SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 747-412, B-KAG
No & Type of Engines:	4 Pratt & Whitney PW4056 turbofan engines
Year of Manufacture:	1992
Date & Time (UTC):	1 March 2008 at 0128 hrs
Location:	Manchester Airport
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to Nos. 1, 2 and 4 engine nacelles, one main landing gear tyre ruptured
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	48 years
Commander's Flying Experience:	10,800 hours (of which 699 were on type) Last 90 days - 188 hours Last 28 days - 55 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was landing at Manchester Airport on Runway 23R at the end of a scheduled cargo flight from Dubai. There was a strong wind from the north-west and a number of aircraft had earlier diverted to other aerodromes.

During final approach, the crew received a windshear warning when the aircraft was at 500 ft agl. They carried out a missed approach and were given radar vectors for another ILS approach. The second approach was described as smoother but still with a strong wind from the north-west, resulting in a crosswind from the right which was close to the operator's limit for landing this aircraft. During the ensuing touchdown the aircraft rolled right and the No 4 engine nacelle made contact with the runway surface. The aircraft then rolled left and Nos 1 and 2 engine nacelles also made contact with the runway and the No 2 tyre on the left main landing gear burst. There were no abnormal indications on the engine instruments and, after an external safety check by the Airport Firefighting and Rescue Service, the aircraft taxied on to a stand.

History of the flight

During the pre-flight briefing for their scheduled cargo service from Dubai to Manchester, the flight crew noted that there were strong winds forecast throughout northern Europe. In particular, the forecast for

Manchester Airport predicted crosswinds which would be outside the co-pilot's 20 kt limit at their estimated time of arrival. Consequently, it was agreed that the commander would act as the pilot flying (PF). Also, in view of the weather forecast, the crew uplifted an extra 2 tonnes of fuel in anticipation of a potential diversion, should that be necessary - 'two approaches before diverting' being the company standard procedure.

The flight was uneventful, apart from a minor problem with the transponder, and, en route, the crew monitored the weather at their destination and potential alternates. Because of the possibility that they might not be able to land at Manchester, the crew contacted their company during the flight to confirm the preferred priority of alternate destinations. They were advised that Nottingham East Midlands was the number one alternate, with London Heathrow as the second.

As they neared Manchester, the crew noted that the Airport's Aeronautical Terminal Information Service (ATIS) arrival information included a warning that moderate to severe turbulence had been reported on the approach to Runway 23R at a range of 16 nm to 10 nm. They did not experience this and established the aircraft on a Category 1 ILS approach to Runway 23R with 30° of flap selected. During the course of the approach the aircraft's airspeed increased above the flap limiting speed and the aircraft's flap load relief system automatically reduced the flap setting to 25°, until the airspeed had reduced sufficiently for flap 30° to be redeployed automatically.

Immediately following the aural annunciation "FIVE HUNDRED" on the flight deck, which is triggered when the aircraft descends through a radio altimeter height of 500 feet, the crew received the aural and instrument indications associated with a windshear warning. Without delay they carried out a missed approach. (The commander later commented that this was the first windshear warning that she had experienced as a result of actual conditions.) The crew advised ATC and requested radar vectors for a second ILS approach to the same runway, for which the Decision Altitude was 450 ft amsl (airport elevation 257 ft). They rebriefed and decided to carry out the second approach with 25° of flap selected, a permitted setting, because of the speed fluctuations and windshear during the first approach.

The second approach was described as being smoother. Approaching a range of 11 nm from the runway, ATC advised the crew that the aircraft ahead had landed successfully. It was established subsequently that this was an Airbus A321 belonging to another operator. B-KAG was fully configured for landing and stabilised on the ILS glideslope and localiser by 1,500 ft aal, and the landing checklist was completed by 1,000 ft aal.

During B-KAG's final approach ATC transmitted a number of surface wind readings. When the aircraft was cleared to land, the crew were advised that the surface wind was 280°/20 KT MAXIMUM 36 KT. Following that, ATC transmitted three instantaneous surface wind readings; 280°/37 kt, 300°/31 kt and 290°/31kt. The aircraft again produced a "FIVE HUNDRED" aural annunciation, followed by another saying "ONE HUNDRED" as the commander disengaged the autopilot and disconnected the autothrust. The co-pilot advised the commander that the aircraft was at the correct approach speed with a 700 fpm rate of descent and ATC transmitted the final instantaneous wind. The aural alert "MINIMUMS" was emitted on the flight deck, confirmed by the co-pilot, and the commander called "LAND". In quick succession, the co-pilot advised her that the rate of descent was 900 fpm, an aural "SINK RATE" warning was generated twice, backed up by the same call from

the co-pilot, a "TEN" [feet] aural alert sounded and the aircraft landed. Later, the commander recalled seeing a rate of descent of 1,100 fpm on the flight instruments at the time of the 'sink rate' warning.

During the rollout, ATC advised the crew that sparks had been seen coming from both wings and that the wings, or some of the engines, had touched the runway during the landing. This was confirmed by a member of the airfield operations staff, who was in a vehicle positioned adjacent to the touchdown zone on Runway 23R. The rollout was completed without further incident and the commander checked that the engine instruments were indicating normally before taxiing the aircraft clear of the runway. She then stopped B-KAG on a taxiway and the Airport Firefighting and Rescue Service (AFRS) attended the aircraft to carry out an external inspection. They reported damage to the Nos 1 and 4 engine cowlings but no signs of any fuel or hydraulic fluid leak. With the agreement of the AFRS, the commander taxied the aircraft slowly on to a stand and the crew shut B-KAG down.

