National Transportation Safety Board
Washington, D.C. 20594

Aircraft Accident Brief

Accident Number: CHI01MA006
Aircraft and Registration: Bombardier CL-600-2B16 (CL-604), C-FTBZ
Location: Mid-Continent Airport, Wichita, Kansas
Date: October 10, 2000
Adopted On: April 14, 2004

HISTORY OF FLIGHT

On October 10, 2000, at 1452 central daylight time,[1] a Canadair Challenger CL-600-2B16 (CL-604) (Canadian registration C-FTBZ and operated by Bombardier Incorporated) was destroyed on impact with terrain and postimpact fire during initial climb from runway 19R at Wichita Mid-Continent Airport (ICT), Wichita, Kansas. The flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91 as an experimental test flight.[2] The pilot and flight test engineer were killed. The copilot was seriously injured and died 36 days later.[3]

A review of air traffic control (ATC) and cockpit voice recorder (CVR) transcripts from the accident flight indicated that the pilot in the left seat was performing the pilot-in-command (PIC) and pilot-flying (PF) duties and that the copilot was performing the radio communications and other related pilot-not-flying (PNF) duties.[4] The flight test engineer was to perform test flight configuration and monitoring duties at his workstation in the cabin. The flight crew was to initiate a standard takeoff and climb and conduct flight testing of modified pitch feel simulator

---

[1] Unless otherwise indicated, all times are central daylight time based on a 24-hour clock. The actual time of accident is approximate, based on flight data recorder (FDR) and air traffic control (ATC) information.

[2] Experimental and engineering test flights are flown to determine whether newly designed and experimental aircraft operate according to design standards. Based on these flights, test pilots make suggestions for improvements. Production test pilots test new airplanes for airworthiness after the airplanes come off the assembly line and before they are delivered to customers.

[3] According to 49 CFR Section 830.2, for classification purposes, a fatal injury is one in which death results within 30 days of the accident.

[4] The accident flight was also a training and orientation flight for the copilot.

(PFS) units[5] above 8,000 feet above ground level (agl).[6] The test required that the airplane be configured with an aft center of gravity (c.g.).[7]

The accident flight was the second flight to collect data to obtain certification by the United Kingdom's Civil Aviation Authority (CAA) for two customer airplanes in the United Kingdom. Following the first flight in 1999, the CAA provided a list of unacceptable items that Bombardier needed to correct before the Challenger 604 could obtain CAA certification, including modification of the PFS units.[8]

On September 29, 2000, about 1806, the airplane returned to Wichita from other flight test operations in Fairbanks, Alaska, and was not flown for about 1 week in preparation for the flight testing of the modified PFS units. On October 6, 2000, the production PFS units were removed and the modified PFS units were installed. The airplane was loaded with 1,100 pounds of water ballast and 734 pounds of tail ballast for an aft c.g. test configuration.

A ground test with the modified PFS units was performed to determine the control column travel needed for full elevator travel in both directions. The test also repeated the baseline tests that were previously conducted with the production PFS units. The ground tests were designed to measure and record force at the control column in pitch at different column positions and at different stabilizer positions. Two systems engineers from company headquarters in Montreal (who also attended the preflight briefing for the accident flight) were present during the static ground tests. Documentation indicated that no anomalies were noted with the PFS installations.

About 1330 on October 10, 2000, a preflight briefing was held at the Bombardier Flight Test Center (BFTC) for the first flight with a modified PFS aboard the airplane. The preflight briefing was attended by the three flight crewmembers, a BFTC aircraft controller, a systems engineer, an avionics engineer, the project engineer, and the two systems engineers from

[5] PFS units replicate aspects of the aerodynamic loads (absent in hydraulically driven control systems) through artificial feel and centering units, allowing the pilots to feel control input resistance. The units increase control column, control wheel, and rudder pedal resistance as the flight control surfaces are moved from their neutral positions.

[6] The maneuver to be flown for the flight test is known as a wind-up turn. During this maneuver, the airplane is put into a bank and the control column is continually pulled back to maintain the indicated airspeed. Control column forces are evaluated throughout the maneuver. A Federal Aviation Administration (FAA) test pilot described the wind-up turn as "one of the hardest maneuvers to do in flight test."

[7] The airplane was equipped with a combination of fixed weights and interconnected forward and aft ballast tanks. A water/glycol mixture could be moved forward or aft between the tanks, to change the c.g. for flight test purposes. The movement of the water/glycol mixture is controlled by an electric pump operated by the flight test engineer, or through gravity transfer (at an appropriate flight attitude). In addition, a lead ballast was located in the rear of the airplane.

