INCIDENT

Aircraft Type and Registration:	Boeing 757-204, G-BYAO
No & Type of Engines:	2 Rolls-Royce RB211-535E4-37 turbofan engines
Year of Manufacture:	1994
Date & Time (UTC):	12 May 2005 at 1648 hrs
Location:	Manchester Airport, Manchester
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 8 Passengers - 234
Injuries:	Crew - None Passengers - None
Nature of Damage:	Scrapes and wear to the rear of aircraft in vicinity of the tail scrape limiting device and auxiliary power unit access doors
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	48 years
Commander's Flying Experience:	10,630 hours (of which 4,030 were on type) Last 90 days - 143 hours Last 28 days - 64 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was departing on a flight to Gran Canaria with the co-pilot handling the flight controls. During the takeoff, staff in the airfield's ATC tower and the crew of another aircraft, which was stationary at a holding point on the aerodrome, saw a significant amount of smoke emanate from the rear of the aircraft as it lifted off the runway. At the same time the crew in the aircraft heard a noise and felt a slight bump. The commander advised ATC that they thought that they had suffered a tailstrike and intended to return to the airfield. The aircraft made a gentle, uneventful landing back at Manchester, 12 tonnes over the maximum landing weight, and used the full length of the runway to minimise the load on the brakes.

The tailstrike was the result of an excessive rate of rotation during the takeoff. This was exacerbated by a variable headwind component which contributed to a lift off speed that was lower than intended by the manufacturer and compounded the loss of tail clearance. The operator has since amended its procedures to ensure better flying continuity and guidance for newly trained co-pilots, and the inclusion in he company operations manual of the advice given in the Boeing 757 Flight Crew Training Manual on the subject of takeoffs in Gusty Wind and Strong Crosswind Conditions.

History of the flight

The aircraft was departing from Runway 06L at Manchester Airport, on a flight to Las Palmas in Gran Canaria. The co-pilot was the pilot flying (PF) and during the take-off roll the commander noticed that he had introduced what he considered to be an excessive amount of into wind aileron for the prevailing conditions. The commander stated that, initially, the co-pilot set about half of the full control wheel roll deflection to the right but he reduced this as the aircraft's speed increased. On the commencement of rotation the commander watched for any signs of roll but the aircraft appeared to remain wings level. He considered that the rate of rotation was normal until the aircraft had reached 8º nose up but, thereafter, it increased rapidly and he was unable to check the control input. The co-pilot felt that the aircraft was a little 'nose light' and that the rate of rotation was too high up to 10º nose up. Passing the 10º pitch up attitude he continued to pull the control column back at a rate that he considered was about 2.5º of pitch/second.

The staff in the Visual Control Room (VCR) of the airfield's Air Traffic Control tower observed that the rate of rotation was somewhat sharper than usual for a Boeing 757-200. They also saw a significant amount of smoke emanate from the rear of the aircraft as it lifted off the runway. At the same time the commander heard a loud bang from the back of the aircraft and the co-pilot stated that he felt a slight bump as the aircraft rotated through an attitude of 12º nose up. The noise was also heard by the cabin crew. The crew of another aircraft, which was stationary at holding point DZ1 adjacent to the mid point of the runway, reported over the radio that they too had seen smoke coming from G-BYAO'S tail, which had seemed close to the runway surface as the aircraft took off.

ATC enquired of the crew as to whether all was well. The commander replied that they thought that the aircraft had suffered a tailstrike and that they intended to return to the airfield. He requested radar vectors and advised ATC that they did not wish to fly above 10,000 ft amsl. The crew completed the Abnormal Procedure for a tailstrike and, as part of that drill, depressurised the cabin. By this stage the aircraft was flying level at 5,000 ft amsl. The commander informed the cabin crew of the nature of the problem and of the decision to return to Manchester. He instructed them to prepare for a precautionary landing and told the passengers that they were returning to the airfield because the cabin could not be pressurised.

Meanwhile, the airport authority organised an inspection of Runway 06L. No marks, damage or debris were found and over the course of the next 24 hours three more inspections were carried out by different personnel, with the same result.