Meteorology

At the time of the occurrence, an area of low pressure lay to the north-east of the United Kingdom resulting in strong to gale force north-westerly winds across north-west England.

The Terminal Area Forecast (TAF) for Manchester Airport for the period from 2200 hrs on 29 February to 0700 hrs on 1 March 2008 forecast a surface wind from 260° at 22 kt, gusting to 35 kt, with visibility in excess of 10 kilometres and scattered cloud at 2,000 ft agl. Temporarily during the period from 2200 hrs to 0300 hrs the surface wind was forecast to veer to 270° and increase to 28 kt, with gusts to 45 kt. There was also a 30% probability of a temporary change between 2200 hrs and 0700 hrs when the visibility would reduce to 7,000 metres in showers of rain and there would be broken cloud at 1,200 ft agl.

The ATIS arrival information for Manchester Airport at 0050 hrs reported the surface wind as 280°/25 gusting 42 kt, visibility greater than 10 kilometres, few cloud at 2,800 ft agl, scattered cloud at 3,200 ft agl and a wet runway. This arrival information also included a report of moderate to severe turbulence on the approach to Runway 23R between 16 nm and 10 nm. The next ATIS arrival information, timed at 0120 hrs, when B-KAG was making its second approach to land, reported the surface wind as being 300°/28 gusting 42 kt. The visibility was still greater than 10 km, there were few clouds at 3,200 ft agl and the runway continued to be wet. The QNH pressure setting was 994 mb.

The UK Air Pilot entry for Manchester Airport contains the following warning:

> *'Pilots are warned, when landing on Runway 23R in strong north westerly winds, of the possibility of turbulence and large windshear effects.'*

Between 0020 hrs and 0220 hrs, the surface wind at Nottingham East Midlands Airport was blowing down the runway at comparable speeds. At London Heathrow Airport a similar situation existed. At both, the visibility and cloudbase were suitable for an approach and landing.

Other aircraft

Between 2115 hrs and 0120 hrs on the same night, ATC logged 10 aircraft, including B-KAG, which carried out go-arounds due to windshear, turbulence or the strength of the crosswind. Of these, five diverted to other aerodromes.

Aircraft loading

The landing weight of the aircraft was 257.8 tonnes, which was less than the maximum landing weight of 295.7 tonnes. The centre of gravity (CG) was at 21.1% Mean Aerodynamic Chord (MAC), towards the centre of the permitted range.

Personnel

Earlier in the day, the commander had flown the aircraft from Hong Kong to Dubai: a Flight Duty Period (FDP) of 9 hours 35 minutes. She then had 11 hours rest, the minimum permitted, during which she slept for 7 to 7½ hours, before reporting for duty and meeting up with the co-pilot. The co-pilot had operated another aircraft from Manchester to Dubai, via Amsterdam. He then had 11 hours 30 minutes rest, achieving about 5 hours sleep. Prior to reporting for duty in Hong Kong for her first sector to Dubai, the commander had had six days off duty.

Neither flight crew reported being fatigued during the two approaches to Manchester, nor was there evidence that it was a factor in the occurrence.

Aircraft description

B-KAG was a B747-400 (s/n 27067) BCF (Boeing Converted Freighter), a freighter conversion of a passenger aircraft. It is a low-winged transport with four engines pylon-mounted below and forward of the wing leading edges (Figure 1). The wingspan is 64.9 m (213 feet) and the overall length is 68.6 m (225 feet). The engines are numbered from left to right, as Nos 1 to 4. The fan duct portion of each engine consists of, from front to rear, a nose cowl, a fan cowl and a translating cowl. The cowl outer skins are predominately of Carbon Reinforced Plastic (CRP).

On the ground, the aircraft is supported on two wing and two body main landing gears (MLG), each with a four-wheeled truck, and a two-wheeled nose landing gear. The MLG wheels are numbered from left to right across the aircraft, front wheels first.

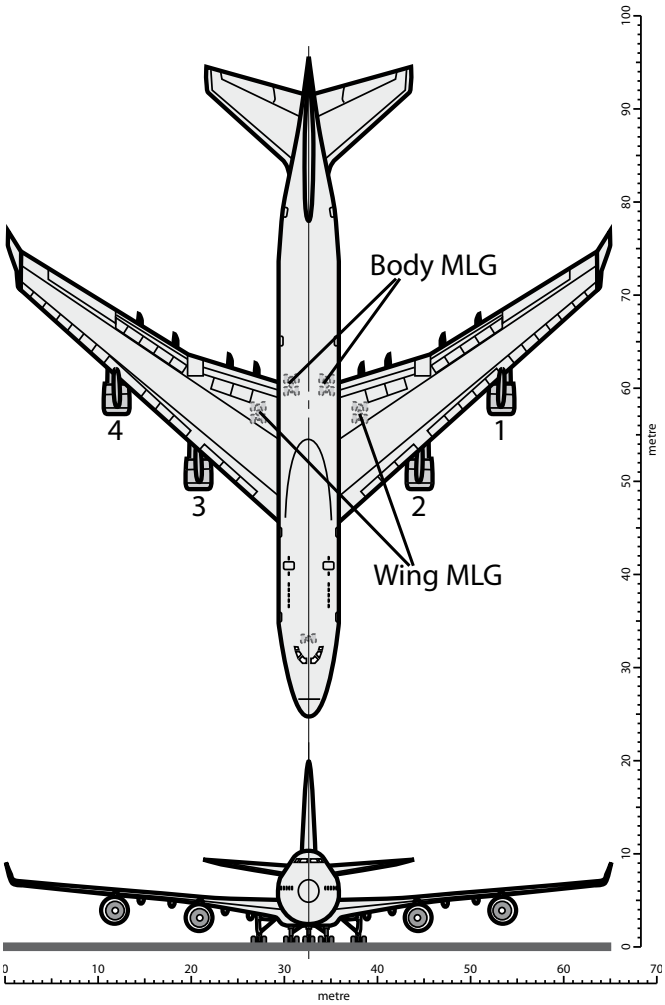

Figure 1

Boeing 747-412 - General arrangement

Nacelle clearance

With the landing gear wheels in ground contact, the clearance of the engine nacelles from the ground is primarily dependent on the combination of aircraft pitch and bank angles. The nominal combinations at which the nacelles contact the ground are shown in Figure 2 (MLG shock struts compressed). Nacelle ground clearance

