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Aviation Investigation Report
Tail strike on take-off and
Aircraft pitch-up on final approach
Air Canada
Airbus 330-343 C-GHLM
Frankfurt/Main Airport, Germany
14 June 2002

Report Number A02F0069

Summary

An Airbus 330-343 aircraft, operating as Air Canada 875, with 253 passengers and 13 crew members on board, was on a scheduled flight from Frankfurt, Germany, to Montreal, Quebec. As the aircraft was taking off at approximately 0830 Coordinated Universal Time on Runway 25R, the underside of the tail struck the runway. The strike was undetected by the flight crew, but they were notified of the strike during the climb-out by Air Traffic Services (ATS) and by a cabin crew member. The flight crew requested a holding pattern to assess the situation. After discussion with the company, the flight crew decided to return to Frankfurt. ATS vectored the aircraft for an instrument landing system (ILS) approach to Runway 25R. While established at 4000 feet above sea level (asl), on the localizer, at about 17 nautical miles (nm) from the threshold, with the autopilot engaged, the aircraft pitched up to 26.7 degrees. The autopilot was disconnected and control of the aircraft was recovered. The approach was completed manually, and an uneventful overweight landing was carried out on Runway 25R. The aircraft sustained substantial structural damage to the underside of the tail as a result of the tail strike. There was no requirement for an evacuation, and there were no injuries.

Ce rapport est également disponible en français.

Other Factual Information

The crew arrived on board the aircraft about 45 minutes before the departure time of 0800¹ to complete the preflight checks. The flight crew listened to the information provided by the automatic terminal information service (ATIS). ATIS "M" recorded at 0720 advised of the following conditions: winds 210 degrees at 10 knots, visibility 10 kilometres, a few scattered clouds at 2000 and 3200 feet, ceiling 4000 feet broken, outside air temperature 20°C, dew point 15°C, altimeter setting

1019 millibars, landing runways 25L and 25R, and departing runways 18, 25L and 25R.

At 0752, the flight crew received the initial load figures from the aircraft communication addressing and reporting system (ACARS), indicating an estimated take-off weight of 222.7 metric tons and a centre of gravity (CG) of 23.7% mean aerodynamic chord. A reduced take-off thrust setting, using an assumed outside air temperature² of 48°C, was planned for a take-off from Runway 25R with a take-off flap 1 configuration. The take-off speeds, provided to the crew by the ACARS, were inserted in the multipurpose control display unit (MCDU) by the pilot not flying (PNF), seated in the right seat. The following speeds were inserted: decision speed (V_1) 156 knots, rotation speed (V_R) 157 knots, and take-off safety speed (V_2) 162 knots. These take-off speeds were valid for any take-off weight of 219.1 to 223.6 metric tons.

At 0808, the ACARS provided the flight crew with the final load figures, indicating a take-off weight of 221.2 metric tons and a CG of 23.8% mean aerodynamic chord. Either during the push back from the gate or during taxiing, the PNF reinserted the final load figures and take-off speeds in the MCDU. By mistake, the PNF typed a V_1 speed of 126 knots instead of 156 knots. Just prior to taking off, the pilot flying (PF) read the speeds off the MCDU as 126, 157 and 162. Neither pilot noted the incorrect V_1 speed.

At 0829:12, the aircraft was cleared for take-off. The take-off was flown by the captain, in the left seat. Flight data recorder (FDR) information showed that the rotation was initiated at 133 knots, and a pitch rate of 2.81 degrees per second was reached from rotation initiation to tail strike. The tail strike occurred when the pitch attitude was about 10.4 degrees and lasted for about two seconds. The aircraft lifted off at a speed of 152 knots at a pitch attitude of 13.7 degrees.

During the radar vectors for a return to the airport and upon localizer interception, the autopilot was engaged. At 0852:27, the aircraft was cleared for the ILS approach to Runway 25R and a descent to 4000 feet above sea level (asl). At 0852:43, the aircraft intercepted the localizer at about 27 nm from the threshold and was levelled at 7000 feet asl. At 0854:36, ATS notified an aircraft that was preceding Air Canada Flight 875 of the possibility of glide path interference due to a taxiing aircraft. This radio transmission was directed only to that aircraft and not to Air Canada 875, at that time about 19 nm from the threshold.

At 0855:20, when the aircraft was about 17 nm from the threshold, at 4000 feet asl, and on the localizer, the flight mode annunciator indicated a glideslope star (G^*), meaning the aircraft was capturing the glide path. The aircraft initially pitched down to follow the glide path signal and then, at 0855:29, started to pitch up, reaching 26.7 degrees nose up at 0855:44. At that time, the PF disconnected the autopilot and applied forward side stick to recover. The positive displacement of the captain's side stick caused a negative g-load of 0.5 g. During the pitch-up, the aircraft reached an altitude of about 5000 feet asl and the airspeed reduced to 145 knots.