The flight crew made preparations for an overweight landing and transmitted a PAN call. They decided to use radar vectors, rather than enter a hold (at MIRSI), and the commander commented later that this had been a great help in reducing their workload. The aircraft landed on Runway 06R at a weight which was 12 tonnes above the normal maximum landing weight of 89,811 kg. The aircraft touched down gently and the commander, who had taken over the role of PF, was able to use the full length of the runway and minimum braking in order to reduce the load on the brakes.

After the aircraft had vacated the runway, the AFRS assessed the state of the brakes, which might have overheated, and advised the flight crew that they appeared to be safe. The commander told the passengers that it was normal for the AFRS to be present following an overweight landing and the aircraft was taxied on to a stand. The AFRS then inspected the brakes again and confirmed that they were still safe. Following that confirmation, the commander instructed the cabin crew to disembark the passengers.

The commander stated that the aircraft had behaved normally during all phases of flight after the takeoff.

Other aircraft departures and arrivals

An Airbus A320 had departed from Runway 06L four minutes before G-BYAO took off. This was sufficient time for its wake turbulence to have dissipated before the Boeing 757 departed. A Britten Norman Islander took off after the A320 but its wake turbulence would not have affected G-BYAO. Aircraft were landing on Runway 06R, but the displacement of the two runways, with the threshold on 06R downwind of the threshold on 06L, did not suggest that landing aircraft could have affected the departing aircraft. In addition, none of the departing aircraft reported any instances of turbulence or windshear.

Performance

The aircraft's gross weight at takeoff was calculated on the computerised loadsheet as 100,410 kg, with the CG at 22.5% mean aerodynamic chord (MAC). This was within the maximum take-off weight for the aircraft, which was 103,699 kg, and towards the centre of the CG range for that weight. A witness, who was present when the baggage was loaded before the flight and unloaded after it, stated that the baggage, which had been loaded in holds two, three and four, had not moved during the flight. Another witness who was involved with off-loading the baggage also confirmed that the baggage nets were still in place and that there was no sign that the baggage had moved.

The flight crew calculated the take-off speeds for a departure with 15º of flap as: V_1 = 141 kt, V_R = 144 kt and V_2 = 148 kt. They selected the stabiliser trim to 4.7 units and used Derate One thrust, which gave an engine pressure ration (EPR) of 1.63. The manufacturer stated that the Flight Data Recorder (FDR) data showed a stabiliser setting of 4.5 units.

For the reported conditions, the manufacturer's recommended take-off parameters were; V_1 = 141 kt, V_R = 143 kt, V_2 = 148 kt, stabiliser setting 4.55 units and an EPR of 1.64.

Procedures

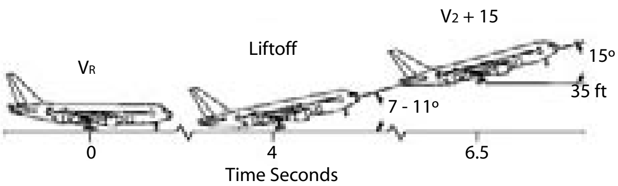
The manufacturer's guidance on *Rotation and Liftoff - All Engines* in its 757 Flight Crew Training Manual (FCTM) includes the following:

> *…When a smooth continuous rotation is initiated at VR, tail clearance margin is assured…..*
>
> *Above 80 knots, relax the forward control column pressure to the neutral position. For optimum takeoff and initial climb performance, initiate a smooth continuous rotation at V_R toward 15° of pitch attitude. The use of stabilizer trim during rotation is not recommended….*
>
> ***Note:*** *Do not adjust takeoff speeds or rotation rates to compensate for increased body length.*
>
> *With a consistent rotation technique, where the pilot uses approximately equal control forces and similar visual cues, the resultant rotation rate differs slightly depending upon airplane body length.*
>
> *Using the technique above, liftoff attitude is achieved in approximately 4 seconds. Resultant rotation rates vary from 2 to 2.5 degrees/second with rates being lowest on longer airplanes.*

Note: The flight director pitch command is not used for rotation.

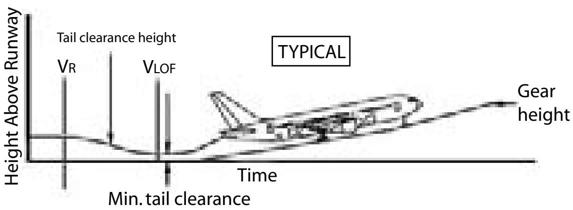
Typical Rotation, All Engines

The following figure shows typical rotation with all engines operating.