is also affected by wing bending due to aerodynamic and inertial loading. With B-KAG standing on all five landing gears, the average nacelle ground clearance was measured at 1.81 m (5.93 feet) for the outboard nacelles and 0.99 m (3.25 feet) for the inboards.

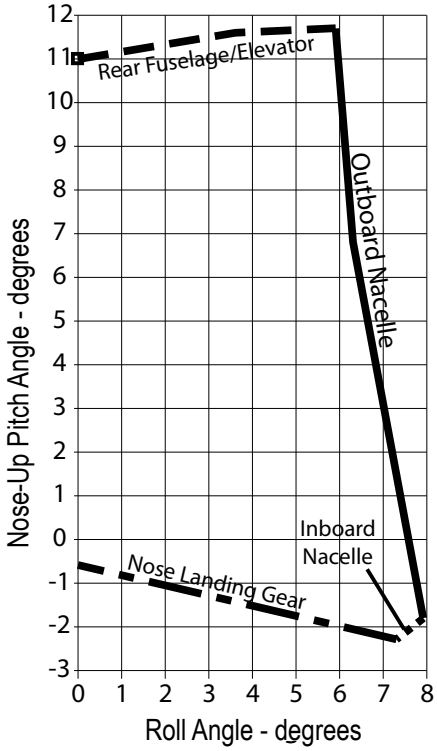

Figure 2

B747-412 Ground contact angles

EGPWS installation

The aircraft was equipped with an Enhanced Ground Proximity Warning System (EGPWS). This system provides audible warnings against terrain-related hazards, windshear events and glideslope deviations. It also provides altitude callouts to aid situational awareness. The system was pin programmed to provide automatic altitude callouts one hundred feet above minimums, at minimums and at radio heights of 2,500 ft, 1,000 ft, 500 ft, 50 ft, 40 ft, 30 ft, 20 ft and 10 ft. These aid situational awareness. These calls are not issued if a higher priority warning, such as the recorded sink rate warning, has been generated.

Runway 23R at Manchester

Runway 23R at Manchester Airport is 3,048 m long and 46 m wide, with an additional 22 m wide paved shoulder on either side. The runway surface is partially concrete and partially asphalt. The published landing distance available (LDA) is 2,865 m. The runway lies south-east of the airport terminal buildings and hangars (Figure 3).

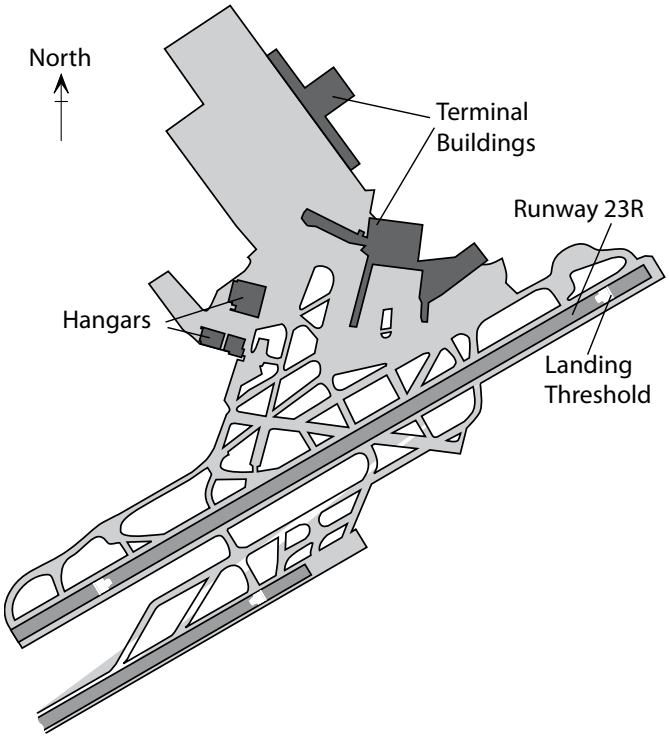

Figure 3

MIA Runway layout

Runway examination

Examination of Runway 23R revealed a number of scrape marks, indicative of nacelle contact, and several tyre track marks that, by virtue of their relative locations and by comparison with the aircraft damage, could be matched to B-KAG's landing (Figure 4).

