Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A04O0020

AIRCRAFT PITCH-UP/STALL WARNING ON DEPARTURE

AIR CANADA
BOEING 767-233 C-GAUE
TORONTO/LESTER B. PEARSON INTERNATIONAL AIRPORT
TORONTO, ONTARIO
26 JANUARY 2004

Canada

Aviation Investigation Report

Aircraft Pitch-Up/Stall Warning on Departure

Air Canada
Boeing 767–233 C–GAUE
Toronto/Lester B. Pearson International Airport
Toronto, Ontario
26 January 2004

Report Number A04O0020

Summary

Air Canada Flight 984, a Boeing 767–233 aircraft (registration C–GAUE, serial number 22518) was on a regularly scheduled flight from Toronto/Lester B. Pearson International Airport, Ontario, to Kingston, Jamaica, with seven crew members and 85 passengers on board. The aircraft departed from Runway 06L in instrument meteorological conditions at 1151 eastern standard time.

The autopilot was selected ON as the aircraft climbed through approximately 2500 feet above sea level (2000 feet above ground level). The aircraft then pitched up to 29.5° and the airspeed decreased to a near stall condition. The pilot flying (first officer) began to take corrective action as the airspeed decreased through approximately 120 knots indicated airspeed (KIAS). As the pitch attitude was being reduced, the stick shaker activated and alerted the pilot not flying (captain) that the aircraft was approaching a stall condition. The captain pushed the control column forward, recovering the aircraft from the near stall condition. The aircraft minimum speed was 109 KIAS. Following the occurrence, the flight crew resumed a normal climb profile and proceeded to Jamaica. There were no injuries to the passengers or flight crew.

Ce rapport est également disponible en français.

Other Factual Information

Meteorological Information

The 1200[1] aviation routine weather report (METAR) for Toronto/Lester B. Pearson International Airport was as follows: wind from 070° True at 17 knots, gusting to 22 knots; visibility ¾ statute mile in light snow; vertical visibility 800 feet; temperature -14°C; dew point -15°C; and altimeter setting 30.24.

Personnel Information

The captain held a valid airline transport pilot licence. He had accumulated over 16 000 hours of total flight time, of which 3000 hours were on Boeing 767 aircraft. He was certified and qualified for the flight under existing regulations. He had been awake for four hours and had been performing duties as a flight crew member for two hours prior to the occurrence. The captain was seated in the left seat and was the pilot not flying (PNF).

The first officer also held a valid airline transport pilot licence. He had accumulated over 7000 hours of total flight time, of which 1000 hours were on Boeing 767 aircraft. He was certified and qualified for the flight under existing regulations. He had been awake for six hours and had been performing duties as a flight crew member for two hours prior to the occurrence. The first officer was seated in the right seat and was the pilot flying (PF). The captain and the first officer had flown together as a crew on one previous occasion, about six months prior to the occurrence flight. Both flight crew members had been off duty the previous three days.

Aircraft Information

Records indicate that the aircraft was certified, equipped and maintained in accordance with existing regulations and approved procedures. During the preceding flight, problems were experienced with the left electronic engine control (EEC), and both EECs were turned OFF. When the aircraft arrived in Toronto, the EEC unserviceability was entered in the Defect Log of the Aircraft Journey Log, in accordance with the minimum equipment list. The aircraft was then released for further flights with the EECs turned ON. However, if there was any indication that the EECs were not operating properly, they were to be turned OFF and the engines monitored. The captain was involved in the decisions regarding the EECs. The left EEC was replaced on 28 January 2004.

Following this occurrence, maintenance personnel replaced the left angle-of-attack vane sensor because they suspected that it was faulty and was related to the pitch-up. The removed sensor was inspected and no anomalies were found.

---

[1] All times are eastern standard time (Coordinated Universal Time minus five hours).