…….Typical Takeoff Tail Clearance

The following diagram and table show the effect of flap position on liftoff pitch attitude and aft fuselage clearance during takeoff. Additionally, the last column shows the pitch attitude for aft fuselage contact with wheels on runway and landing gear struts extended….



Model	Flap	Liftoff Attitude	Minimum Tail Clearance inches (cm)	Tail Strike Pitch Attitude degrees)
757-200	1 5 15 20	10.3 10.0 9.5 8.5	30 (76) 33 (84) 38 (97) 47 (119)	12.3
757-300	5, 15, 20	7.5	26 (66)	9.5

……..Effect of Rotation Speed and Pitch Rate on Liftoff

Takeoff and initial climb performance depend on rotating at the correct airspeed and proper rate to the rotation target attitude. Early or rapid rotation may cause a tail strike…..

The FDR data was checked for any stabiliser trim inputs before or during the aircraft's rotation, before the landing gear was retracted. None were recorded.

Under the heading of ***Gusty Wind and Strong Crosswind Conditions*** the FCTM's advice is to:

avoid rotation during a gust. If a gust is experienced near V_R, as indicated by stagnant airspeed or rapid airspeed acceleration, momentarily delay rotation. This slight delay allows the airplane additional time to accelerate through the gust and the resulting additional airspeed improves the tail clearance margin. Do not rotate early or use a higher than normal rotation rate in an attempt to clear the ground and reduce the gust effect because this reduces tail clearance margins. Limit control wheel input to that required to keep the wings level. Use of excessive control wheel may cause spoilers to rise which has the effect of reducing tail clearance. All of these factors provide maximum energy to accelerate through gusts while maintaining tail clearance margins at liftoff.

This advice does not appear in the operator's Operations Manual.

The operator's Operations Manual Part B for the B757/767 states, in relation to the takeoff:

At "Rotate" the aircraft should be rotated smoothly to 15º pitch attitude at an average rate of 2.5º/sec. Having achieved 15º pitch, and when airborne, but not before, follow the flight director pitch commands with an upper limit of 20º.

Personnel information

Initially the co-pilot had been employed by the operator on a temporary basis, as part of a partnership training programme with an approved flying training organisation. He completed his line training on 16 February 2005 and his temporary contract ended on 22 April 2005. He last flew on that contract on 19 April 2005. On 1 May 2005 he restarted his employment with the operator on a permanent contract but was unable to operate on the line until he had completed an Operator Proficiency Check (OPC) in the simulator on 6 and 7 May. The accident flight was his first since that OPC and came 23 days after his previous flight. He had accrued a total of 576 flying hours on all types of aircraft and 323 hours on the B757-200. His performance during training had been commensurate with that expected of a capable pilot with low hours and limited experience. The operator stated that there had been no sign of any particular trend in the co-pilot's flying during his training.

The commander had significantly more experience, both in terms of total flying hours and hours on type. As both the aircraft commander and the non flying pilot (PNF), his role was to monitor PF and his actions. The two pilots had not flown together before so their pre-flight preparation included introducing themselves to each other. All their preparation was completed in good time and neither felt rushed at any stage. The aircraft pushed back off stand three minutes ahead of schedule.

During the investigation it became apparent that, despite never having flown together, the crew co-operated well together and with the cabin crew, both before and after the tailstrike. Their response to the event was clear and decisive, included the relevant procedures and was well communicated.

Meteorology

An observation taken at the airport at the time of the accident recorded the surface wind as 070º/14 kt, visibility greater than 10 km, no cloud below 5,000 ft above airfield level (aal), outside air temperature 14ºC, dew point 1ºC and the QNH pressure was 1022 hPa.

When cleared for takeoff the surface wind was 070º/15 kt. This contrasted with a surface wind of 100º/14 kt which the crew had recorded on the operator's 'take-off form', on which they had also annotated the speeds for V_1, V_R and V_2, as well as the thrust and configuration for takeoff.