Other tyre marks from B-KAG may have been present but hidden by the dark-coloured asphalt forming the

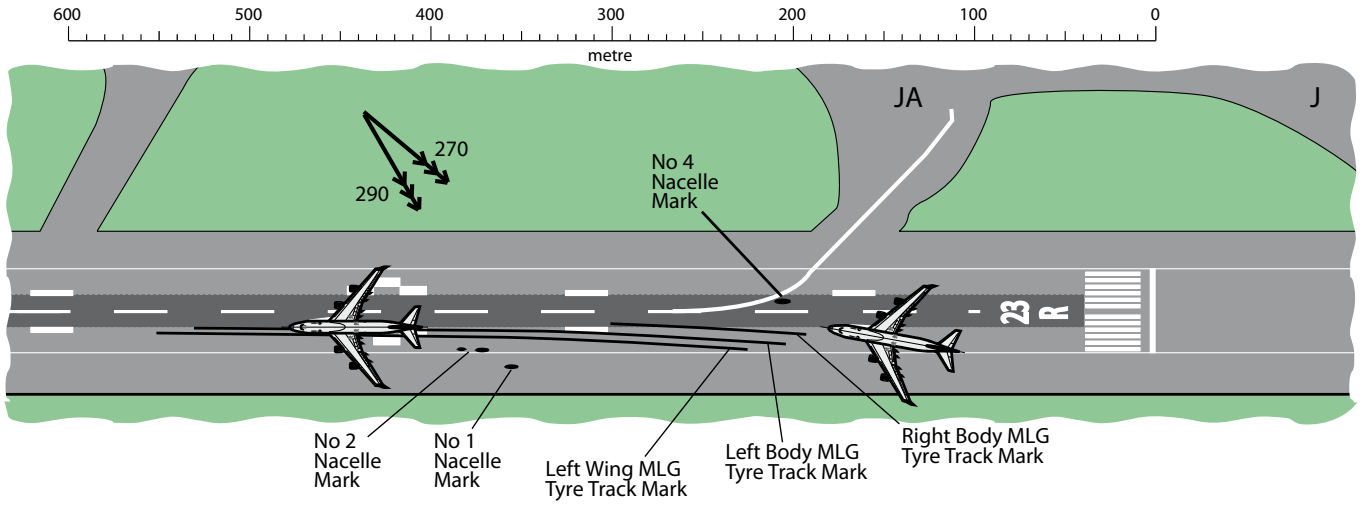

Figure 4

Runway marks

central portion of the runway surface and by multiple heavy tyre smudges present in the touchdown area. The following distances, along the runway from the threshold and left or right of the centreline, are approximate.

The initial mark, from the right body MLG tyres, started around 193 m from the threshold. This was almost immediately followed by a short scrape mark, 6.1 m right of the runway centreline, caused by momentary contact of the No 4 nacelle, and by the start of tracks from the left body MLG tyres. The markings indicated that the aircraft Centre of Gravity (CG) was around 15 m left of the runway centreline at initial touchdown, with the aircraft tracking approximately 4° right of the runway heading. Tracks from the left wing MLG started at 226 m.

The MLG tyre tracks continued, curving to the left. A short scrape mark from the No 1 nacelle started at 359 m and two short scrape marks from the No 2 nacelle started at 375 m. The tyre tracks showed that by around 500 m B-KAG was tracking parallel to the runway, approximately 8 m left of the centreline.

Aircraft Examination

Examination of the aircraft showed that the underside of No 1, 2 and 4 nacelles had sustained scraping and abrasion damage, consistent with having contacted the runway. The most severe damage was to the No 4 nacelle, where the bottom of the nose cowl, fan cowl and translating cowl had been heavily abraded and locally deformed. Distortion of the translating cowl also resulted in minor damage to the HP gearbox driveshaft cover installed on the engine. In the case of the No 1 nacelle, the bottom of the rear part of the nose cowl and the forward part of the fan cowl had been scuffed. The No 2 nacelle suffered locally heavy abrasion damage in the same areas as the No 1.

The direction of the scrape marks indicated that the aircraft had been heading approximately 7° right of its track when the No 4 nacelle contacted the runway.

No evidence of anomalies with the landing gears was found, with the exception of rupture of the No 2 tyre (forward right tyre of the left wing MLG). Tyre pressures measured some hours after the incident were

measured at 190-195 psig for all MLG tyres (normally 200-205 psig), except for the ruptured No 2 tyre. MLG shock strut pressure readings were within limits.

The No 2 tyre rupture resulted from a 'flat' worn completely through the carcass, indicative of the wheel having been locked during part of the ground run. No faults with the wheelbraking system were apparent and none was recorded on the aircraft's central maintenance computer (CMC) when the brake control system was tested using its built-in test equipment (BITE). However, an operational check by the operator found that the No 2 brake failed to release to prevent the wheel from locking. Testing revealed that the No 2 anti-skid control valve (PN 39-617, SN 059627620) was inoperative, and that the valve's electrical insulation resistance was below the minimum specified. The type of valve is not 'lifed' and the operator was unable to establish its time in service. While the brake system BITE includes an integrity check of the servo coil in the anti-skid control valve, it would apparently not detect all faults that might render the valve inoperative.

A Boeing Fleet Team Digest (FTD) (No 747-440-FTD-32-04009, issued 24 September 2004) described reports from operators of water ingress into Anti-Skid Control Valves, resulting in corrosion of several parts of the assembly. The FTD noted that in two cases a tyre skid-through had resulted. In all cases the problem had concerned wing MLG valves. These are installed facing down and appeared to be more susceptible to water ingress than the body MLG and alternate anti-skid valves. The valve manufacturer, Crane Hydro-Aire, had issued a Service Information Letter (SIL) (No 39-617-3-12, Revision 1 of 1 July 1994) recommending adding RTV106 sealant at all external interfaces of the servo valve body and cover. A further SIL (No 39-617-2-14, Revision 1 of 16 December 1994) provided for improvements in the valve cover. The FTD noted that even with this configuration it was possible that a water ingress path was present in the connector area.

Flight recorders

Recordings were recovered from the flight data recorder (FDR), a 2-hour cockpit voice recorder (CVR) and the enhanced ground proximity warning system (EGPWS). The following is derived from these recordings and reported in UTC.