Flight Recorders

As the State of occurrence, the German Federal Bureau of Aircraft Accidents Investigation (BFU) started the investigation. On 31 July 2002, the BFU requested that Canadian authorities, as the country of the operator, conduct the investigation as per Annex 13, Chapter 5, to the Convention on International Civil Aviation.

The FDR unit was removed from the aircraft by the BFU and the raw data was sent electronically to the TSB Engineering Branch for analysis. The FDR recorded more than 200 parameters and approximately 25 hours of data, which covered the entire incident flight.

The cockpit voice recorder (CVR) contained two hours of recorded data, 60 minutes of flight data and 60 minutes of post-flight data.

Aircraft Information

The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. Following the event, an assessment of aircraft damage revealed damage to the fuselage between frame stations 68 and 74 and stringers 53 right and 54 left.

Flight Crew Information

The flight crew were certified and qualified for the flight in accordance with existing regulations. Both pilots were qualified as captain on the A330.

The captain had been employed by Air Canada for more than 29 years and had approximately 21 000 flying hours, including 300 on the A330 as captain. He passed his initial pilot proficiency check as an A330 captain in September 2000, and his line check was performed in November 2000. Company training records indicate that he completed all required recurrent training. He completed his last line check in August 2001. He was qualified as an approved check pilot (ACP) on the A330 and A340 and was conducting a re-qualification route check on the PNF during the occurrence flight.

The first officer had been employed by Air Canada for more than 36 years and had approximately 14 000 flying hours, including about 2000 hours as captain on the A330. He joined the training department in 1991 and was the department manager from 1995 until 1996. He passed his initial pilot proficiency check as an A330 captain in August 1999 and his line check in October 1999. Company training records indicate that he completed all required recurrent training. He completed his last line check in August 2001. He was qualified as an ACP on the A330 and A340.

Cockpit Preparation

During cockpit preparation, flight crew enter data into the MCDU by typing it onto the scratchpad. The data are then entered by pressing the line select key adjacent to the desired field. The take-off speeds are typed on a keypad similar to that of a telephone. As per the standard operating procedure (SOP), the data were inserted by the PNF, cross-checked by the PF, and reviewed in the take-off briefing during the pre-departure review. At that time, the estimated take-off weight was 222.7 metric tons and the take-off speeds inserted were: V_1 156, V_R 157, and V_2 162.

Prior to push-back from the gate, the final load figures were provided to the crew. The take-off weight was then revised to 221.2 metric tons. According to the SOP, the gross weight must be reinserted if changed by more than plus or minus 500 kilograms. This was the case and the PNF reinserted it. He also re-entered the take-off speeds, although he was not required to do so, since the take-off speeds initially provided by the ACARS were valid for any take-off weight above 219.1 metric tons up to 223.6 metric tons.

The captain normally taxis the aircraft while the first officer makes any last minute changes to the planned routing, load, or performance data. After confirmation of correct data input and an updated briefing, the PF sets the PERF TAKE-OFF page on his MCDU and, just prior to take-off, reads the take-off speeds off that page. According to the SOP, any time a crew member makes any adjustments or changes to any information or equipment on the flight deck, the other crew member is advised of the intentions and acknowledges the information. It could not be determined if the take-off speeds were re-entered in the MCDU during the push-back or while taxiing. However, when they were re-entered, the PNF typed in 126 as V_1 instead of 156, and this error was not detected by either flight crew member.

The MCDU is designed to display an error message if the data are out of range or not formatted correctly. In the case of take-off speeds insertion, the message will appear only if the speed inserted is below 100 knots.

Once the take-off speeds are inserted in the MCDU, they are displayed on the airspeed scale of both primary flight displays (PFD) and are used as a reference by the PNF to call " V_1 " and "Rotate" during the take-off roll. V_1 speed is represented by "1" on the airspeed scale or by the V_1 value when it is off the scale. V_R speed is indicated by a blue circle and corresponds to the value inserted in the MCDU. V_2 is represented by the target speed index.

In the majority of A330 take-offs, the V_1 and V_R spread is in the range of one to two knots. Since the spread between the two speeds is usually small, the V_R blue circle is most often superimposed by the "1", and the PNF will typically call " V_1 " and "rotate" in quick succession. In this occurrence, the PNF called " V_1 " as the speed reference index approached the "1", and called "rotate" immediately after. This prompted the PF to initiate the rotation well below the calculated V_R . Since the proper V_R speed was inserted in the MCDU, the blue circle indicating the V_R was probably off the scale and not visible to the flight crew.

