Tailstrike on landing, Boeing 747-267B, TF-ATD

Micro-summary: **This Boeing 747-267B experienced a tailstrike while landing in poor visibility.**

Event Date: **2002-10-16 at 0632 UTC**

Investigative Body: **Aircraft Accident Investigation Board (AAIB), United Kingdom**

Investigative Body's Web Site: **http://www.aaib.dft.gov/uk/**

Note: **Reprinted by kind permission of the AAIB.**

Cautions:

1. Accident reports can be and sometimes are revised. Be sure to consult the investigative agency for the latest version before basing anything significant on content (e.g., thesis, research, etc).

2. Readers are advised that each report is a glimpse of events at specific points in time. While broad themes permeate the causal events leading up to crashes, and we can learn from those, the specific regulatory and technological environments can and do change. ***Your company's flight operations manual is the final authority as to the safe operation of your aircraft!***

3. Reports may or may not represent reality. Many many non-scientific factors go into an investigation, including the magnitude of the event, the experience of the investigator, the political climate, relationship with the regulatory authority, technological and recovery capabilities, etc. It is recommended that the reader review all reports analytically. Even a "bad" report can be a very useful launching point for learning.

4. Contact us before reproducing or redistributing a report from this anthology. Individual countries have very differing views on copyright! We can advise you on the steps to follow.

Boeing 747-267B, TF-ATD

AAIB Bulletin No: 8/2003 Ref: EW/C2002/10/01 Category: 1.1

Aircraft Type and Registration:	Boeing 747-267B, TF-ATD	
No & Type of Engines:	4 Rolls Royce RB 211 turbofan engines	
Year of Manufacture:	1980	
Date & Time (UTC):	16 October 2002 at 0632 hrs	
Location:	Teesside International Airport, Co Durham	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew - 16	Passengers - 430
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Scraped underside of aircraft tail section	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	60 years	
Commander's Flying Experience	Total 17,566 hours (of which 2,577 were on	type)
	Last 90 days - 103 hours	
	Last 28 days - 54 hours	
Information Source:	AAIB Field Investigation	

History of the Flight

The aircraft departed Calgary Airport in Canada at 2220 hrs the previous evening on a charter flight to Teesside Airport in the UK. The flight deck crew comprised two pilots and a Flight Engineer (F/E). The commander was the handling pilot for the sector and an uneventful north Atlantic transit was made at FL350. The crew carried out a full briefing for the ILS approach to Runway 05 at Teesside before commencing the descent. This included the commander briefing the co-pilot that due to the short, wet runway he would ensure he did not have any excess speed or height in the final stages of the approach. The aircraft landing weight was calculated by the F/E as 254.3 tonnes, which was confirmed by the commander who also calculated the minimum approach speed (V_{REF}) of 141 kt which was verified by the co-pilot. The Landing Distance Available (LDA) was determined from the Jeppesen airfield chart as 7,516 feet and from the Landing Performance Flap 30 graph, the commander calculated that the aircraft was within the maximum permitted landing weight for the ambient conditions. The Teesside ATIS current at the time of the landing was information "GOLF", timed at 0620 hrs which was reporting a surface wind of 360°at 12 kt variable between 350° and 080° with visibility of 9 km in light rain showers with scattered cloud at 2,500 feet and 4,800 feet. The temperature was +8°C and the Dew Point +5°C, QNH 1003 mb with the runway surface reported as wet.

As the aircraft was radar vectored for the approach, it was correctly configured for landing with 30° of flap lowered and the landing gear selected down with medium auto-brake set. Anti-ice systems which had been selected on at 5,000 feet were switched off once clear of the icing band at about 1,000 feet.