[8] To comply with the PFS unit control force item listed by the CAA, Bombardier had the vendor (Lucas Aerospace Division of TRW Aeronautical Systems) modify the elevator control system's PFS units to increase the second break out force. The first breakout force is the force necessary to move the control column, rudder, or other flight controls from the neutral position. The production PFS units provided initial movement of the control column from zero after the first breakout force was exceeded. The column force then increases linearly with column position until a second breakout force is reached, after which the column force continues to increase with column position at a reduced rate (to prevent excessive column movement). The modification on the accident airplane added shims at the end of an internal spring to increase preload for the second breakout. The change increased the second breakout point from the original 40 pounds to 50 pounds of force. According to Bombardier, the test flight was intended to demonstrate that the modified PFS units were sufficient to meet the CAA requirements in the heavy weight/aft c.g. configuration.

Montreal. The BFTC aircraft controller stated that the briefing had been postponed several times because the airplane was not ready. However, he added that there was no rush to fly that day and that the airplane had no outstanding maintenance items when it was released about 1330.

Statements from briefing participants indicated that several minutes before the briefing, the accident pilot asked the accident flight test engineer to obtain a risk analysis from BFTC's manager of flight test operations and safety. The manager of flight test operations and safety stated that he first learned about the test flight at this time. He stated that he assessed the flight's risk level as low because the airplane was operating within its c.g. range and because "the modification was stabilizing."

The briefing began with a description of the airplane's configuration and the presentation of load sheet information. The accident copilot reportedly asked, "why are we so far aft?". The flight test engineer responded that this configuration (with the production PFS units) was previously flown on airplane number 5991 (the accident airplane) with the CAA test pilot during the 1999 flight test. The flight crew reportedly responded, "okay." The briefing continued with a presentation comparing the characteristics of the production PFS and modified PFS units. The pilot reportedly stated that the airplane was going to "handle like a pig." According to briefing participants, flight test maneuvers and procedures to address potential anomalies in the modified units were not discussed. The briefing concluded about 1400 and flight crewmembers boarded the airplane about 1415.

At 1420:33, the CVR recorded a sound similar to several warning systems being checked, followed by the "before engine start" checklist items and conversations about the airplane's systems. The right engine was started at 1432:07. The PIC performed two flight control sweeps at 1434:24. The first sweep included the aileron, rudder, and elevators. The second sweep was a slow control sweep of the elevators.[9]

At 1448:45, the tower issued a takeoff clearance and instructed the flight crew to fly a heading of 230°.[10] At 1449:21, the pilot stated, "okay, here we go," and a sound similar to an increase in engine RPM was recorded 2 seconds later. At 1449:29, the pilot stated, "set thrust," and the copilot responded, "thrust set" 6 seconds later. At 1449:37, the copilot called out "airspeed's alive eighty knots." At 1449:48 the copilot called out "V one" (takeoff decision speed) and "rotate". The pilot responded, "okay, we're flying," followed by the copilot calling out "V two" (takeoff safety speed).

At 1449:51, the CVR recorded a sound similar to stick shaker[11] for 2.2 seconds, during which time the pilot stated "whew," and the flight test engineer stated "what are you doing?". The CVR then recorded the mechanical voice warning "bank angle"[12] and a sound similar to stall aural warning for 1.1 seconds at 1449:53.. "Bank angle" was recorded at 1449:54 and again at

[9] The flight control sweeps were flight test checklist items to collect data.

[10] The pilot and copilot display control panels retained a selected heading of 230º in nonvolatile memory.

[11] The stick shaker, or control column shaker, is designed to warn pilots of an impending aerodynamic stall, and is accompanied by audible alerts and lights. For more information about the airplane's stall warning system, see section 1.8.

[12] The CL-604 is equipped with an aural bank angle warning system. For more information about the airplanes aural warning systems, see section 1.8.

1449:55. A sound similar to stick shaker was recorded for 0.15 seconds beginning at 1449:57, followed by "bank angle" again at 1449:57.36.

At 1449:58, and for the next 2 seconds, a sound similar to stick shaker was recorded for 0.22 second, and the pilot stated, "hang on." A sound similar to stick shaker" was recorded again for 0.3 seconds, the flight test engineer repeated "what are you doing?," followed by a sound similar to stall aural warning for 0.82 seconds, and "bank angle" again. At 1449:59.59, the pilot stated, "hang on." The recording ended at 1450:00.

Witnesses reported seeing the airplane bank to the right after takeoff. They stated that the airplane's right wing rolled and impacted the ground first and that the airplane exploded on impact. The airplane crashed through an airport perimeter fence and came to rest adjacent to a two-lane, north-south road.