Aircraft Tail Strike Limit

The manufacturer's *Flight Crew Operating Manual* (FCOM), Bulletin number 05/4, dated March 1998, gives guidance for the avoidance of tail strikes. According to the bulletin, early rotation is one of several factors that can increase the risk of a tail strike. The earlier the rotation, the greater the chance of a tail strike.

Early rotation occurs when an erroneous V_R is computed and/or the rotation is initiated prior to V_R . The FDR for this occurrence indicated that the rotation was initiated 24 knots below the calculated V_R of 157 knots. According to Airbus, this event is the only tail strike that occurred on the A330 fleet in 787 883 departures.

Runway and Approach Information

Frankfurt Airport has two parallel runways: 07L (left) and 07R (right) for take-offs and landings in a northeasterly direction, and 25L and 25R for take-offs and landings in the opposite direction. There is a third runway (18/36). Runway 25R is 13 123 feet long by 200 feet wide with a down slope of 0.27%. The runway surface was dry at the time of the occurrence.

The ILS glide path antenna system for Runway 25R is on a line parallel to the runway centreline, about 300 metres down the runway from the threshold, offset about 140 metres south of the centreline. This is in compliance with ICAO standards.

The ability of each subsystem that comprises the ILS to provide reliable and accurate guidance information depends primarily on the proper formation of their respective radiation patterns. Article 2.1.10.3.2 of Attachment C of the ICAO Annex 10 - *Aeronautical Telecommunications* - indicates that very large aircraft, when parked or taxiing within several thousand feet of the glide path antenna and directly between the antenna and the approach path, will usually cause serious disturbance to the glide path.

The Aeronautical Information Manual, an official guide to basic flight information and ATS procedures, is produced by the United States Federal Aviation Administration and provides guidance regarding ILS signal distortion. Section 1-10 (k) states:

All pilots should be aware that disturbances to ILS localizer and glide path courses may occur when surface vehicles or aircraft are operated near the localizer or glide path antenna. Most ILS installations are subject to signal interference by either surface vehicles, aircraft or both.

To prevent, as much as possible, ILS signal interference, an ILS critical area-this includes a localizer critical area and a glide path critical area-is defined and is intended to protect the ILS facility from moving aircraft and vehicles. The course structure and the integrity of an ILS can be compromised when protection of the ILS critical areas cannot be assured.

At Frankfurt Airport, Taxiway D between Runway 25R and Taxiway C is located in the critical area of the glide path antenna. A note on the approach plate for

Runway 25R indicates that the glide path signal may be interfered with by taxiing aircraft when the ceiling is 1500 feet and the visibility is three miles or better, which was the case in this occurrence. That note was not briefed by the flight crew prior to or during the approach phase. An ATS procedure is established and permits aircraft to taxi onto that portion of Taxiway D when visual weather conditions prevail. According to the procedure, when aircraft are cleared to use Taxiway D between runways 25R and 25L, all aircraft established on the ILS for Runway 25R at a distance of 12 nautical miles or less from the threshold shall be informed about possible glide path interference. The investigation could not determine the exact position nor the type of the reported taxiing aircraft; however, it is reasonable to believe that it was on Taxiway D since Runway 25R was also used for departures and ATS reported the possibility of glide path interference, as required by their procedures.

Although no significant ILS signal fluctuation of any runway at Frankfurt Airport has been reported in the past years, similar events have happened at other airports. The Aviation Safety Letter 3/2002 produced by Transport Canada, entitled *ILS System Failure - A Free Lesson*, reported an incident where a crew, with no warning in the cockpit to advise them otherwise, followed an invalid glide path signal while cockpit indications were normal. The crew, realizing they were too low in relation to their distance from the field, carried out a missed approach.

During a precision approach, flight crew use on-board ILS equipment to provide the lateral and vertical guidance, and they use other equipment depicted on an approach plate to validate the guidance provided by the ILS ground equipment. The approach plate for the ILS to Runway 25R indicates that crews should plan to intercept the glide path at 4000 feet asl overhead the REDGO intersection, located 11.2 nm from the threshold of Runway 25R. In this occurrence, the aircraft was at 4000 feet asl and about 17 miles from the threshold when the crew received the indication that the glide path was being intercepted.

