However, information from the FCTM also indicated that the respective pitch and roll attitudes at landing (6.7º right bank and 1º nose down) had not exceeded the ground contact envelope of the nacelles. Instead, at a pitch attitude of 1º nose down, the bank angle required to contact both the inboard and outboard nacelles was approximately 7.8º. The aircraft manufacturer advised that the FCTM ground contact envelope represented a rigid wing rotated about the wing gear outside tyre, with the landing gear struts compressed.

The manufacturer was provided with the FDR data and performed a dynamic load analysis. Results indicated that the sink rate at touchdown had been about 6 ft/sec. This would result in the wing flexing downwards between 1º and 1.5º, about two seconds after touchdown on the main gear. At a pitch attitude of 1º nose-down, the nacelle ground contact bank angle would have been reduced from about 7.8º to between 6.3º and 6.8º two seconds after touchdown. The recorded bank angle of 6.7º had occurred about two seconds after touchdown.

During the landing, the control wheel and roll attitude were seen to be out of phase with each other. This was especially evident after the touchdown. In a classic Pilot Induced Oscillation (PIO), pilot commands are the only factors that influence the motion response of the aircraft. However, when other forces act on the aircraft, such as turbulence and ground contact, it becomes harder to determine whether the aircraft is responding to pilot commands or external influences.

The aircraft manufacturer was asked for an opinion regarding the nacelle ground contact being as a result of PIO. Analysis of the data indicated that there had been a direct cross-wind of approximately 20 kt, with wind variations of +/- 5 kt. The touchdown was firm at 1.43 g and the aircraft landed left gear first, which would have resulted in reactive forces that substantially influenced the aeroplane's motion at touchdown. The manufacturer's conclusion was that, although the control wheel and roll attitude was out of phase after touchdown, this was not the only factor affecting the aircraft's motion. Based on the FDR data, a combination of a firm touchdown, variable crosswind conditions, ground interactions at touchdown and control wheel inputs all contributed to the ground contact of the nacelles.

The refresher training that the crew received following the incident identified that the commander had a tendency to over-control during the final phase of a landing in crosswind conditions. This observation appears to be reflected in the control inputs recorded by the FDR during G-VLIP's landing. By the end of this training, the commander was achieving smooth and consistent landings in strong crosswinds using the correct technique. This addressed three of the factors deemed to have been relevent in this incident,namely the control wheel inputs, the firmness of the landing and, consequently, the ground interactions at touchdown.

The co-pilot recalled that his instinctive roll control input was made as the aircraft was rolling left after it had reached 6.7° of roll to the right, following touchdown. This coincided with the largest degree of aircraft roll to the left recorded during the landing. Consequently his additional input on the flying controls was probably made after the two engine nacelles on the right wing had made contact with the ground.

Significance of Manning Level and Working Conditions

Use of one individual working alone on one aircraft in the conditions of the day would have been demanding. Although many operators regard such manning as sufficient to carry out the transit check on the type in as little as one hour, this is only realistic when weather conditions are benign, no faults are identified, no rectifications are required and the engineer has no other responsibilities. Manning of safety-critical functions must, however, take account of adverse circumstances such as those being experienced on this occasion.

The Engineer working on G-VLIP identified the need for a wheel change and was required to jack the aircraft and change a wheel after locating both replacement wheel and jack. He was also required to carry out a special service to each of the lavatories on board. He was ultimately responsible for the other aircraft, while handling interruptions from loaders who were unable to open the freight hold doors of G-VLIP. Given the adverse weather conditions, it could be argued that the workload, including the normal range of checks, was excessive in the prevailing conditions, especially given the period of just less than 4 hours available for its completion. This pressure is considered to have had a detrimental influence on his ability to identify the fact that the aircraft was damaged.

The EASA requirements place a responsibility on the national regulator (in this case the UK CAA as the UK's nominated Competent Authority) to audit the functions of JAR 145 maintenance companies on a two year basis. The audit includes an assessment of the approved organisation's procedures for establishing the appropriate skill and experience levels and the manpower resource availability to cover their forecast maintenance activities. This can be done as a single audit at two yearly intervals, or may be carried out as a rolling audit ensuring that each aspect of the function is reviewed at intervals of no more that two years. This is not a straightforward task. The dramatically fluctuating workload at some line stations can disguise the precise manpower needed at peak times. In the case of this operator at this base, it appears that a substantially increased workload was contracted to be carried out on behalf of other operators some time after manning levels were last audited.

This particular turn round brought a number of factors together which made it more demanding than usual, not least the environmental factors under which the engineers had to work. It is known that damaged undersides of nacelles have gone unnoticed during turn rounds of large turbofan aircraft in the past and it is possible that even under more favourable conditions this damage may have been missed. Nonetheless, the nature of workload and circumstances made missing this damage more likely. The absence of any flight crew comments, either verbally or as a technical log entry, decreased the likelihood of the damage being detected.

Operator's Response

The operator had originally planned to review the manning implications following the new contract customers at the Gatwick base, in April 2007. As a result of the incident, the review was brought forward and a decision taken to increase total staff and reduce the proportion of contracted staff (perceived to be more likely to leave at short notice than permanent staff). The operator also planned to re-align shift patterns to give a greater overlap of manning in the early morning period when scheduled workload is at its highest.