PILOT INFORMATION

The pilots were certificated under Federal Aviation Administration (FAA) certification requirements and held Transport Canada exemptions from holding Canadian pilot certificates.

The Pilot Flying

The PF, age 33, was hired by Bombardier Aviation Services in Tucson, Arizona, in July 24, 1995, as a flight test pilot, where he performed airplane modification and supplemental type certificate (STC)[13] test flights on Learjet 31A, Learjet 60, and Challenger 604 aircraft. He also performed aerodynamic stall testing and system evaluation flights on Learjet customer service aircraft. He was hired at BFTC as an experimental test pilot on May 5, 1999.

From August 1989 to October 1990, he performed avionics certification testing as a flight test engineer for an avionics manufacturer. He was employed as a captain on an Aero Commander 500 for 14 CFR Part 135 cargo operations from October 1990 to September 1993. From October 1993 to September 1995, he was employed as a captain on a Beechcraft Baron and Piper Chieftain and as a first officer on a North American Saberliner for an unscheduled Part 135 cargo and passenger operator.

He held an airline transport pilot (ATP) certificate issued on August 25, 1991, with type ratings in the CL-65 (Canadair Regional Jet), CL-604, Learjet-60, and Bombardier BD-700 (Global Express). In addition, he was a certified flight and ground instructor. His first-class medical certificate was issued on May 16, 2000, with the limitation "holder shall wear corrective lenses."

According to FAA documents, the pilot received an order of suspension of his ATP certificate on July 19, 1996, for failure, as PIC, to ensure that cargo aboard a Part 135 cargo flight was secured to prevent shifting under anticipated flight and ground conditions. The suspension was later withdrawn and replaced with an order of assessment on September 27, 1996, fining the pilot $750.

[13] An STC authorizes alteration of an aircraft engine or other component that is operated under an approved type certificate.

According to company records, he had logged 6,159.3 hours flying time, including 1,187 hours at Tucson Production Flight Test; 359.3 hours engineering flight test flying time at BFTC; 557.2 hours of production flight test PIC time at Tucson; and 126.4 hours of engineering flight test as PIC at BFTC. He had logged 189 flying hours in the Challenger 604, of which 94.6 hours were as PIC. He received his initial type rating in the Challenger 604 on October 15, 1998. His last proficiency check was accomplished on March 24, 2000.[14] According to BFTC's manager of flight test operations and safety, there was no record that the pilot flying had received formal test pilot training. Bombardier's vice president of flight tests stated that the PF was assigned to entry-level flying assignments as an experimental test pilot and flights typical of normal flight operations. The PF had a bachelor of science degree in aviation technology.

The PF had flown a total of 95.7 hours, 55.2 hours, 4.6 hours and 1.9 hours in the last 90 days, 30 days, 7 days and 24 hours, respectively. The pilot was off duty on October 8, 2000. He worked from 0800 to 1800 on October 9 and returned to work on the day of the accident at 0800.

The Copilot

The copilot, age 43, was hired by Bombardier on February 1, 1999. He was a former U.S. Air Force F-15 fighter pilot and instructor pilot. He was employed as a test pilot by Swearingen Aircraft Company, where he performed development and certification test flights on Metroliner airplane systems from August 1991 to January 1994. In addition, he was employed as an engineering test pilot on high-performance jet prototypes at Cessna Aircraft Company. He performed developmental and certification test flights involving performance and handling qualities, stalls, and envelope expansion on Cessna Citation and Excel airplanes in Wichita from January 12, 1994, to January 29, 1999. He was also an FAA-designated engineering representative.

He held an ATP certificate issued on June 10, 1990, with type ratings in the Cessna CE-500, CE-525S, CE-560XL, CE-650, CE-750, Bombardier CL-65 (Regional Jet), CL-604, and SA-227 Metro III. He was a certified flight instructor and held an airframe and powerplant certificate issued on January 4, 1979. His first class medical certificate was issued on September 27, 2000, with no limitations.

According to company records, he had logged 6,540.7 hours of flying time,[15] including 463.7 hours at BFTC; of which 254.4 hours were as PIC at BFTC. He had logged 6,076 flying hours when he was hired by Bombardier, of which 2,123 hours were flight test. He had attended a 2-week test pilot short course, according to company records. He had 1.2 hours flying time in the Challenger 604, of which 0.4 hours were as second in command. He received his type rating in the CL-604 on June 23, 2000. This was also his last proficiency check. He had flown a total of 88.1 hours and 17.1 hours in the last 90 and 30 days, respectively. He had logged no flying hours in the last 7 days or 24 hours.