The Terminal Area Forecast (TAF) for Manchester between 1600 hrs and 0100 hrs predicted a surface wind of 110º at 11 kt, visibility in excess of 10 km, one to two octas of cloud at 4,000 ft agl and the visibility temporarily reducing to 8,000 m between 2200 hrs and 0100 hrs.

Aircraft examination

Following the incident, the aircraft was taken to a local maintenance facility, where it was later examined by the AAIB. G-BYAO had been fitted with a Tail Scrape Limiting Device (TSLD) which consisted of an inverted section made of nickel alloy, enclosed and sitting proud of a composite fairing. The TSLD was mounted underneath the aircraft, on its centreline, at structural frame 1743.85 (the first frame aft of the rear pressure bulkhead) and deliberately located so that it would be the first point of contact during a tail scrape.

The TSLD had extensive contact damage, with the inverted section worn down so that it was flush with its fairing. Around the device, the airframe skin had buckled and rivets, attached to the frame, had pulled away from the external skin. Internally, frame 1743.85 had been buckled in two diametrically opposite areas where stringer 29L and stringer 29R were attached to the frame. This buckling was consistent with an extensive upward force on the TSLD with the load being transferred into the frame, pushing this upward and causing the plastic deformation of the frame and aircraft skin.

Moving aft from the TSLD, the next contact point was at the APU fire extinguisher access door located between frames 1862 and 1885. Light scrapes were evident 150 mm aft of frame 1862, with these worsening toward the rear of the aircraft. 420 mm aft of the frame, the paint on the access door was worn away in line with the centreline of the aircraft and over an area measuring 160 mm wide and 90 mm in length. The APU access doors were mounted just aft of frame 1885, with a deflector strip mounted on the frame. The centre of the deflector strip was totally worn away, with scuffing of the airframe skin underneath over a width of about 100 mm either side of the aircraft centre line. The scrape damage continued onto the two APU access doors up to a point 470 mm aft of frame 1885. The APU doors contained several proud roundhead rivets and those along either side of the centre line had been completely worn down; coupled with additional wear of the door down to its metal skin. This damage was worse on the right hand door, with the damage at its widest point some 65 mm to the right of the centre line. The left door also suffered similar damage but this only extended 20 mm to the left of the centreline.

Various aircraft systems were checked for serviceability. This included the airspeed indication system stabiliser trim, elevator, flaps and a visual examination of the forward and aft bulk cargo holds. No problems were identified that could have contributed to the tail scrape.

The airframe damage was limited to the un-pressurised area of the aircraft. The aft pressure bulkhead remained undamaged, which was mainly as a result of the TSLD. The aircraft was later flown to its home base for repair. The frame and the skin damage repairs at frame 1885 were carried out in accordance with prescribed manufacturer structural repair manual instructions and a bespoke doubler repair was carried out to the skin surrounding the TSLD. The APU fire extinguisher doors, the two APU access doors and the deflector strip were all replaced with new parts. (See Figure 1)

Flight Recorders

General

The aircraft was equipped with a 25-hour duration FDR, a 30-minute cockpit voice recorder (CVR) and a quick access recorder (QAR), which was utilised by the operator to support its flight data monitoring (FDM) program. When the CVR was replayed the takeoff, approach and landing phases were found to have been overwritten as the CVR power had not been isolated in sufficient time to preserve information relating to the incident. The FDR was downloaded and data for the entire flight was successfully recovered. Data from the QAR was also recovered.

Flight Data

All times quoted were recorded from the commander's clock. At 1644 hrs the aircraft taxied onto a magnetic heading of about 061º and came to a stop with the engines at idle, flaps were at 15º and the horizontal stabiliser position was at about 4.6 units, where it remained until after the aircraft was airborne. The recorded gross weight was 100,624 kg at the time. The aircraft remained stationary for about two minutes before the engine thrust was gradually increased. EPR for both engines stabilised at about 1.63 and the aircraft started to accelerate. During the majority of the take-off roll the