The unusual pitch-up, while established on the localizer, can qualify as an "unusual attitude" and requires prompt reaction from the flight crew to recover. According to the SOP, the flight parameters should be closely monitored by both pilots during the final approach phase. The PF announces any flight mode annunciator changes and the PNF calls out any deviations. Pitch attitude greater than 10 degrees is one of several deviations that should be called. No such call was made during this occurrence. The SOP states that the autopilot should be disengaged if it does not guide the aircraft as expected. The autopilot was not disengaged until the aircraft had reached a pitch attitude of 26.7 degrees nose up and about 1000 feet above the cleared altitude.

Analysis

Neither aircraft airworthiness nor environmental conditions contributed to either event in this occurrence. Since two distinct and unrelated events happened during this flight, the analysis will be divided into two parts to cover separately the tail strike and the aircraft pitch-up event.

Tail Strike

The aircraft tail struck the runway surface at a pitch attitude of about 10.4 degrees nose up. This suggests that the oleos were almost fully compressed due to insufficient lift induced by the early rotation, which decreased the clearance between the tail and the runway to a point that the tail struck the runway surface.

The early rotation was induced by the erroneous V_1 speed. It could not be determined why neither the PF nor the PNF noticed the unusually large spread between V_1 and V_R when the PF read the speeds off the MCDU just before the take-off roll. It is possible that the PNF did not notice the discrepancy at that time because, having entered the data himself, he heard what he expected to hear. During take-off, the PNF, as was his habit, called V_1 as he saw the speed reference index reach the "1" on the PFD, followed immediately by the "rotate" call. Had both flight crew members maintained situational awareness during the take-off roll, they would have noticed the absence of the blue circle, usually superimposed by the "1", or would have noticed that the actual indicated airspeed was well below the briefed rotation speed of 157 knots.

To identify errors, the SOP offered several opportunities to cross-check the take-off speeds inserted in the MCDU: during initial insertion; during the take-off briefing, once reinserted; and prior to take-off. Even though it was necessary to re-enter the new load figures according to the SOP, the PNF did not have to re-enter the take-off speeds since they were the same for the actual take-off weight as for the initial estimated take-off weight. Doing so increased the potential for error, which happened when he entered 126 instead of 156 as the V_1 .

This class of error is known as a substitution error, where a character that was to be entered is substituted with erroneous information. Substitution errors result when information is initially misread, when information is mis-encoded at the time it is entered, or as a result of a human key entry error. It was not possible to determine the exact etiology of the substitution error in this occurrence; however, it is possible that the number "2", which is located directly above the number "5" on the keypad of the MCDU, was accidentally hit.

When the PNF inserted 126 as V_1 instead of 156, it was not detected by the captain. Cross-checking requires flight crew attention and implies that the validation of that which is being cross-checked is accurate. In this case, the take-off speeds were cross-checked prior to reaching the take-off position on the runway, but the accuracy was not validated. Without any cockpit warning or error messages, airmanship and situational awareness were critical to detecting the error and correcting it.

Aircraft Pitch-up

The investigation revealed that the pitch-up was caused by a disrupted glide path signal, probably induced by a taxiing aircraft. The recorded glide path signal received by both on-board ILS receivers indicated a large signal fluctuation. When the glide path signal was disrupted by the taxiing aircraft, the signal bent down to meet the actual altitude of the aircraft. The aircraft ILS on-board equipment received a zero glide path deviation signal. The autopilot, being engaged and coupled to the ILS on-board equipment, captured the signal and continued to follow it when it returned to normal position, causing the aircraft to pitch up.

The design philosophy of the autoflight systems on the A330 is to reduce pilot operational workload. This philosophy does not remove the pilot from the responsibility of maintaining a high level of situational awareness. In this occurrence, 15 seconds elapsed from the time the aircraft started to pitch up until the autopilot was disconnected, indicating a lack of situational awareness. During that time, the aircraft climbed about 1000 feet, a situation that could have created a conflict with other aircraft in the area. Additionally, had the PNF called the pitch deviation as per SOP, it would have given the PF the opportunity to take corrective action earlier than he did.

While it may be desirable to completely restrict critical areas from all surface traffic, this is not generally feasible since normal access to and from the runway, terminal areas, and ramps may necessitate movement through these areas. Because Runway 25L was also used for take-off, aircraft parked on the north side of the field were allowed to taxi on Taxiway D to reach the threshold of Runway 25L.

Since the weather conditions were VFR, ATS applied their procedure and notified an aircraft that was within 12 nm from the threshold of Runway 25R of the possibility of glide path interference. As Air Canada 875 was more than 12 nm on final at that time, there was no requirement to inform the flight crew of this possibility. Had the flight crew briefed adequately prior to or during the approach phase, they probably would have noticed the note on the approach plate in regards to the possibility of glide path fluctuation, which would have prepared them for such an eventuality.