Flight Recorders

The aircraft was equipped with a Honeywell Universal flight data recorder (FDR), model #980–4100–AXUN. The FDR was removed and downloaded by the operator. A copy of the raw data was sent to the TSB Engineering Laboratory for analysis. Appendix A is a plot of the FDR data from the beginning of the take-off run and shows the pitch up and near stall event. The data shows that, during the occurrence take-off, aircraft rotation started at 148 knots indicated airspeed (KIAS) and at 158 KIAS the aircraft lifted off. The calculated rotation and take-off safety speeds (Vr and V_2) were 141 and 145 KIAS. The aircraft accelerated through 170 KIAS about 3 seconds after lift-off, and continued to pitch up until a pitch attitude of approximately 16° was established. This pitch attitude was maintained and the aircraft continued to accelerate to approximately 185 KIAS during the next 20 seconds. The vertical speed was approximately 3000 feet per minute (fpm) during this time.

Approximately 25 seconds after lift-off, the pitch attitude began increasing over the next 10 seconds from 16° to 22°. The rate of climb increased to approximately 5100 fpm and the airspeed began to decrease. About 30 seconds after lift-off the flight director (FD) pitch mode changed from take-off to altitude capture (ALT CAP) mode. Approximately 10 seconds later, the centre autopilot was engaged. During this 10-second period (between ALT CAP mode annunciation and autopilot engagement), the airspeed decreased to approximately 160 KIAS. After the autopilot was engaged, the aircraft attitude remained at 22° up for about 4 seconds and then increased to 29.5° over the next 10 seconds. At the time the autopilot was engaged, the engine pressure ratio (EPR) was decreasing from 1.45 (take-off power) to 1.35 (climb power). The aircraft maintained 29.5° of pitch for about 3 seconds before the autopilot was disconnected and the flight crew began a 0.4*g* pushover to recover from the near stall. The autopilot was engaged for about 17 seconds, during which time the airspeed decreased from 160 KIAS to 109 KIAS. The vane angle of attack reached a maximum value of approximately 13° during the pitch-up; this corresponds to a body angle of attack of 17°. During the recovery the aircraft pitch attitude reduced to 3° nose up. The aircraft descended 300 feet during the recovery; the aircraft developed a momentary sink rate before re-establishing a positive rate of climb. Over the next 18 to 20 seconds, the airspeed increased to 180 KIAS and the pitch attitude increased to approximately 12°.

History of the Flight

After a normal start and completion of the cockpit checks, the aircraft taxied to the de-icing facility where it was sprayed to remove a trace of ice. The aircraft then taxied to Runway 06L for take-off.

The flight crew were assigned a departure heading of 065°, a slight heading change from the runway heading of 057°. In preparation for take-off, the FD, which displays pitch and roll commands on the electronic attitude direction indicator, was in take-off mode and the pitch and roll commands were 8° nose-up and wings level, respectively. As the aircraft accelerated through 80 KIAS, the FD changed to an air mode and commanded a pitch attitude to maintain an initial

climb speed equal to the greater of V_2[2] +15, or lift-off speed +15, but limited to V_2 + 25. In this occurrence, the captured speed was V_2 + 25 or 170 KIAS. During the initial climb, the FD command bars were commanding a higher-than-normal pitch attitude. Rather than follow the command bars, the PF limited the pitch of the aircraft to approximately 16° nose up initially and then 22°. Although the pitch attitude was not increased enough to capture the FD command bars, a high rate of climb (5100 fpm) was established during the initial climb after take-off.

After take-off, the aircraft heading wandered right to about 076° before corrective action was taken to bring the aircraft back to the assigned heading of 065°. Climbing through 400 feet above ground level (agl), the PF called for heading select, which caused the FD roll command to target the heading bug.

As the aircraft climbed through 1000 feet agl, the PF called for flight level change (FLCH), climb thrust, command centre[3] and bug up[4] in accordance with standard operating procedures. When the FLCH was selected, the FD combined auto-throttle and flight-control computer modes to target the selected altitude, which was set at 5000 feet; the target speed was then automatically reset to the current speed of approximately 185 KIAS. When the target speed was reset to the current speed, the FD command bars came down to match the current pitch attitude. The flight control computers, using the aircraft's speed and rate of climb, computed that the 5000-foot target altitude was achievable, and the FD switched to ALT CAP mode and a green ALT CAP was displayed on the FD. The ALT CAP mode denoted a transition manoeuvre entered automatically from the FLCH mode.

When climb thrust was selected, engine power was automatically reduced in accordance with a predetermined computer schedule for a more economical climb setting. The FD remained in the ALT CAP mode with the previously calculated capture profile.