The CVR recordings indicated that throughout the flight the crew were communicating fully with each other, discussing the situation and observing procedures, briefings and check lists in a professional manner.

The aircraft took off from Dubai at 1728 hrs on 29 February 2008. The aircraft climbed to cruise at FL340 and then FL360, with a short period at FL380. The descent started at 0049 hrs. During the descent the crew discussed the high wind conditions enroute, at the destination and at alternate airports with reference to the aircraft limits. Whilst enroute, it was stated that the destination airport was at the time "RIGHT ON THE LIMITS" and the others were within limits. Windshear and go-around briefings were made. Emphasis was given to checking the ATIS and ensuring updated surface wind conditions were received.

Passing through 9,000 ft, the surface wind of 290°/30 kt gusting between 31 and 41 kt was reported. This was highlighted by the crew as out of the operator's limits. The decision was made to continue the descent and prepare to go around if the surface wind remained out of limits.

The final descent on the first approach to Runway 23R commenced from 3,500 ft amsl with the three-channel

autopilot tracking the glideslope and localizer and with the autothrottle SPEED MODE engaged. The aircraft was flown with 20° of drift to maintain track, reducing with altitude. The flaps were progressively deployed, with FLAP 30 selected at 1,460 ft amsl and 3.3 nm to the threshold. Just prior to the automatic "ONE THOUSAND" altitude callout, the surface wind was reported as 290°/24 kt gusting 42 kt which was described as being "JUST IN". At 490 ft agl and 1.3 nm to go, a windshear warning was triggered by the EGPWS. The autopilot and autothrottle switched to go-around modes, flaps were reduced, gear raised and the crew flew a go-around. Prior to the windshear warning, the drift had reduced to 13°; this changed to 9° in the following 3 seconds.

The aircraft climbed to 3,500 ft amsl, and then 4,000 ft amsl, and was vectored for a second approach. During the go-around the crew elected to make a further attempt to land at Manchester, this time with FLAP 25. As the aircraft captured the localizer the wind was reported as 280°/23 kt gusting between 14 and 36 kt and the crew were informed that the aircraft ahead had landed.

By 10.5 DME, and descending through 3,700 ft amsl, the three autopilot channels were fully coupled to the glideslope and localizer and the autothrust was in speed mode. By 6 DME and 2,200 ft amsl the aircraft was fully configured with gear down and FLAP 25. At this point the aircraft was flying with 16° of drift and reducing. Subsequent wind checks received were 290°/24 kt gusting 36 kt, 290°/23 kt gusting 36 kt and 280°/20 kt gusting 36 kt. At this point the aircraft was cleared to land and the 1,000 ft automatic callout was triggered.

The next call was 280°/21 kt gusting 36 kt. This was followed 13 seconds later by the automatic 500 ft callout and then periodic 'instantaneous' surface winds as shown in Figure 5.

Figures 5 and 6 show the recorded information during the final approach and landing. Of note are the gusty conditions evident in the data. The only wind parameter recorded was the wind direction and this was only recorded once every 4 seconds, which is inadequate for analysis of the prevailing wind conditions.

The autopilot and autothrottle systems were disconnected at approximately 270 ft agl and 220 ft agl, respectively. During this period "MINIMUMS" was called and the captain responded with "LAND". At this point the aircraft was slightly to the right of the centreline and rolling left to recover the centreline. Right pedal and roll inputs were made, checking the left bank and motion at the same time that the wind speed started to ramp up and change direction so it was mostly from the right of the aircraft. The aircraft started yawing right and rolling right. Left control wheel and rudder inputs were made, slowing the rate of roll to the right but not stopping it before touchdown.

At touchdown, the aircraft was to the left of the centreline and had a recorded right roll of 9.7°. This exceeded the nominal 'pod scrape' roll limit for the recorded pitch angle. At the point of touchdown only a small Normal acceleration was measured. However, it is worthy of note that the sensor position is inappropriate for measuring forces at the wing.

The aircraft rolled left and the maximum recorded left roll was 6.7°. This did not exceed the nominal 7.5° pod scrape roll limit for the recorded pitch angle but the peak value of roll may not have been recorded and the pod scrape limit would not account for dynamic flexing of the wing. The rollout then stabilised.

From the recorded data, it is clear that the aircraft was being subjected to a strong crosswind component, with