The approach speed to be flown (V_{APP}) was calculated as 146 kt; this was derived from the flight manual instruction which stated, *'with landing flap set, the final approach speed will be landing bug + half the steady headwind component + all the gust. Maximum increment 20 kt, minimum increment 5 kt'.* The command airspeed bug was set at 146 kt and the aircraft fully established on the ILS at 1,800 feet. The ILS approach was initially flown using the autopilot to capture the localiser and glide-slope with the flight director coupled and engaged in the approach mode. The flight director guidance bars were selected on both the main attitude indicators. The Command Airspeed Bug (CAB) had been reset by the commander, as the handling pilot, as each selection of flap was made. The V_{APP} of 146 kt was set during the final approach and was not changed until the aircraft shut-down checks were performed. At an altitude of 1,500 feet the commander was satisfied that the approach was stabilised and informed the flight deck crew that he was disengaging the autopilot. When the autopilot was disengaged, the airspeed was 142 kt, four knots below V_{APP}. The F/E made standard altitude calls every 100 feet from 500 feet above the decision altitude of 315 feet. A line of rain showers were located across the approach, which the commander described as "like a curtain of rain just short of the runway threshold, which did not appear to reach the ground". Whilst the aircraft was equipped with an autothrottle, it was not used below 10,000 feet.

The aircraft was cleared to land and the surface wind of 010° at 10 kt was passed by ATC. At a height of 400 feet the windscreen wipers were selected on and the co-pilot advised the commander that the drift was 4° to the right. The runway lights were clearly visible through the rain and the approach was continued visually without difficulty. The aircraft maintained a stable approach until a height of 200 feet when airspeed reduced from 144 kt to 132 kt in four seconds, with the aircraft descending half a dot below the glidepath which activated the GPWS aural warning of "GLIDESLOPE". The commander reported seeing three red lights and one white light on the PAPIs for which he took corrective action to regain the glide-slope. In accordance with company procedures, the F/E called the radio altimeter heights every 10 feet from 50 feet and below. At 40 feet the co-pilot called "watch the speed" which had reduced to 129 kt and the commander described the sensation of the aircraft being sucked down onto the runway. He applied aft control column to arrest the rate of descent and the aircraft touched down heavily but it did not appear to bounce. The speed brakes deployed and using reverse thrust together with manual braking from 80 kt, the aircraft was slowed to a stop by the intersection with Taxiway B, a landing distance of approximately 4,400 feet. After shutdown a ground inspection of the underside of the tail section revealed that the aircraft's tail had struck the runway.

Meteorological information

The synoptic situation at 0600 hrs on the morning of the accident, showed an area of low pressure located in the southern North Sea creating a moderate north-easterly air flow over the Teesside area. Rain showers had passed over the airfield and were observed in the vicinity of the airport at the time of the accident flight. The visibility generally was 20 km but reducing to 7 km in the showers. The wind speed and direction measured by the anemometer close to the 05 threshold, was recorded every thirty seconds as an average direction and speed over the previous two minutes. The wind backed from 354° to 349° and reduced from 17 kt to 11 kt at 0631 hrs. The recorded average direction and speed remained at 349° and 11 kt until the time of the accident at 0636 hrs.

Examination of the runway

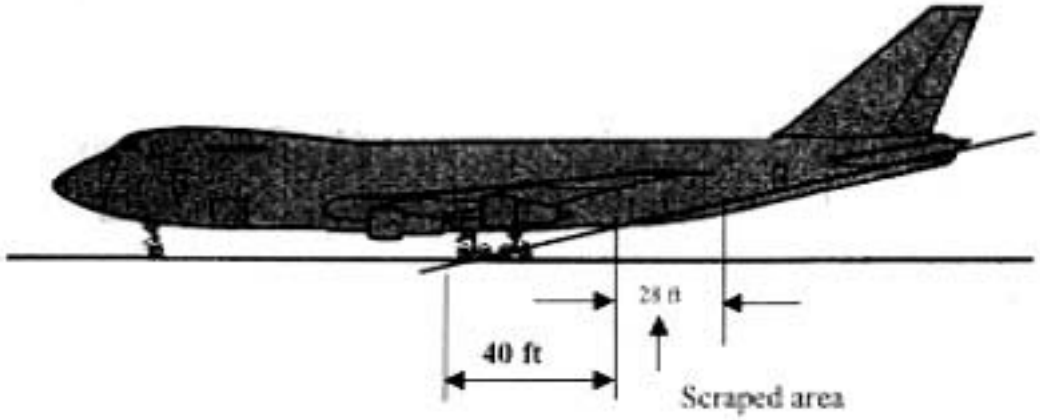
The tyre marks from the aircraft were clearly visible starting approximately halfway between the end of the 'piano keys' and the first of the touchdown zone markings, making the touchdown point around 70 metres from the start of the runway. The disposition of the tyre marks indicated that the aircraft was slightly to the right of the runway centreline, with touchdown being made sequentially on the left wing gear, left body gear, right body gear and right wing gear. This in turn indicated that the aircraft had landed with a small amount of left bank.