Normally the time interval between the activation of FLCH, climb thrust, command centre and bug up is the time it takes for the PNF to reach over, press each of the push button switches and select the appropriate speed on the IAS/Mach selector knob, which is about 3 to 5 seconds total. In this occurrence, at least 10 seconds elapsed between the selection of FLCH and centre autopilot engagement. The PF observed a green ALT CAP indication before the PNF had selected command centre autopilot. The PF had never seen the ALT CAP indication this early in the climb profile. The centre autopilot, when engaged, followed the FD in the ALT CAP mode. This resulted in both the airspeed and rate of climb decreasing until the aircraft was no longer able to achieve the ALT CAP profile.

---

2 V_2 – Take-off safety speed.

3 The aircraft is equipped with three autopilots, referred to as command left, command centre and command right.

4 "Bug up" is a standard-operating-procedure call to reset the target airspeed to Vref30+80 (Vref30 represents a specific approach speed with the aircraft configured at 30° of flap). The autopilot flight director system will then command a lower pitch attitude to allow the aircraft to accelerate to the higher speed and then a pitch attitude to maintain that speed.

When the PNF made the command centre selection, the PF indicated that the FD command bars came down to meet the airplane symbol, which was pitched up 22°. After concluding that the autopilot was functioning and flying the aircraft, the PF focussed his attention on the engine gauges to ensure that climb thrust was maintained. When he returned his scan to the electronic attitude direction indicator, he noted that the FD command bars had disappeared and he alerted the PNF. He also noted that the green ALT CAP indication had turned amber.[5] This amber light indicated a "degraded operating condition" in that the aircraft was no longer able to achieve the ALT CAP profile. Some manner of intervention by the flight crew would be required to rectify the situation, including, but not limited to, disengaging the autopilot and manually flying the aircraft. In this occurrence, neither pilot intervened, and the autopilot was not disengaged.

By the time the PNF looked at the PF's electronic attitude direction indicator, the FD command bars had reappeared, and he observed a normal display. However, he reset the FD to confirm its operation and then continued with other PNF duties. Resetting the FD had no effect on its operation other than to refresh the display screen. Observing the return of the FD command bars, the PF returned his attention to the engine gauges. Moments later, he noted that the aircraft had pitched up to about 30°, observed the airspeed decreasing through 140 KIAS, and at 111 KIAS he deactivated the autopilot and began to push the control yoke forward. The stick shaker then activated, prompting the PNF to aggressively push the control yoke forward.

There are several versions of the flight-control computer software in use on Boeing 767 aircraft. The Air Canada fleet uses two different versions of the software. C–GAUE was equipped with customer option 3, which, in the event of an excessive angle of attack, provides passive stall protection in the form of a Level B caution. This protection consists of the following aural and visual warnings: the FD command bars are hidden from view, the ALT CAP indication changes to amber, the amber autopilot light illuminates, a master caution light illuminates and an aural warning sounds.

Other aircraft in the Air Canada Boeing 767 fleet are equipped with customer option 6, which also includes active speed protection; there are options, other than 3 and 6, that are available. For aircraft equipped with the option 6 flight control law upgrade, the FD command bars will automatically come down to direct the pilot or autopilot to decrease the pitch if the airspeed decreases below the selected speed (5 knots below the selected speed if the autothrottle is engaged).

Analysis

When the aircraft began the take-off run, all systems were operating normally. During the initial climb, the PF allowed the airspeed to increase above the desired climb speed, and thus the aircraft had ample energy to meet the ALT CAP parameters early in the initial climb phase. When the PF increased the pitch attitude to 22°, the airspeed began to decrease. When climb thrust was selected, the airspeed decreased more quickly, which resulted in insufficient energy

---

[5] An "amber light" is denoted by an amber line drawn through the ALT CAP mode annunciation.

to maintain the ALT CAP capture profile. The autopilot pitched the aircraft up to 29.5° in an attempt to maintain the ALT CAP profile and, as a result, the airspeed decreased further. This attitude was maintained until the stick shaker activated and the flight crew took recovery action.