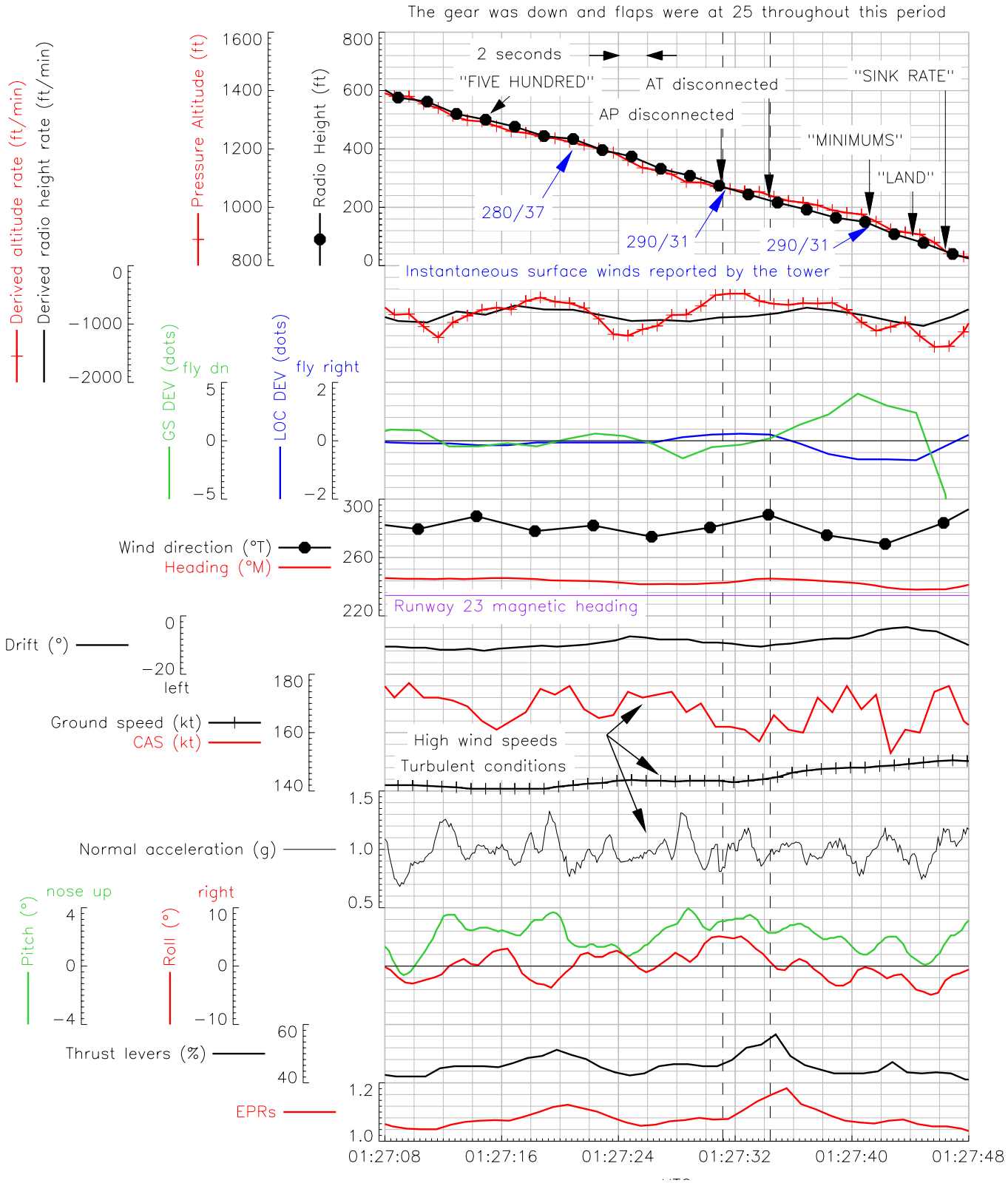

Figure 5

Salient FDR parameters - final approach

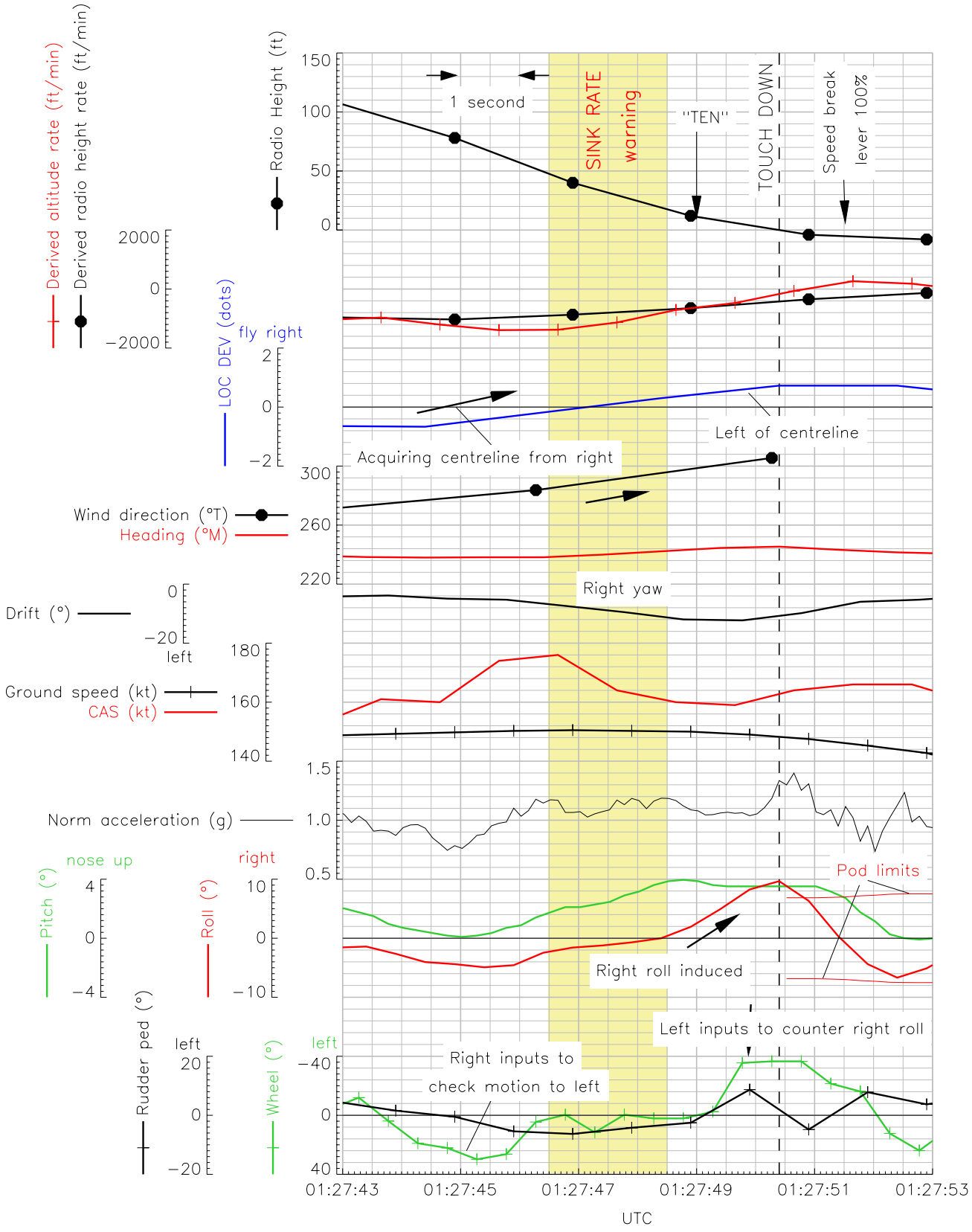

Figure 6

Salient FDR parameters - landing
Flight data analysis by aircraft manufacturer

gusts, and a change in wind direction and speed occurred just prior to touchdown.

An EGPWS sink rate warning was triggered just prior to touchdown and the sink rate was reduced prior to ground contact and only a relatively small normal acceleration was measured at touchdown. The sink rate warning issued by the EGPWS inhibited the majority of altitude callouts in the final stages of the landing.

The aircraft roll at touchdown was sufficiently large to indicate a pod strike on the right engine. The data pertaining to the subsequent left roll did not indicate a pod strike on this side but the limits do not account for flexing and the sample rate of the roll parameter is likely to have missed the peak left roll.

The aircraft manufacturer was provided with flight data and asked for analysis, principally concerning whether the aircraft responded correctly to the crew's control inputs although the sample rate of the wind direction parameter, once every four seconds, was insufficient to assess dynamic wind conditions. The manufacturer used simulation tools that calculated the wind conditions based on the recorded parameters, which improved the understanding of the wind conditions. The calculated wind showed large shifts in direction and magnitude just prior to touchdown.

The simulations and modelling indicated that the aircraft was responding correctly to crew control inputs and that the inputs were appropriate, although their magnitude may have contributed to the likelihood of a nacelle contact.

Operator's procedures

Limitations

The operator's crosswind limit for the Boeing 747-400 when landing on a wet, non-contaminated runway (no standing water, slush, loose or compacted snow, or ice) is 30 kt. The manufacturer's Landing Crosswind Guideline, for the same conditions, is 32 kt. The manufacturer does not regard this as a limitation but, rather, as assistance to operators when establishing their own crosswind policies.

The operator's operations manual repeats the manufacturer's advice:

> *'The crosswind guidelines…. are based on steady (no gust) conditions…. Gust effects were evaluated and tend to increase pilot workload without significantly affecting the recommended guidelines…. '*

Stable approach criteria

Within its '*Approach and Landing Procedure'*, the operations manual provides guidance on a '*Stabilised Approach'*. It states:

> *'In order to comply with company approach requirements, the following should be achieved at or before the altitudes stated:*
>
> - *Landing Configuration by 1,500 ft AAL.*
> - *stabilised on Glideslope/ Final Approach Path by 1,500 ft. AAL.*
>
> *A missed approach is mandatory if any of the following have not been achieved by 1,000 ft. RA:*
>
> - *Landing configuration.*
> - *Stabilised on Glideslope/Final Approach Path.*