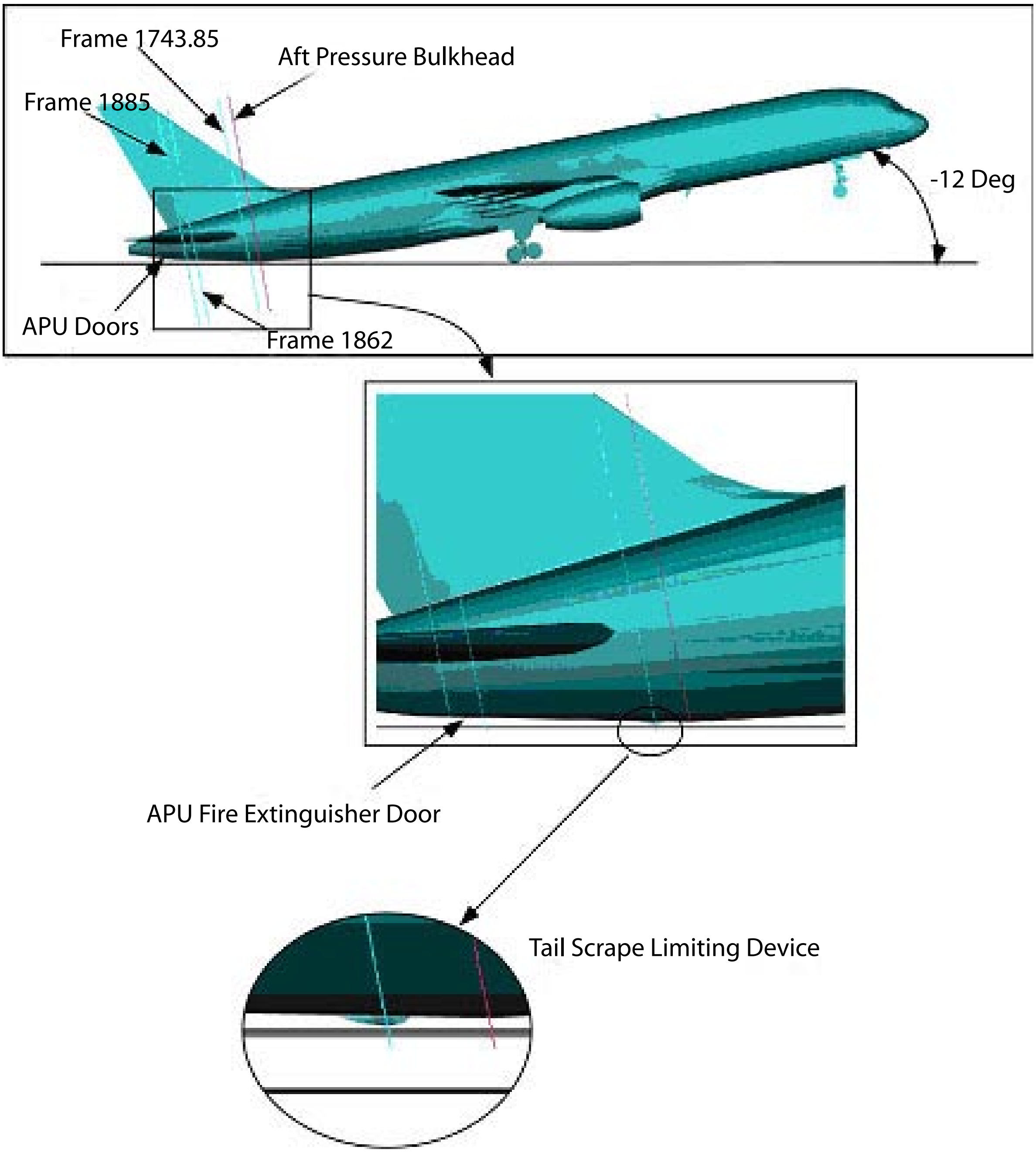


Figure 1

control wheel position was about 18º to the right and a small amount of left rudder was also applied. During the takeoff the airspeed was between 10 kt and 30 kt greater than the groundspeed.

Figure 2 details the salient parameters during the takeoff phase. At 1647:18 hrs, at an airspeed of about 144 kt and a groundspeed of about 120 kt, the control column started to move aft (Figure 2, Point A) and about two seconds later the nose squat switch indicated that the nose gear was no longer compressed (Figure 2, Point B).