Also clearly visible was a 17 metre long scrape mark, consisting of paint flakes and fine aluminium dust, which started 28 metres before the first tyre mark. The scrape was located well to the right of the centre of the runway, approximately in line with the right wing gear, and indicated that the aircraft

had touched down whilst yawed to the left of the runway heading, ie side-slipping to the right. Subsequently, a continuous line within the scrape mark was found to have been made by the rear toilet drain mast.

Examination of the aircraft

The underside of the rear fuselage had suffered abrasion damage, severe enough to expose the edges, in a few places, of two fuselage frames. The rear toilet drain mast had been flattened to the fuselage and the left-side cabin outflow valve, located aft of the damaged area of the fuselage, and which stood proud of the skin, had been ground away on its lower corner. The right cabin outflow valve had escaped damage however, which confirmed the left roll attitude at touchdown.



The damage to the fuselage underside extended over an area approximately 28 feet in length, as indicated in the above illustration. The aft limit was immediately ahead of the rear pressure bulkhead, which is at Fuselage Station 2360. (Note: Fuselage Station numbers refer to the distance in inches aft of a defined datum ahead of the aircraft nose.) A subsequent inspection inside the fuselage, under the floor in the aft cargo area, revealed some minor damage to some of the fuselage frames. The forward limit of damage was approximately 40 feet aft of the wing gear. Thus the 'slant distance', (ie with the aircraft in its touchdown attitude) between the rear pair of wing gear landing wheels and the aft limit of fuselage damage was around 70 feet, or 21.5 metres. Since the distance between the start of the scrape mark on the runway and the first of the tyre marks was 28 metres, or around 90 feet, as noted earlier, it follows that the rear fuselage contacted the ground fractionally before the wheels.

The 'grounding line,' as shown in the illustration, which would vary slightly with oleo compression, is around 12°; this compared favourably with the DFDR data, as discussed later in this report.

The scratches on the fuselage underside were angled relative to the longitudinal axis of the aircraft, which, when measured, indicated that the aircraft was yawed 8.25° to the left of its ground track.

Additional on-site examination of the aircraft was limited to pressurising the hydraulic systems and exercising the flying controls, which were found to function normally.

Pitot/static system

The aircraft was flown, unpressurised, to Amsterdam where it was repaired over a period of several weeks. During this time, the operator, at the request of AAIB, conducted a test on the aircraft's pitot/static systems. The results indicated leaks in each of the two auxiliary static systems. However these are connected to aircraft systems that are unrelated to the altimeters and airspeed indicators, which are supplied from the main pitot/static systems. No leaks were found in the latter, with the

Captain's and First Officer's altitude and airspeed indications being within the Maintenance Manual limits.

Recommended landing technique

The aircraft manufacturer issued an Operations Manual Bulletin Number 71-4 dated 18 January 1971 covering the subject of *'Aft fuselage contact with the runway during takeoff and landing'*. It was reissued on 5 March 1979 as Bulletin Number 79-2 to re-emphasise the landing technique. The relevant parts of the Bulletin are reproduced below:

'Initiate the flare when the main gear is approximately 30 feet above the runway surface. Body attitude at touchdown is about 5 degrees. Do not allow the aeroplane to float just off the runway surface, but fly the aeroplane onto the runway and accomplish the landing roll procedure'.

'Pitch attitude increases as airspeed decreases and fuselage - runway clearance diminishes. Fuselage contact with the runway will occur at approximately 10 degrees pitch attitude when the oleo struts are compressed and about 12 degrees when the oleo struts are extended. Assuming a touchdown attitude of 5 degrees for a flaps 30 and firm contact with the runway (oleos compressed) about 4 feet of clearance margin is available. The margin can be reduced to zero if airspeed decreases 10 to 15 knots below V_{REF} prior to touchdown'.