> - *Stabilised at Command Speed taking into consideration the prevailing conditions.*
> - *Landing Checklist complete.'*

Next, under the heading *'Mandatory Missed Approach'*, it states:

> *'A Missed Approach is mandatory and shall be executed by the PF immediately if:*
>
> - *The aircraft has not achieved the parameters defined under the stabilised approach, or…*
> - *The successful outcome of the manoeuvre is in doubt, or….*
> - *The Captain announces "Go-Around".'*

Approach speed

The operations manual's guidance on approach speed stated:

> *'If the auto-throttles are disconnected, or are planned to be disconnected prior to landing, position the MCP Command Speed to VREF [the landing reference speed] plus:*
>
> - *½ the steady wind component, and*
> - *All the gust.*
>
> *The maximum wind/gust additive to VREF is 20 kt....*
>
> *The gust correction should be maintained to touchdown while the steady headwind correction may be bled off as the aircraft approaches touchdown.'*

On this basis, the appropriate approach speed, in view of the surface winds broadcast on the ATIS and reported by ATC when the aircraft was cleared to land, was V_{REF} + 20 kt; the gust factor being at least 14 kt.

The landing weight of the aircraft was 257.8 tonnes, for which the FLAP 25 V_{REF} was 152 kt, and the crew set a Command Speed of 167 kt (V_{REF} plus 15 kt). The appropriate Command Speed, for the conditions, was 172 kt and the target speed at touchdown was 166 kt.

Approach monitoring

The operations manual provides guidance for the Pilot Not Flying (PNF) during an approach to land. It states:

> *'The PM [pilot monitoring] shall monitor approach parameters and call any abnormal indications or deviations….*
>
> ***Above DH, MDA or above 500 ft. AAL on Visual Approach (below 2500 ft. RA).***
>
> *Airspeed and descent rate calls may be omitted if the PF [pilot flying] is controlling the IAS and rate of descent satisfactorily.*
>
> *Satisfactorily is defined as Command Airspeed plus 10 kt. to minus 5 kt. and rate of descent less than 1000 fpm below 1000 ft. AAL.*
>
> *If these tolerances are exceeded the PM shall call "Speed" or "Sink Rate". The PF shall acknowledge this call and take corrective action.*
>
> *Corrective action is to be taken for all close to tolerance situations on approach.*
>
> ***Below DH, MDA or below 500 ft. AAL on Visual Approach.***
>
> *The PM will call airspeed and rate of descent using the Command Speed as the base value....*
>
> *Always emphasise descent rates in excess of 1,000 fpm.'*

Landing technique

The operator's operations manual describes three techniques for landing in crosswinds. They are the de-crab technique (with the removal of crab in the flare), the touchdown in crab technique and the sideslip (wing low) technique. The last of these is not recommended with crosswind components in excess of 20 kt. The commander recalled using the crab technique for the approach and not de-crabbing during the flare because of the sink rate immediately before touching down.