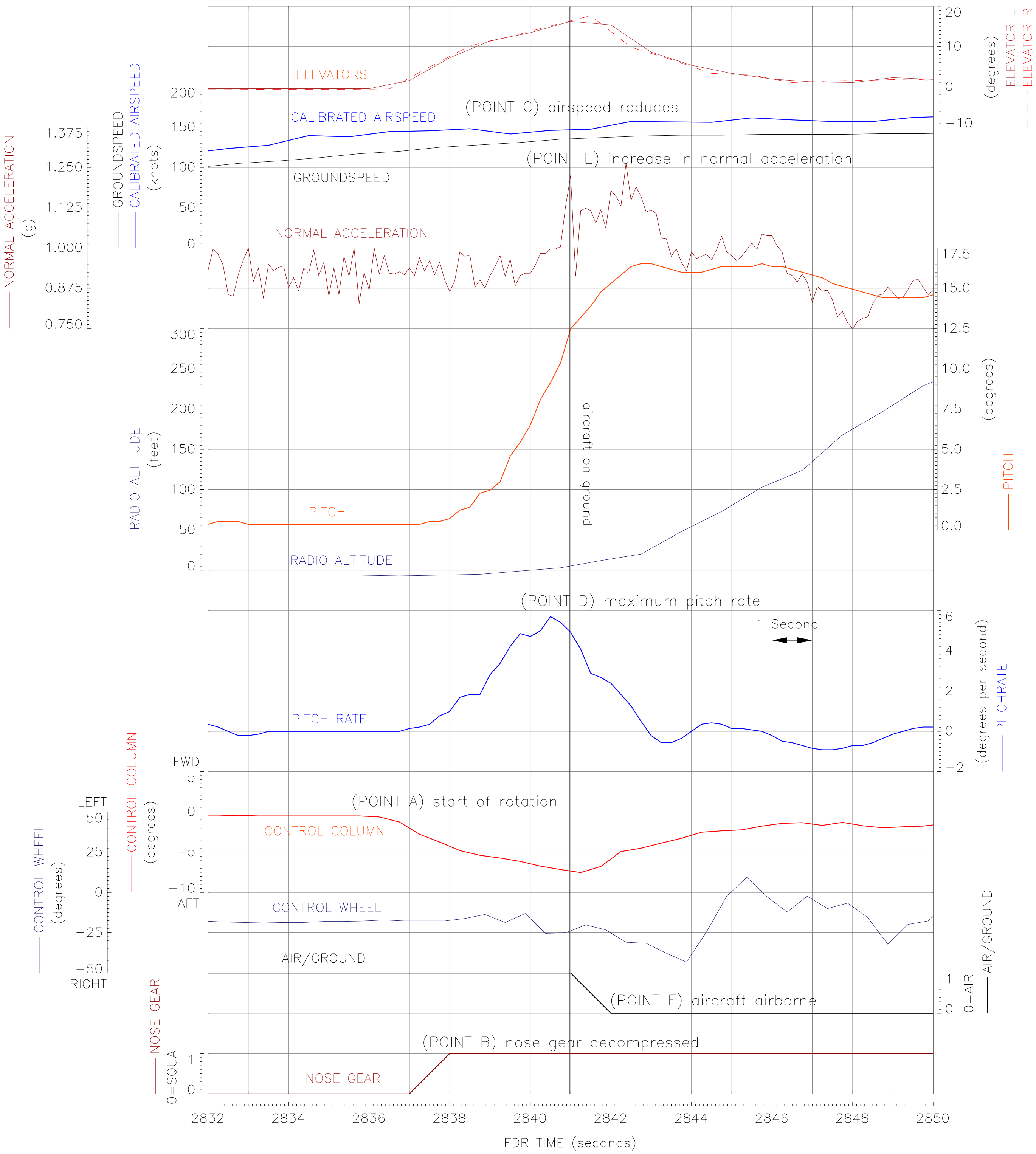


Figure 2

Salient FDR Paramenters

About one second later the airspeed reduced to about 142 kt (Figure 2, Point C), however the groundspeed continued to increase.