'The key to a safe, optimum performance landing is to have the proper altitude, airspeed, rate of descent and thrust setting when flare is initiated. Fly the aeroplane onto the runway at the desired point whilst reducing the rate of descent and decreasing thrust to idle by touchdown. This procedure will ensure touchdown at a speed very near V_{REF} and a generous fuselage - runway clearance margin'.

The graph shown below illustrates the relationship of body attitude and speed for the gross weight of the aircraft, which on the accident flight was 254.3 tonnes. The aircraft was 20 kt below V_{REF} at touchdown.

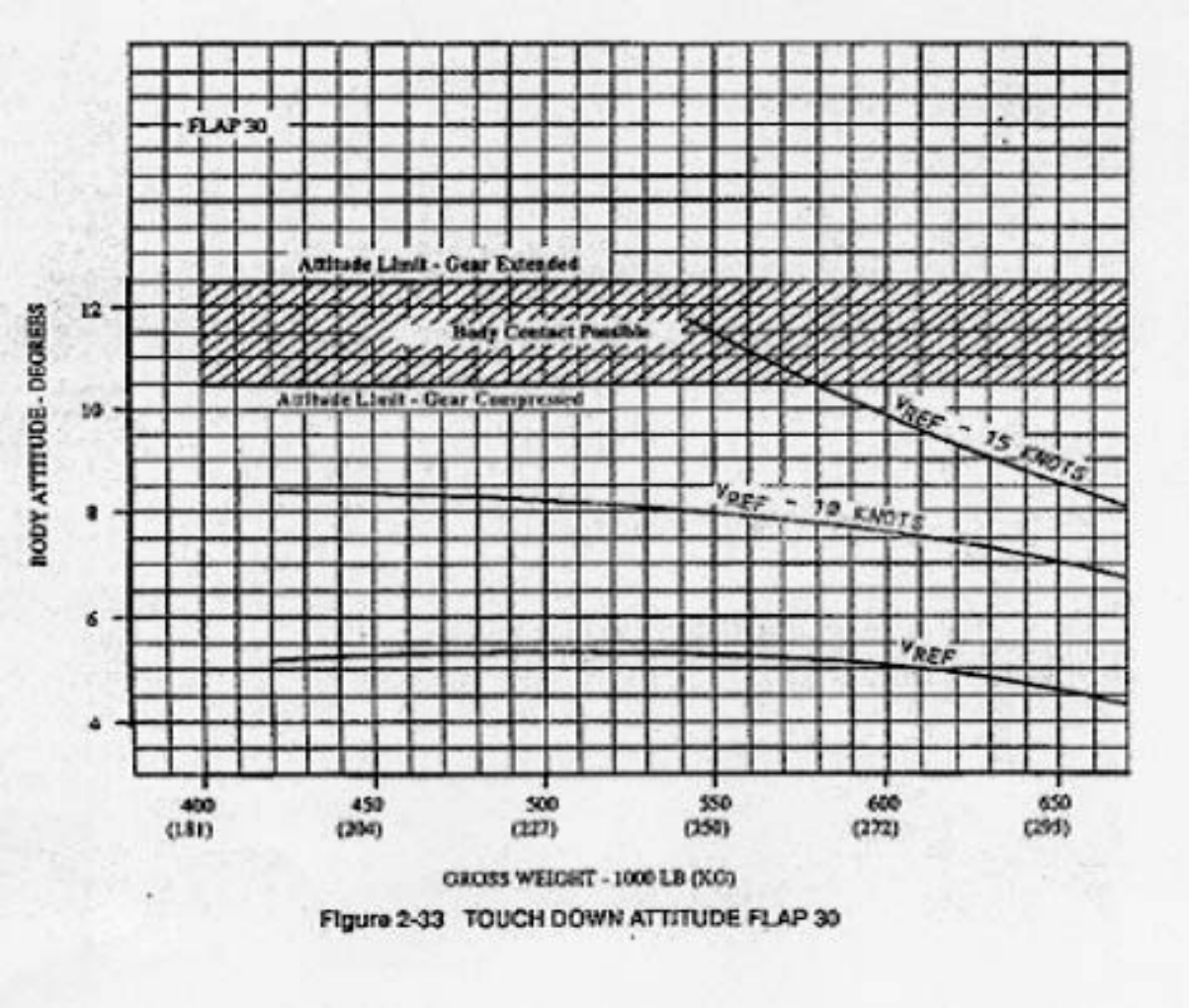


Figure 2-33 TOUCH DOWN ATTITUDE FLAP 30

Flight recorders

TF-ATD was equipped with a 25 hour duration Flight Data Recorder (FDR) preserving the time histories of 102 recorded parameters and, a 30 minute duration, 4 channel, Cockpit Voice Recorder (CVR). Both recorders used plastic tape as a recording medium. The only significant unserviceability in the recording installations was that the commanders 'hot-mic' channel recording was unavailable. The contact of the rear fuselage with the runway during touchdown caused some corruption of recorded flight data. The corrupted data was recovered using manual methods.

The FDR contained, inter alia, the entire flight from Calgary to Teesside. The CVR recording contained the descent into Teesside. Both recordings were uneventful and routine until the aircraft was on its final approach to Runway 05 at Teesside Airport.