During the initial climb after take-off, the FD command bars were reset to match the aircraft's current pitch attitude when the FLCH selection was made, not when the command centre autopilot was engaged. When the FD command bars were hidden from view, the PF did not realize this was an indication of an autopilot mode failure, nor did he realize that the amber ALT CAP light also denoted an autopilot mode failure. Thus he did not disconnect the autopilot. It was not determined why the flight crew did not respond to the remaining mode fail protection warnings: the autopilot amber light, a master caution light and the aural warning.

While the autopilot was engaged, the PF focussed his attention on the engine gauges. He did not effectively scan the aircraft flight instruments and, as a result, did not observe the aircraft performance degrade until the aircraft approached the near stall condition. There was nothing found to indicate that the autopilot did not operate as designed during this occurrence; it was trying to do what the PF requested of it.

The captain was immersed in his PNF duties and did not adequately monitor the aircraft and the PF. As a result, he was not aware of the aircraft's attitude and airspeed until the stick shaker activated.

When auto systems are activated or engaged, the crew's responsibility to continue the monitoring of aircraft systems and instruments is not diminished. In this occurrence, both crew members relied too heavily on automation.

The following TSB Engineering Laboratory report was completed:

LP020/2004 – FDR Examination

This report is available from the Transportation Safety Board of Canada upon request.

Findings as to Causes and Contributing Factors

1. The altitude capture profile was too aggressive for the energy available at the time, and the autopilot pitched the aircraft up in an attempt to fly the commanded altitude profile. As a result, there was a decrease in airspeed.

2. The pilot flying (PF) did not operate the aircraft as required during the initial climb after take-off, which allowed the aircraft speed to reduce until stick shaker activation.

3. The PF focussed his attention on monitoring the engine gauges and ceased to effectively scan the flight instruments once the autopilot was engaged.

4. The PF did not understand the flight director and autopilot mode failure indications presented to him and, as a result, he continued to operate the aircraft with the autopilot engaged.

5. The captain did not adequately monitor the aircraft or the PF following the take-off phase, and he was not aware of the excessive pitch attitude or the decrease in airspeed until the stick shaker activated.

6. The flight crew did not respond to the visual and aural warnings: an excessive angle of attack, the FD command bars disappearing, the ALT CAP indication changing from green to amber, the autopilot amber light illuminating, a master caution light illuminating and the aural warning sounding.

Other Finding

1. The autopilot was functioning as designed during the occurrence.

Safety Action Taken

Following this occurrence, Air Canada implemented several initiatives aimed at enhancing flight crew safety awareness. They are as follows:

Company manuals have been updated to reflect new information on speed protection annunciation and information received from Boeing that addresses autopilot operations in a degraded mode of operation.

The *Flight Crew Training Manual* was updated with a description of the incident, along with awareness that when the aircraft is on autopilot and operating in a degraded mode, speed protection will not be available and crew intervention will be required.

The 2004 winter Instrument Procedures Flight has, as part of the pre-briefing, a PowerPoint presentation and instructor/candidate interactive dialogue that includes what happened during this event. Flight crews now view a pictorial display of flight deck indications that demonstrate when crew intervention would be required.

Flight Technical personnel, in conjunction with Air Canada Tech Ops, are determining if all aircraft need to be configured to flight control computer Customer Option 6 or one of the other available options. A study is under way to determine which options are compatible with the current fleet and if the change to a different option will make significant safety enhancements to the B767 aircraft.