---

[14] Recurrent simulator training was the only formal proficiency check performed by Bombardier at the company's commercial training facility in Montreal.

[15] Pilot logbook information indicates a total time of 6,585.5 hours.

The copilot had returned from Amsterdam, Holland, on October 8, 2000, about 2230. On October 9, 2000, he worked from 0715 to 1630 and returned to work on the day of the accident at 0730.

AIRPLANE INFORMATION

The accident airplane, serial number 5991, was registered and owned by Bombardier Inc., Canadair, and was equipped with two General Electric CF34 turbofan engines. Manufactured in 1994, the airplane was used exclusively as an engineering development and sustaining program test airplane. The airplane was operated on a Canadian flight permit (experimental type certificate) and was not issued an airworthiness certificate. A special flight authorization (SFA)[16] was issued by the FAA's Wichita Manufacturing Inspection District Office (MIDO) on September 5, 2000. The SFA was issued to conduct flight test(s) required to obtain a U.S. type certificate. The SFA stipulated the operational conduct and limitations for the flight crew and airplane.

The airplane fuel tank system comprised a left wing tank, right wing tank, auxiliary fuel tank and tail fuel tank (see figure 1). The auxiliary fuel tank system beneath the center cabin had a forward, center, and aft tank that were interconnected by pipes and that were not isolated from each other by shutoff valves or check valves. The tail fuel tank system had two saddle tanks and a third tank at the rear of the tail cone. (see figure 1).

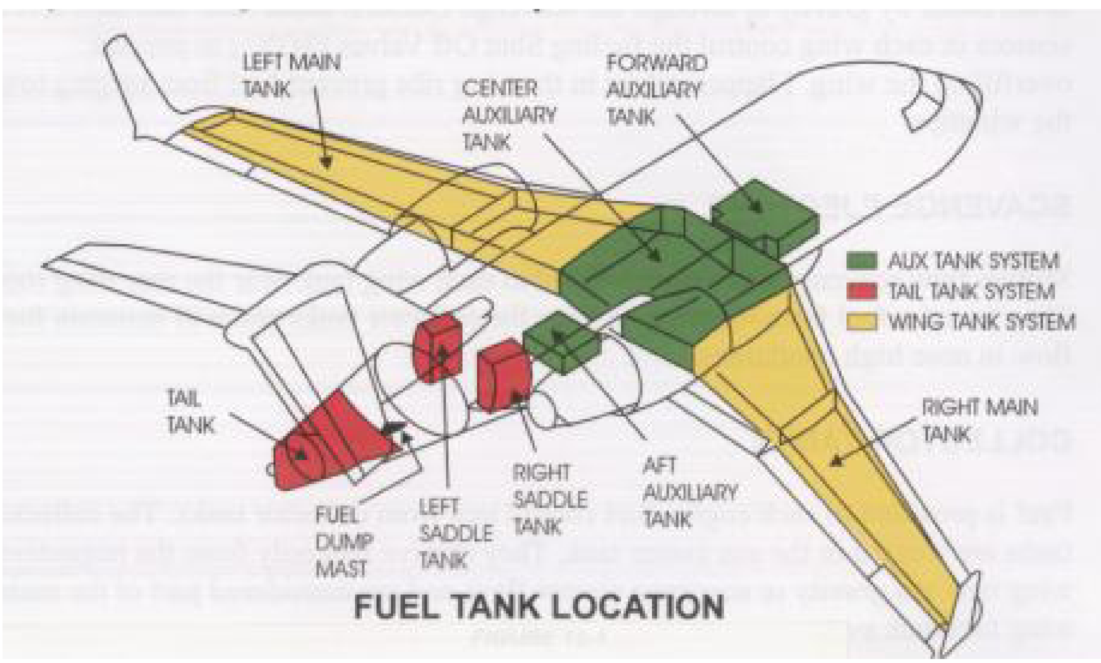

Figure 1. Airplane Fuel System Diagram

The airplane was equipped with a ground proximity warning system, which provided voice message alerts. The "bank angle" voice message is based on the airplane's roll attitude and radio

[16] A special flight authorization permits a foreign-registered civil aircraft that does not have the equivalent of a U.S. standard airworthiness certificate to be operated within the United States.

altitude. The roll angle limit ranges linearly from 10° at 30 feet agl to 40° at 150 feet agl. It ranges from 40° at 150 feet agl to 55º at 2,450 feet agl. When the airplane's roll angle exceeds the alert threshold, the "bank angle, bank angle" aural alert activates. An additional "bank angle" alert is generated if the roll angle increases by another 20 percent of the threshold. If the roll angle exceeds 140 percent of the threshold, an aural alert is issued every 3 seconds.