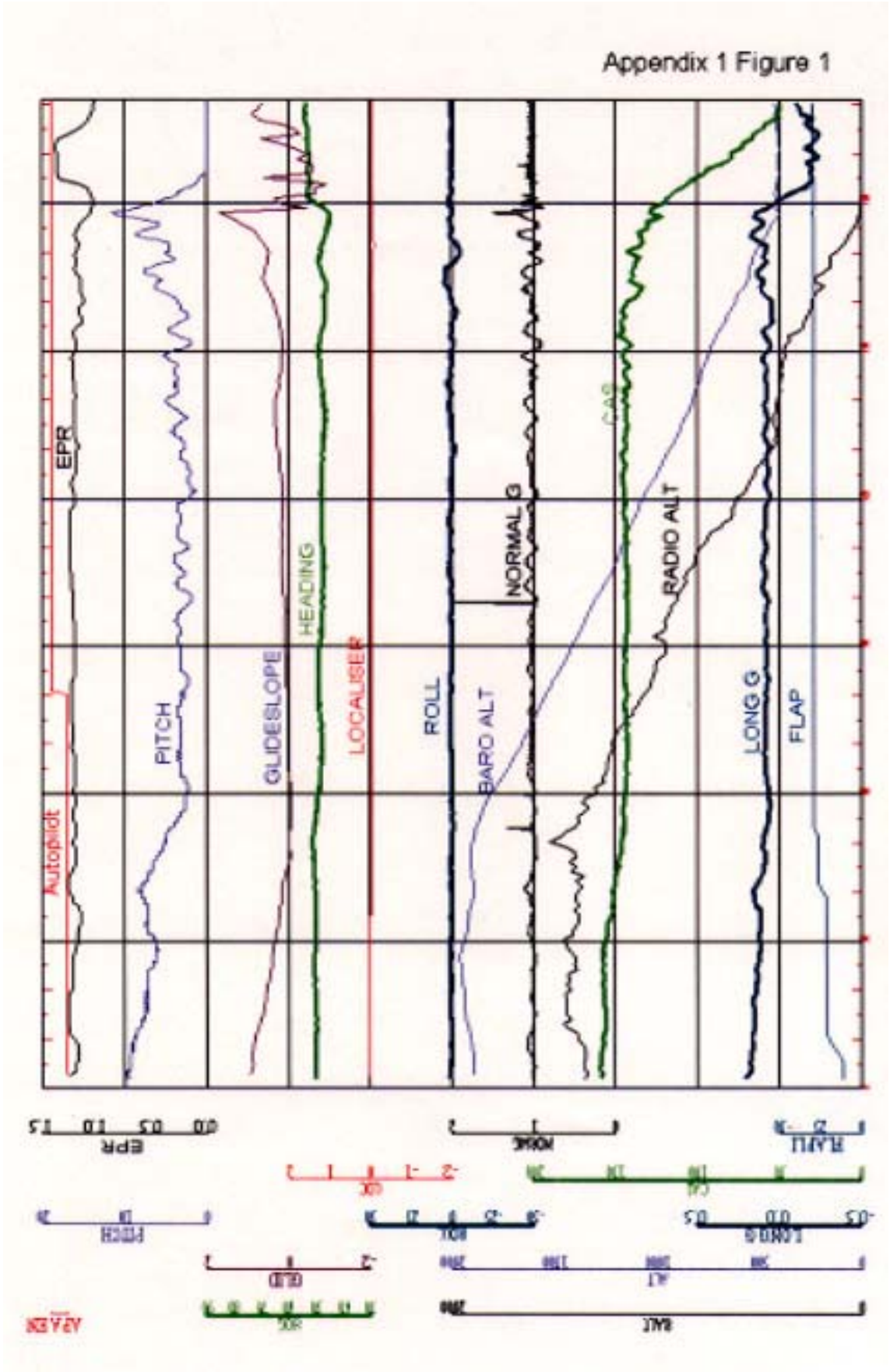
Flight data analysis

The FDR data was analysed by the AAIB independently and by the aircraft manufacturer independently using raw binary data supplied by the AAIB.

AAIB flight recorder analysis

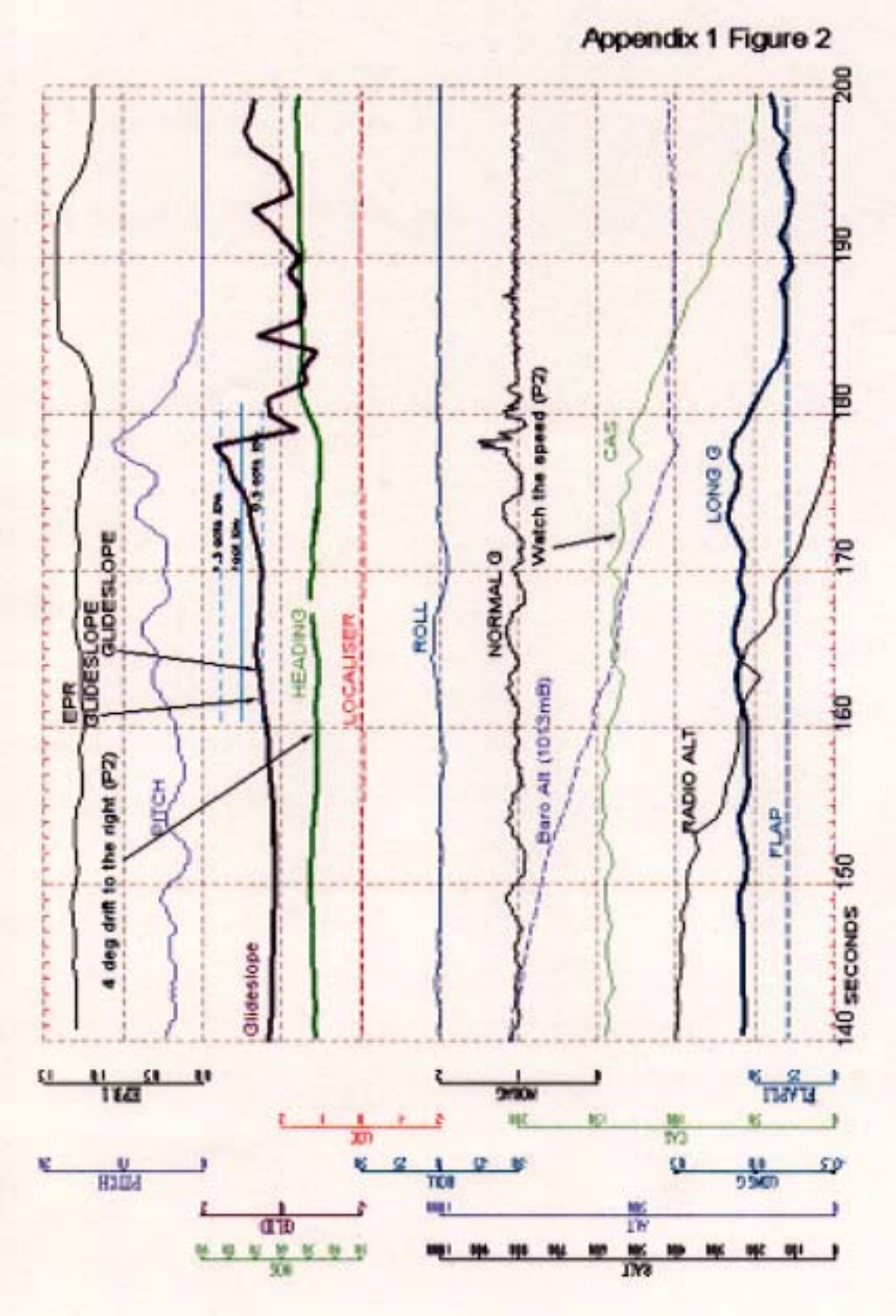
The first step in the AAIB analysis was to ensure that the recorded airspeed was correct and that it agreed with that presented to the flight deck crew. Where applicable, speed calls on the CVR plus the manually recorded speeds made by the crew during the takeoff from Calgary, during the flight and during approach were cross checked against the FDR recording. All the checks showed good