The operations manual states:

> *'Touchdown In Crab*
>
> *The aircraft can land using crab only (zero side slip) up to the landing crosswind limit speeds.'*

but adds:

> *'....touchdown in a crab only condition is not recommended when landing on a dry runway in strong crosswinds.*
>
> *On very slippery runways, landing the aircraft using crab only reduces drift toward the downwind side at touchdown and permits rapid operation of spoilers and autobrakes, because the main gear touchdown simultaneously. This may reduce pilot workload since the aircraft does not have to be de-crabbed before touchdown. However, proper rudder and upwind aileron must be applied after touchdown to ensure that directional control is maintained.'*

Go-around

The manufacturer approves go-arounds up to the point that reverse thrust is initiated after touchdown.

The operator advises crews that a touchdown beyond 2,500 ft from the threshold is undesirable and gives the commander the option to discontinue the landing and initiate a go-around if this is likely. The implication is that the go-around will be carried out before touchdown.

Summary - engineering

The evidence from the runway marks showed that B-KAG's right body MLG touched down around 193 m from the runway threshold with the aircraft tracking approximately 4° right of the runway heading and its CG around 15 m left of the runway centreline. Almost simultaneously, the No 4 nacelle contacted the runway and scrape marks indicated that it had around 7° left drift at the time. Shortly afterwards, the left wing MLG touched down. With the aircraft turning left and closing the runway centreline, this was followed, some 166 m after initial touchdown, by light runway contact by the No 1 nacelle and then by two momentary contacts by the No 2 nacelle.

No anomalies with the aircraft were found, with the exception of a fault in the No 2 Anti-Skid Valve. This probably allowed the No 2 MLG wheel to lock under braking, causing the tyre to wear through and rupture.

The manufacturer's simulations and modelling, based on the recorded flight data, indicated that the aircraft was responding correctly to crew control inputs and that the inputs were appropriate, although their magnitude may have contributed to the likelihood of a nacelle contact.

Discussion - operations

As forecast, the crosswind at Manchester Airport was outside the co-pilot's limit when B-KAG made its approach to land. However, the cloudbase was above 3,000 ft agl and the visibility was good. Having gone around from the first approach, following a windshear warning, the crew carried out a second approach. During it, they were advised by ATC that the aircraft ahead of them had landed. The aircraft in question was a different type and there was, therefore, no reason to link the success of its landing with the one B-KAG was about to make.

B-KAG's second approach, using a flap setting of 25° for the landing, appears to have been stable until the autothrust was disconnected at a height of 220 ft agl. The aircraft then drifted above the glideslope, before descending through it, during the course of which B-KAG lost 20 kt of airspeed in one second and then gained 23 kt in the next four seconds. The pitch attitude reduced from 2° above the horizon to 0° and then increased back to 4° nose-up for the landing. The rate of descent increased to a maximum of approximately 1,400 ft/min, resulting in a 'sink rate' warning below a height of 50 ft aal, but then reduced to about 300 fpm at touchdown. The aircraft landed at an airspeed of 163 kt.

When the aircraft rose above the glideslope, it also started to drift to the right of the localiser. The correction back on to the localiser coincided with the increase in rate of descent. The aircraft continued through the localiser, to the left of the extended runway centreline, and right roll was applied, reaching a maximum of 9.7° at touchdown. It was at that point that the underneath of No 4 engine nacelle struck the runway. The aircraft then rolled left, to a degree that was less than that required for a static aircraft to suffer ground contact with an engine. However, the dynamic behaviour of the wing probably accounted for the flexing that enabled the Nos 1 and 2 nacelles to touch the runway surface.

Following the clearance to land, the magnitude of the crosswind, as reported, reached a maximum of 28 kt. That was within the operator's specified crosswind limit for the commander. However, evidence indicates that there was significant variation in the strength and, possibly, the direction of the wind experienced by the aircraft. This was commensurate with the warning contained in the UK AIP entry for Manchester Airport, regarding the possibility of turbulence and large windshear effects when landing on Runway 23R in strong north westerly winds. It seems that the conditions were as challenging as any the commander had experienced since converting on to the B747.

An option existed for the commander to initiate a go-around and divert to an alternate destination where the surface wind conditions were more favourable for a landing. However, the conditions at Manchester Airport, the planned destination, were within the aircraft's and the commander's limits and it was only on landing that the aircraft rolled sufficiently for the nacelles to strike the ground, the earlier high rate of descent having been corrected to an acceptable level.

Although the commander employed the 'Touchdown In Crab' method, the aircraft had drifted from the right of the localiser to be 15 metres to the left of the runway centre line at touchdown. The roll to the right, which had developed just prior to touchdown, was countered with substantial left control wheel and left rudder pedal inputs. The combination of these, and the reactive forces on the aircraft during the landing, resulted in the subsequent roll to the left.

In this serious incident the landing conditions were challenging and very close to, or at, the crosswind limit for this operator. It appears from the recorded data that the last stage of the approach to land coincided with a change in wind direction and speed. There is no evidence that the flight crew were fatigued.