The airplane's stall warning system provided aural, visual, and tactile warning of an approaching stall. As the airplane's vane angle of attack (AOA)[17] increases, tactile warning is provided by a stick shaker. A further increase in vane AOA activates a stick pusher. Visual stall warnings are provided by flashing red "STALL" annunciators on the left and right glareshield and by a low-speed indicator on each of the primary flight displays. An aural warbler warning begins when either stall channel signals the pusher to fire. Both channels are required to activate the pusher. In addition to the warnings, the autopilot disconnects and continuous ignition is activated.

The stick pusher forces the control columns forward to lower the nose (AOA) and are designed to prevent an aerodynamic stall. The system's dual (left and right) channel stall protection computer (SPC) monitors the following inputs to calculate the AOA trip points:

- AOA
- Lateral acceleration
- Flap position
- Weight on wheels
- Altitude
- Weight on wheels fail

In the event of an AOA rate increase greater than 1° per second, the SPC lowers the AOA trip points (phase advance) to prevent the airplane's pitching momentum from carrying it through the stall warning/stick pusher sequence into the stall. An acceleration switch disconnects the stick pusher mechanism if less than 0.5 G is reached during the stick pusher activation. The stick pusher can also be de-activated by pressing and holding the autopilot/stick pusher disconnect switch located on the pilot's and copilot's control wheel. The stick pusher is capable of operating immediately once the autopilot/stick pusher switch is released. In case of malfunction, the stick pusher can be disabled by selecting the "PUSHER" switch to "OFF" on the pilot's or copilot's stall protection panel. Both the pilot's and copilot's switches must be in the "ON" position for stick pusher activation.

The accident airplane's SPC actuation could be modified for flight test purposes. After takeoff, and the removal of weight from the landing gear, the nominal design provides for a 2-second interruption (time out) of the phase advance for shaker and pusher activation. During this time, the SPC activation angles for the shaker and pusher are not phase advanced, and will activate only if the AOA threshold is exceeded. The accident airplane's SPC could be adjusted to interrupt the phase advance to the AOA threshold. Examination of flight test data indicated that of the two SPC channels, the left timed out at 5.5 seconds on the airplane's three previous flights

[17] Stall protection vanes are located on the left and right side of the fuselage. They measure the local airflow on the forward fuselage. The stall vane measured angles are used to derive the airflow over the airplane's wings and provide stall warning and stall prevention. All AOA values in this report are vane AOA.

and the right channel timed out at 2.0 seconds, which is the production standard.[18] According to Bombardier documents included in a November 5, 2001, letter to the National Transportation Safety Board, there was insufficient data to determine the timeouts for the accident flight. The letter stated that although the left shaker activation may have been delayed, the increased timeout would not have affected stick pusher activation.

The following are normal production shaker and pusher activation vane angles:[19]

Shaker	19.2º with a tolerance of +/- 0.35º
Pusher	23.1º with a tolerance of +/- 0.35º

Recorded test flight data indicated that the activation vane angles for the accident airplane were set at the following values:

Shaker Left Channel	19.7º
Shaker Right Channel	19.3º
Pusher Left Channel	23.6º
Pusher Right Channel	23.2º[20]

No mechanical flight control system discrepancies were reported during the 30-day period before the accident.

Airplane Limitations

The *Challenger 604 Operating Manual* contains weight and balance information for a normal category, certificated CL-604. According to a restriction and/or special instruction, the accident airplane had an expanded weight and balance envelope for takeoff and landing. The c.g. range changes based on airplane configuration. According to the CL-604's type certificate data sheet (No. A21EA), the airplane's aft c.g. limit was 38 percent mean aerodynamic chord (MAC) between airplane weights of 43,000 and 47,700 pounds. The accident airplane's weight at takeoff was 44,849 pounds.

Weight and Balance and Performance Calculations

The preflight weight and balance data for the accident flight were as follows:

Zero Fuel Weight	29,254 lbs.
Left Wing Fuel	4,850 lbs.
Right Wing Fuel	4,850 lbs.
Center Fuel	3,800 lbs.
Aft Fuel	2,500 lbs.

[18] No SPC maintenance was recorded during the period that included the airplane's final five flights.

[19] The non-phase advanced shaker and pusher angles are based on a flap setting of 20º and a pressure altitude of less than 2,000 feet.

[20] The stick pusher activates when each vane angle (on the left side and right side of the airplane's nose) reaches the preset activation angle.