correlation. In addition the operator carried out a calibration of the pitot/static system with the FDR installed and operational.



Appendix 1 Figure 1 shows a graphical time history of selected FDR parameters beginning three minutes before landing. Figure 2 is an expanded graph of the data with relevant annotations from the CVR recording.

From Figure 1 it is clear that the aircraft was tracking the glidepath and localiser signals until about 400 feet agl. At 400 feet there was a small reduction in engine power, the barometric altitude indicated an increase in rate of descent and the ILS glidepath signal showed the aircraft beginning to deviate below the glidepath. The aircraft remained below V_{APP}, but above V_{REF} until 300 feet when the airspeed increased to 148 kt remaining at around 146 kt to 250 feet. Thereafter, pitch attitude increased and the airspeed started to reduce. Coincident with the flight engineer's 200 foot call the GPWS initiated the first of two Mode 5 aural "GLIDESLOPE" warnings. The aircraft pitch attitude continued to increase and the glidepath deviation stabilised for about 7 seconds at about 1/2 dot 'fly up' demand. As the pitch attitude increased, the airspeed reduced and at 100 feet agl the speed was 136 kt. There was a small increase in power at about 90 feet agl; however, the pitch attitude continued to increase and the airspeed decayed further. Airspeed continued to decay to 129 kt at 36 feet with the aircraft 1/2 scale deflection below the glide-slope and thrust reducing. At about that time the CVR recorded the non handling pilot call "watch the speed". From 20 feet above the runway the fuselage nose-up pitch angle increased rapidly from 7° and at 5 feet above the runway, the airspeed was 121 kt with the thrust set at idle.



The aircraft touched down with a pitch attitude of 11.5° (nose-up) on a heading of 43° M (about 8° left of runway heading), at a speed of 129 kt (12 kt below V_{REF}). The speedbrake was activated within 0.5 seconds of touchdown and reverse thrust was deployed 2 seconds later. After touchdown the aircraft quickly turned onto runway heading, decelerated normally and stopped within 25 seconds.

Although the recorded body accelerations showed no clear evidence of turbulence on approach, there were a number of fluctuations in recorded airspeed between 150 feet agl and landing. Some of the fluctuations were explainable by pitch attitude changes and ground effects. However some were not. Furthermore, the commander commented on the CVR that he was aware of "a shear" at 100 feet agl.

No data on wind speed, wind direction, angle of attack or aircraft track were recorded on the FDR. The angle of attack was derived from recorded pitch attitude and calculated flight path angle. The derived angle of attack was used in conjunction with the aircraft manufacturer's lift slope graphs to produce a time history of lift coefficient. From this work the aircraft lift and drag were calculated and used together with thrust to analyse aircraft performance. The analysis showed that the aircraft performance was consistent with recorded power and pitch attitude until 150 feet agl. Performance calculations below 150 feet agl were unreliable due to the absence of recorded wind speed and direction data.

An attempt was made to derive wind data from the time histories of the accelerations recorded on the FDR. This method is limited because of datum errors, low data recording rates and the low resolutions of the recordings. Whilst the sampling rate of the body accelerations was insufficient to enable any rapid changes in atmospheric conditions to be identified, calculations showed a reduction in the headwind component of between 8 and 10 kt.