About four seconds after the control column had started to move aft the pitch attitude was at about 10º nose up and the airspeed was about 146 kt; at that time the pitch rate was about 5.7º per second (Figure 2, Point D). The control column continued to move aft and the pitch attitude continued to increase. When the pitch attitude was at about 12.5º nose up, a normal acceleration of 1.22 g was recorded (Figure 2, Point E). At that time the main undercarriage truck tilt parameters indicated that the aircraft was on the ground and the elevators were at about 16º trailing edge up. For a short duration the control column continued to move aft and the elevators moved to about 17.6º trailing edge up, before the control column was then moved forward. About half a second later the air ground parameter indicated that the aircraft was airborne[1] (Figure 2, Point F), airspeed was about 148 kt and the groundspeed was about 137 kt. During the take-off roll and rotation phase the aircraft had remained predominantly wings level.

The aircraft continued to climb until it reached FL047, where it remained until about 1704 hrs when the aircraft started to descend and was then configured for landing. The approach and landing were uneventful with touchdown occurring at about 1711 hrs.

Operators Flight Data Monitoring (FDM) program

Overview

The operator utilised a FDM program to monitor the operation of aircraft across the fleet. The FDM program analysed QAR data and identified if operational and/or aircraft performance limits, which had been set by the operator, had been exceeded. The QAR data was typically available for up to six months following analysis.

FDM high pitch attitude and high pitch rate at takeoff detection

The operators FDM program included the capability to identify if pitch rate and/or pitch attitude had exceeded FDM limits. The program had been configured to identify if the pitch attitude at takeoff had exceeded 10º for half a second or more and if the average pitch rate[2] was greater or equal to 3.5º per second during take-off rotation.

The FDM program utilised the normal acceleration and air/ground parameters in its calculation of the take-off point. When the airspeed had exceeded a preset limit the FDM program monitored for an increase in the normal acceleration parameter values or a change of state of the air/ground parameter to identify the take-off point.

FDM historic and incident data

The operator made available FDM data for the handling pilot's previous takeoffs and the incident flight. The FDM program did not identify any events associated with either a high pitch attitude or high pitch rate for any of the takeoffs prior to the incident. This was confirmed by visual analysis of the flight data.

When the FDM program analysed the incident flight it identified that both the pitch attitude and pitch rate at takeoff had exceeded the limits set by the operator during takeoff. The FDM program identified that the

Footnote

[1] The FDR air/ground is recorded in the air mode when the main undercarriage gear trucks are tilted and the nose gear shock strut is extended and the truck positioner hydraulic actuator inlet pressure switches are closed.

Footnote

[2] The average pitch rate was calculated by determining the time difference between when the aircraft pitch attitude had reached two degrees or more and the sample of pitch prior to being greater then twelve degrees; the difference in pitch attitude between the two points was then calculated and divided by the time difference.

maximum pitch attitude at takeoff was 13.2º. This value was consistent with the period when the tail would have been in contact with the runway surface during the takeoff.

Elevator position at takeoff

The manufacturer calculated that for the aircraft configuration an elevator position of between about 10º to 12º would have been required to have maintained an average pitch rate of about 2.5º per second.

Aircraft lift off speed (V_{LOF})

The manufacturer advised that the typical airspeed increase from V_R to V_{LOF} would have been about 13 kt based on the aircraft configuration. V_R was 143 kt and V_{LOF} would have been about 156 kt based on an average pitch rate of about 2.5º per second.

FDR Analysis

About four seconds after rotation had been initiated the pitch attitude had reached 10º, this was in accordance with the manufacturer's recommended average rotation rate of 2.5º per second over a four second period, however the pitch rate at the commencement of the rotation had initially been low and had then rapidly increased. During the rotation the elevator had moved to about 17.6º, about 5.6º beyond the maximum position that the manufacturer advised would have been necessary to have maintained an average pitch rate of about 2.5º per second. The control column position and coincident elevator movement indicated that the rapidly increasing pitch rate had been due to an increase in the aft column position.

During the take-off roll the aircraft had been experiencing a headwind component, which had been varying between 10 kt and 30 kt (as indicated by the difference between the airspeed and groundspeed). As the aircraft had started to rotate the headwind component started to reduce which, as the aircraft had approached 10º of pitch attitude, resulted in an airspeed that was about 10 kt below V_{LOF}. The pitch attitude continued to increase while the aircraft's landing gear was still in contact with the runway and it was most likely that at about 12.5º pitch attitude the aft body made initial contact with the runway as indicated by the coincident recording of 1.22 g.