Ramp Weight	45,254 lbs.
c.g.	37.4 percent MAC

Flight test tolerances for the accident flight were as follows:

- Stick Shaker/pusher set to nominal
- Test weight tolerance: +5 percent to –1 percent
- c.g. position tolerance: 7 percent of total travel
- Airspeed tolerances are 3 knots
- Non-turbulent conditions

Postaccident Fuel Weight Calculations and Weight and Balance

The CL-604 fuel computer uses a fixed constant fuel weight (density)[21] of 6.75 pounds per U.S. gallon (variability of density due to nonstandard temperature was not considered in the equation).[22] After the accident, Bombardier recalculated the airplane's weight and balance based on a takeoff weight of 44,849 pounds and a fuel weight value of 6.75 pounds per gallon.[23] In a December 13, 2000, memorandum to the Safety Board, Bombardier's calculations indicated that the airplane's c.g. was 37.9 percent MAC at the start of the takeoff roll.

In addition, Bombardier recalculated the airplane's c.g. estimating both the shift within the tanks and the amount of fuel transfer between fuel tanks during the takeoff roll and initial rotation. The transfer rates calculated between fuel tanks were as follows:

Forward auxiliary tank to center auxiliary tank	0.735 gallons per second
Center auxiliary tank to aft auxiliary tank	0.875 gallons per second
Saddle tanks to tail cone tank	0.484 gallons per second

The following table compares fuel tank quantity and transfer changes between the start of the airplane's takeoff roll (zero pitch angle as the airplane accelerated down the runway before rotation) and 20 seconds later with an airplane pitch angle of 13.8°at rotation:[24]

Table 2. Comparison of Fuel Tank Quantity and Transfer Changes

Tank	Before Acceleration, at Zero Pitch Angle	13.8° Pitch Angle, at Rotation
Forward Auxiliary	41.5 gallons	26.8 gallons
Center	491 gallons	488.2 gallons
Aft Auxiliary	26 gallons	43.5 gallons
Saddle Tanks	212.5 gallons	202.8 gallons
Tail Cone	165 gallons	174.7 gallons

[21] FAA publication FAA-H-8083-1, *Aircraft Weight and Balance Handbook*, states that fuel weight is determined by its specific gravity and temperature.

[22] The standard day, sea level density for Jet A fuel is about 6.789 pounds per U.S. gallon.

[23] Fuel samples taken at the Bombardier facility on November 16, 2000, nearly matched the typical fuel density of 6.75 pounds per gallon.

[24] The 13.8° value was chosen as a minimum flow, or best-case scenario assuming fuel shifts near rotation.

In addition, Bombardier stated that fuel could also shift between rib bays in the airplane's wing fuel tanks. Based on Bombardier fuel shift calculations evaluated by the Safety Board staff, the airplane's c.g. increased to 40.5 percent MAC by the time it reached a 13.8° pitch angle 20 seconds later.[25]

Postaccident Center-of-Gravity Related Airworthiness Directives

The fuel shift/c.g. issue was addressed by Bombardier, Transport Canada and the FAA following the accident. On February 1, 2001, Bombardier issued a temporary revision to the Challenger flight manual changing the airplane's aft c.g. limit from 38 percent MAC to 34.5 or 35.0 percent, depending on airplane weight. The same day, Transport Canada issued Airworthiness Directive (AD) CF-2001-07 to make the revision permanent. The FAA issued emergency AD 2001-03-52 on February 2. The FAA's AD stated that the Challenger's "fuel tanks are not baffled, which allows fuel to migrate when the airplane pitches up." The AD added that "fuel migration under conditions of acceleration and/or climb, if not corrected, could result in the airplane exceeding the aft center of gravity limit, and consequent loss of control of the airplane." The AD stated that the revision was intended to "prevent fuel migration from resulting in a rearward shift of the c.g. to the degree that will result in controllability problems."

METEOROLOGICAL INFORMATION

The ICT automated surface observing system (located 4,500 feet from the approach end of runway 19R) recorded the following information at 1450:

> Wind 190° at 20 knots gusting to 26 knots; 10 statute mile visibility; few clouds at 12,000 feet agl; scattered clouds at 20,000 feet agl; temperature 17° Celsius (C); dew point of –11° C; altimeter 30.21 inches of mercury. Peak wind of 29 knots from 170°occurred at 1400.

No microburst or gust front activity was recorded between 1250 and 1450. According to the low-level wind shear alert system, centerfield winds were generally from the south/southwest with speeds from 15 to 22 knots.