False guidance as a result of signal fluctuation is a known phenomenon. Pilots have generally come to believe that ILS equipment is extremely accurate and reliable. Normally this is so. The aircraft steering information is created by a combination of signals such that, if any one of them is not radiating correctly, the aircraft will receive false guidance. Such false guidance can result in "on course" or "on glide path" indications regardless of the actual position of the aircraft, with no flag or alarm indications in the cockpit to warn otherwise, as was the case in this occurrence. However, even though the flight crew had no warning in the cockpit of a false glide path signal, had they compared their actual distance from the threshold with the distance depicted on their approach plates, they would have noted that they were too far out from the threshold to be on the glide path.

Nothing in the flight crew's collective experience and training had prepared them for this type of failure because, in general, when flight crew are trained in a simulator,

they are usually trained for an ILS system failure which provides a clear warning in the cockpit. When such warnings appear, flight crew generally react quickly. Nevertheless, the flight crew was experienced enough to recognize and to recover from the "unusual attitude" encountered, but did not act appropriately, in a timely manner.

The consequences associated with a false glide path signal can be catastrophic. In this occurrence, the false signal caused the aircraft to pitch up, but it could have caused the opposite. If an aircraft pitches down due to a false glide path signal, when close to the ground and if not recognized quickly by the flight crew, the aircraft could strike the surface.

Summary

The speed insertion error was not detected, despite the safety defence provided by the SOP. Neither crew detected the unusually large and incorrect spread between V_1 and V_R , when read by the PF just before take-off. The absence of the rotation speed blue circle on both PFDs was not noted during the take-off roll nor during the take-off calls. During the approach, the flight crew did not validate the glide path interception with the information provided on the approach plate, which would have indicated that the aircraft was too far from the threshold to intercept the glide path. Contrary to the SOP, no deviation calls were called by the PNF during the pitch-up nor was the autopilot disconnected by the PF when he realized that the autopilot was not guiding the aircraft as expected. Even though the tail-strike and the pitch-up events are not related, there was a demonstrated lack of situational awareness and airmanship related to the two events. It is possible that a flat authority gradient in the cockpit could have played a role in the occurrence. Both pilots were experienced, senior pilots with the company, and both were ACP. While the atmosphere in the cockpit was professional, it is possible that this flat authority gradient contributed to a more relaxed attitude toward cross-checking each other's actions or confirming other information.

The following laboratory report was completed:

LP 071/2002 - CVR FDR Analysis

Findings as to Causes and Contributing Factors

1. The pilot not flying (PNF) inadvertently entered an erroneous V_1 speed into the MCDU. The error was not detected by either flight crew, despite numerous opportunities.
2. The PNF called "rotate" about 25 knots below the calculated and posted rotation speed.
3. The pilot flying (PF) initiated rotation 24 knots below the calculated and posted rotation speed and the tail of the aircraft struck the runway surface.
4. A glide path signal was most probably distorted by a taxiing aircraft and provided erroneous information to the autopilot, resulting in a pitch-up event. The pitch-up could have been minimized if the autopilot had been disconnected earlier by the PF.

Findings as to Risk

1. Other than proper cross-checking, as per SOP, and the speeds displayed on the PFD, the flight crew had no other means to know that an incorrect speed was inserted in the MCDU. A lack of situational awareness and airmanship contributed to not detecting the incorrectly set speed.
2. No warnings in the cockpit were provided to the flight crew indicating that the on-board equipment was receiving a false glide path signal. Had the flight crew noted the information depicted on the approach plate, it is likely that the PF would have been better prepared and reacted accordingly.
3. The flight crew was not directly informed of the possibility of glide path interference caused by a taxiing aircraft because the aircraft was not within 12 nm from the threshold, in compliance with ATS procedure.
4. The PF allowed the aircraft to climb 1000 feet during the pitch-up, which could have caused a conflict with other aircraft.

Other Findings

1. While the atmosphere in the cockpit was professional, it is possible that the flat authority gradient contributed to a more relaxed attitude toward cross-checking each other's actions or confirming other information.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 29 April 2003.

1. All times are Coordinated Universal Time.
2. The pilot can use flexible take-off when the actual take-off weight is lower than the maximum permissible take-off weight for the actual temperature. The maximum permissible take-off weight decreases when temperature increases, so it is possible to assume a temperature at which the actual take-off weight would be the limiting one. This *assumed temperature* is entered into the aircraft's computers. When take-off thrust is then requested, the engines automatically go to the appropriate reduced thrust setting.

<http://www.tsb.gc.ca/en/reports/air/2002/A02F0069/A02F0069.asp>