Boeing flight recorder analysis

The aircraft manufacturer's analysis stated: 'Based on an analysis of the provided data, Boeing believes that while the atmospheric conditions played a role in the tailstrike event, a more significant contributor appears to have been the reduction in approach speed. The FDR data indicate that the approach was flown in varying wind conditions and that there was a tail windshear during the flare. The data also show that a slower than recommended approach speed was flown, increasing in approach pitch attitude and reducing tail clearance margin. The large column inputs during the approach, combined with the effect of the tail windshear, increased the pitch attitude enough to result in tail contact at touchdown'.

Although the available FDR data precluded an accurate calculation of wind data, the data did provide enough information to conclude that atmospheric activity most likely played a role in the tailstrike event, as a contributing factor. In addition to the overall approach speed, the FDR airspeed data from 400 feet above ground level to touchdown show perturbations in the order of 5-10 knots that suggest variable headwind/tailwind components. During the flare there is a 9-knot loss in airspeed and about a 0.2 g reduction in normal load factor, suggesting a decrease in headwind or increased tailwind component.

The Boeing analysis concluded that, *'although there is evidence of a horizontal wind shear when the aircraft was at 100 feet agl it was already below the glidepath, some 10 knots below VREF and in a high incidence and hence high drag attitude. The large column inputs during the approach, combined with the effect of the tail windshear, increased the pitch attitude enough to result in tail contact at touchdown'.*

Approach technique

The commander had used a combination of flying the aircraft visually with reference to the runway perspective and PAPIs as well as in the earlier stages of the approach, using the ILS flight director bars to monitor the correct approach path was being maintained. The approach had been flown generally slower than the intended approach speed of 146 kt but above the V_{REF} of 141 kt down to a height of 110 feet. From that height, the airspeed reduced significantly and the aircraft descended below the glidepath as the commander attempted to land at the earliest point in the touch down zone. The co-pilot alerted the commander to the speed deviation but this was when the airspeed had reduced to 129 kt, which was 12 kt below V_{REF} and just prior to touch down. This call was delayed due to the commander briefing the co-pilot that he intended not to "carry any excess speed or height".

From the 'Touch Down Attitude Flap 30' chart supplied by the manufacturer and included in the Recommended Landing Technique section above, the relationship between low airspeed below V_{REF} and the attitude limit with the landing gear compressed is illustrated. At an airspeed of 14 kt below V_{REF} the aircraft is placed in the 'body contact possible' area of the graph.

Conclusion

Whilst the approach had generally been flown slower than the intended approach speed down to a height of 200 feet, below that height the approach became destabilised and the aircraft deviated significantly below the safe approach speed and glide-path. Only one call was made by a crew member alerting the handling pilot to the speed deviation and this was when the airspeed had reduced to 129 kt, 12 kt below V_{REF} and just before touch down. The low airspeed and deviation below the glidepath were due to the commander attempting to land at the beginning of the touch down zone. He had briefed the flight crew that he did not wish to carry any excess airspeed or height due to what he considered was a short, wet runway.

The investigation considered that the accident occurred when the commander deviated from the normal landing technique and the approach became de-stabilised in the latter stages. The reduction in airspeed below V_{APP} caused the aircraft pitch attitude to be 4.5°, which was greater than the normal 2°. Pitch attitude at main gear touch down should have been 4.5° but due to the low airspeed, it increased to 8° at 50 feet and 11.5° at touchdown, partly because thrust was retarded to idle during the flare.

The drop in the recorded two minute average surface wind from 17 kt to 11 kt at the runway threshold indicated the presence to some degree of windshear which may have been created by the adjacent line of showers. The commander's comment that the aircraft appeared to be "sucked down" onto the runway was probably due the loss of headwind component or increase in tailwind component referred to in the aircraft manufacturer's report. The windshear caused an increased rate of descent at about 30 feet agl which was addressed by the application of full aft control column. This meant that the body contact angle of 10.5° was exceeded as the aircraft's nose pitched up to 11.5° at touchdown.