AIRPORT INFORMATION

ICT is located about 5 miles southwest of Wichita. The airport has three concrete runways: 01L/19R (10,300 feet by 150 feet, grooved concrete), runway 01R/19L (7,302 feet by 150 feet) and runway 14/32 (6,301 feet by 150 feet). The airport is equipped with aircraft rescue and firefighting (ARFF) units under provisions of 14 CFR Section 139.317 Index C.[26]

---

[25] The value of 40.5 percent MAC does not include tolerances for c.g. position or for changes in fuel density that could change this MAC value by more than 1 percent in either direction.

[26] Index C includes air carrier aircraft of at least 126 feet in length but less than 159 feet in length. According to 14 CFR 139, a minimum of two or three ARFF vehicles must carry a total quantity of 3,000 gallons of water for foam production.

Twelve air carriers and three fixed base operators serve the airport. In addition to Bombardier, two other airplane manufacturers use the airport for flight test operations. The air traffic count from September 1999 to September 2000 was 180,878 flights.

FLIGHT RECORDERS

The airplane was equipped with an airborne data acquisition system (ADAS) capable of recording 1,780 flight test data parameters. The magnetic flight test data tape and the digital flight data recorder (FDR) tape, which recorded additional parameters, were recovered from the wreckage. Thermal damage destroyed ADAS flight test data recorded after takeoff rotation. Safety Board staff synchronized the instrumented data with the recovered FDR data.[27]

The airplane was equipped with a Fairchild model A-100A CVR. The CVR exterior received some structural and fire damage. The interior and the tape were not damaged. The recording comprised four channels of good quality audio information.[28] A transcript was prepared from the entire 31-minute recording.

WRECKAGE AND IMPACT INFORMATION

The airplane first impacted the ground 437 feet from the intersection of runway 19R's centerline and the extended centerline of taxiway B. The airplane came to rest upright about 1,174 feet from the initial ground impact scars and 850 feet to the right of the runway centerline. Wreckage was found along the entire path. Parts of the right wing, radome, and nose structure were found within the first 300 feet of the wreckage path. A large concentration of right engine structure was found just past the wreckage path's midway point. The left wing was found largely intact and attached to the fuselage. The right wing was consumed by fire. The empennage separated from the fuselage and was heavily damaged by fire. It came to rest in a drainage ditch near the fuselage. Flight control cables were found in their approximate correct locations throughout the wreckage, but complete cable continuity could not be determined because of extensive right wing and empennage damage. Fuel system components in the fuselage and right wing were consumed by fire.

Wreckage of both engines was recovered in the debris field. The left engine was found attached to the fuselage. The right engine was located on the road, about 30 feet behind the fuselage. An external examination did not reveal evidence of pre-impact anomalies.

---

[27] For more information on the synchronization of flight test and FDR data, see the Flight Data Correlation Study in the Safety Board's docket for this accident.

[28] The Safety Board uses the following categories to classify the levels of CVR recording quality: excellent, good, fair, poor, and unusable. An excellent recording is one that is very clear and easily transcribed. A good recording is one in which most of the crew conversations can be accurately and easily understood. The transcript that is developed may indicate unintelligible words or phrases. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other. A poor recording is one in which a transcription is nearly impossible because a large portion of the recording is unintelligible.

The flight spoiler power control units were found in the stowed position. The extensions of the flap actuator jackscrews were replicated on a similar airplane in the Challenger Service Center, and the flap setting was calculated to be about 20º.

The cockpit's left side was heavily sooted close to the floor and the multifunction displays (MFD) in the instrument panel were damaged by heat. The instrument panel was displaced aft and downward. The outboard edge of the instrument panel was separated from its structure and displaced aft, inboard, and downward. The control yoke was turned to the right. Both rudder pedals were jammed against the forward bulkhead. The windshield was crazed and sooted.

The cockpit's right side was crushed into the copilot's seat. The outboard corner of the instrument panel was separated from the structure and displaced inboard about 3 inches. The floor beneath the copilot's station was displaced upward about 6 inches and rearward about 14 inches. The copilot's MFDs were heat damaged. The floor forward of the seat was destroyed and displaced rearward with the rudder pedals visible from outside the airplane. The outboard lower side panel was displaced inboard and separated from the structure. The upper panel was displaced rearward. The circuit breaker panel bulkhead was displaced downward about 9 inches at its forward side and was free of its upper attachments.