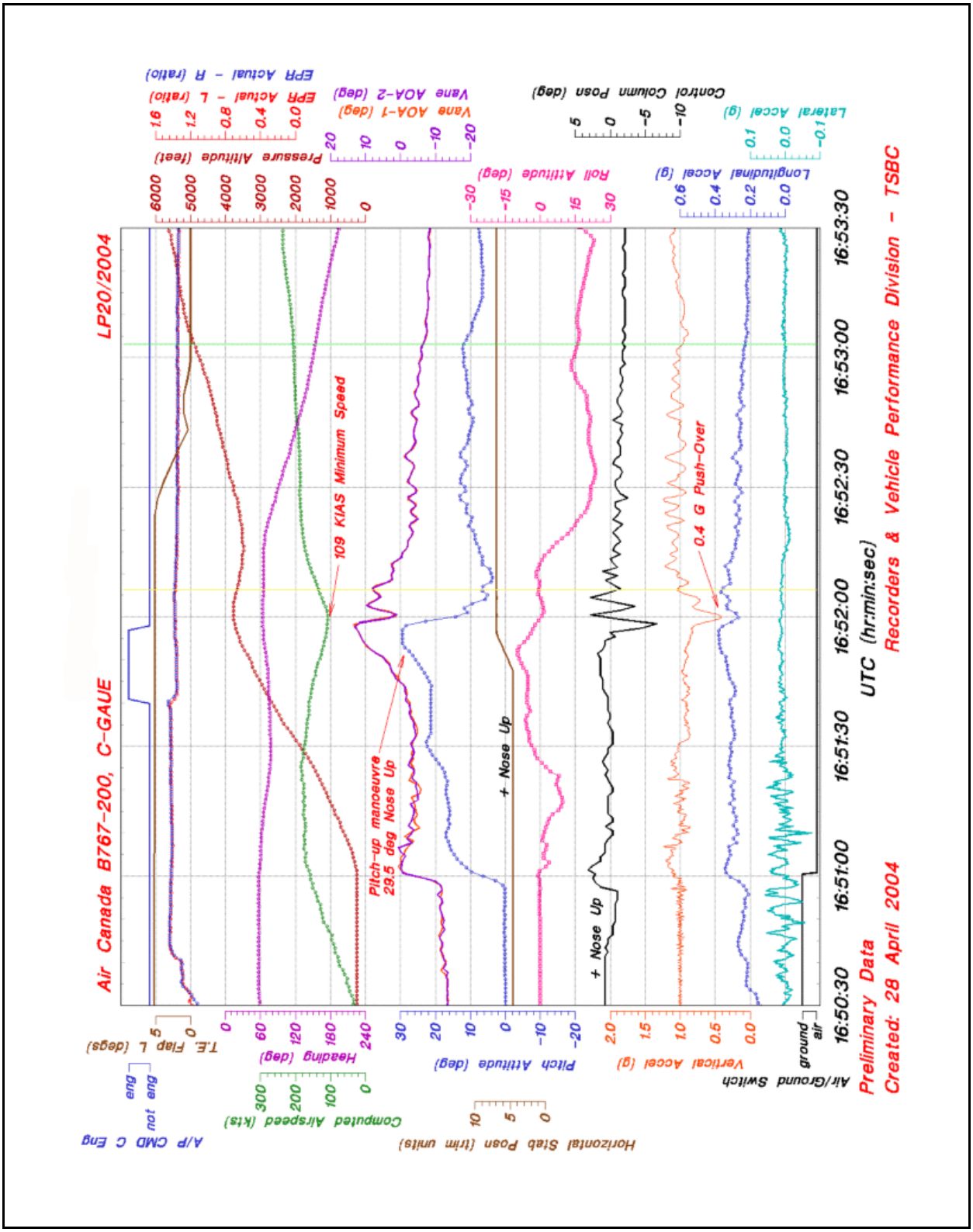
An Aircraft Technical Bulletin has been created to make crews aware of speed protection annunciation and autopilot flight director system failures. This Bulletin will remain active until all of the relevant information is made available in the *Aircraft Operating Manual*.

Boeing B767 Standard Operating Procedures, Initial Climb, have been amended to include an Autoflight Speed Protection warning: "WARNING - The autoflight system design lacks airspeed protection in ALT CAP mode. Excessive rate of climb when transitioning to ALT CAP mode can create an insufficient energy condition resulting in rapid airspeed decay."

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 18 May 2005.

*Visit the Transportation Safety Board's Web site (**www.tsb.gc.ca**) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.*

Appendix A – Flight Data Recorder Plot



Appendix B – Glossary

agl	above ground level
ALT CAP	altitude capture
C	Celsius
EEC	electronic engine control
EPR	engine pressure ratio
FD	flight director
FDR	flight data recorder
FLCH	flight level change
fpm	feet per minute
g	acceleration due to gravity
KIAS	knots indicated airspeed
PF	pilot flying
PNF	pilot not flying
TSB	Transportation Safety Board of Canada