Operator's actions

The operator implemented the following changes to their procedures:

1. In the first three months following their final line check, new co-pilots are to be rostered for sufficient sectors to ensure consolidation of their training and to allow for close monitoring.

2. Commanders are to be encouraged to give feedback and appropriate advice to new co-pilots.

3. During training, training pilots are to explain the rotation self timing technique and encourage its use.

4. Examine the possibility of obtaining trends from flight data monitoring recordings and providing continuation training for pilots where necessary.

5. The operator has amended his operations manual to include the advice given in the Boeing 757 Flight Crew Training Manual on the subject of takeoffs in Gusty Wind and Strong Crosswind Conditions.

Previous studies

Tail strike accidents in the past have prompted a number of studies. One such, initiated by the manufacturer, listed four take-off risk factors. Namely:

- Mistrimmed stabiliser
- Rotation at improper speed
- Excessive rotation rate
- Improper use of the flight director

Discussion

The results of the investigation indicate that the tailstrike was a result of the excessive rate of rotation during the takeoff; one of the four take-off risk factors for a tailstrike that have been identified by the manufacturer. Rotation was initiated at the correct airspeed but at a low rate. Then it increased rapidly, so that four seconds after the control column had started to move aft the pitch rate peaked at about 5.7º per second. At that point the aircraft's pitch attitude was about 10º nose up and its airspeed was about 146 kt. This compared with the recommended rotation rate of 2.5º per second over a four second period and a lift off pitch attitude of 9.5º nose up. However, having exceeded the recommended pitch rate, the aircraft continued to rotate faster than the manufacturer's and operator's manuals advised. Also G-BYAO's airspeed was less than would be expected at that stage of the takeoff, by some 10 kt. The FDR data indicated that this was because of changes in the headwind component which varied between 10 kt and 30 kt and caused a non-uniform airspeed acceleration. The manufacturer gives guidance, in his Boeing 757 Flight Crew Training Manual, on the procedure to use during takeoffs in gusty wind and strong crosswind conditions to cater for this situation. At the time, the operator did not include this advice in his procedures but this has been addressed and that guidance has since been added to the operator's Operations Manual.

Although the FDR data gave indications of a variation between the airspeed and groundspeed of between 10 and 30 kt, it is of note that neither the meteorological forecast nor observations mentioned wind gusts and no crews in any of the aircraft which were taking off around the time of the accident reported gusty or windshear conditions.

The aircraft lifted off with a nose up pitch attitude of 13.2º and an airspeed of 148 kt, 8 kt slower than the manufacturer's expected lift off speed. The tailstrike occurred before that, when the aircraft's pitch attitude was 12.5º nose up. The data indicated that the pitch attitude and rate of rotation were related to the rearwards movement of the control column. It eventually gave an elevator position which was 5.6º beyond the maximum trailing edge up angle that the manufacturer advised would have been necessary to have maintained an average pitch up rate of about 2.5º per second.

The co-pilot was the handling pilot and there had been no sign of any particular trend during his recent training. His performance during that training had been commensurate with that expected of a capable pilot with low hours and limited experience. However, he had not flown for over three weeks before the tailstrike flight, apart from a two day session in the simulator. The operator has since amended his procedures to ensure that newly trained co-pilots receive better flying continuity and that training and line captains are encouraged to give co-pilots feedback on their handling technique.

The commander had been unable to intervene in time to prevent the tailstrike when he noticed the rate of rotation increase. The recorded flight data indicated that there had been a cue from the stagnating airspeed in the last few seconds before lift off, which might also have alerted PNF to the gusty conditions, albeit at a very late stage in the take-off run. The operator subsequently arranged for him to receive some simulator training to address the situation that he had been faced with. The co-pilot also received further training.

The crew's reaction to the tailstrike reflected well on their ability to handle the consequences of the event and, having never flown together before, to co-operate together and with the cabin crew. The aircraft returned to the airport for an uneventful, overweight landing. Appropriate precautions were taken by the crew and airport authorities to guard against the possible danger of overheated brakes before the passengers disembarked from the aircraft.