The right side wall and outer cabin floor structure in the forward-to-mid cabin, forward of the flight test engineer's station, were destroyed by fire.[29]

MEDICAL AND PATHOLOGICAL INFORMATION

Autopsies of the PF and flight test engineer were conducted by the Sedgwick County Regional Forensic Science Center in Wichita, Kansas. According to the autopsy report, the pilot died at the scene of the accident after suffering blunt force trauma, smoke inhalation and burns. The cause of death was listed as "carbon monoxide toxicity and smoke inhalation." The flight test engineer died at the scene of "blunt force trauma of head and neck." The report added that he also suffered "postmortem thermal burns," fractured vertebrae and cervical spinal cord lacerations. There was no evidence of carbon monoxide or soot in his airways or lungs, according to the autopsy report. The copilot, who sustained blunt force trauma and burns, was removed from the cockpit by rescuers and transported by ambulance to a local hospital, where he arrived about 1548 hours. He died on November 15, 2000, of "complications from thermal burns."

The Regional Forensic Science Center and the FAA's Civil Aerospace Medical Institute performed toxicological testing of the pilot and flight test engineer. The tissue and blood specimens tested negative for a wide range of drugs, including major drugs of abuse.[30]

[29] For information about the cabin passenger door, emergency exit and the flight test engineer's seat see the section titled, "Survival Aspects."

[30] The five drugs of abuse tested in the postaccident analysis are marijuana, cocaine, opiates, phencyclidine, and amphetamines.

EMERGENCY RESPONSE

Two ARFF vehicles arrived at the accident site within 90 seconds, according to ARFF dispatch logs and personnel statements.[31] Wichita Fire Department (WFD) was notified about 1452 and the first unit arrived about 1458, according to WFD dispatch logs. WFD responded with 48 personnel and 23 vehicles. Both pilots were reported to be conscious when the initial ARFF units arrived at the accident site.

Access to the crash site from the airport was hampered by the damaged fence and by a ditch along the road. ARFF vehicles Safety 1 (S-1) and Safety 3 (S-3)[32] responded first with three firefighters, all of who were wearing protective gear. S-3, manned by one driver, was first to arrive. ARFF vehicle S-1 arrived with a driver and the airport police captain. The ARFF training captain and the ARFF deputy chief followed in an airport pickup truck, along with ARFF vehicle S-2, which was manned by one driver. The ARFF chief arrived in his car.

The drivers of vehicles S-1 and S-3 initially remained in their trucks and used foam to extinguish the fuselage fire and burning fuel under the airplane. The S-3 driver stated that, when he arrived, the fuselage was “engulfed in flames, even the roof.” He stated that he first used his roof turret to extinguish fires on the left wing and the airplane’s left side and top before moving into position to put out fires on the right wing and fuselage.

After the S-2 vehicle arrived, the driver of S-3 exited his vehicle and assisted the training captain, who was attempting to break holes in the cockpit side windows to direct water from hand-held hoses into the cockpit and onto the pilots.[33] ARFF personnel used fire axes, sledgehammers, and crowbars to break holes in the left and right side cockpit windows. A hole was first made in the cockpit’s left side window, and water was directed into the cockpit to suppress the fires and protect the flight crew. A second hole was also punched through the copilot’s window.[34]

Upon their arrival, firefighters observed an impact-related hole on the top of the fuselage’s left side (located aft of the main passenger door and forward of the left wing) and directed fire extinguishing agent through the hole. After WFD personnel arrived, forced entry tools (hydraulic cutters and spreaders) were used in an unsuccessful attempt to force the

[31] ARFF officers and firefighters reported that they first heard a loud noise and saw black smoke at the west side of the airport. The crash alarm activated as personnel were running to their vehicles. The ARFF chief stated that, before he responded to the scene, he confirmed that the ARFF dispatcher had contacted 911 and had requested mutual assistance from Sedgwick County and the Wichita Fire Department (WFD).

[32] In addition to two police cars, the airport had four ARFF vehicles: S-1 was a 1997 quick response vehicle equipped with 300 gallons of water, 40 gallons of 3 percent aqueous film forming foam (AFFF) and 450 pounds of dry chemical agent. Safety 2 and 3 were Oshkosh T-1500 vehicles equipped with 1,585 gallons of water, 205 gallons of 3 percent AFFF and 700 pounds of dry chemical agent. S-4 was an Oshkosh M-1500 equipped with 1,500 gallons of water and 180 gallons of 3 percent AFFF; S-4 was undergoing maintenance and did not respond to the accident.

[33] According to the Federal Aviation Regulations (FAR), cockpit front and side windshield panes and the supporting structure for these panes must withstand, without penetration, the impact of a 4-pound bird when the velocity of the airplane (relative to the bird along the airplane’s flightpath) is equal to the value of V_c (design cruise speed) at sea level, described in 14 CFR 25.335(a). V_c for the accident airplane is 300 knots indicated airspeed below 8,000 feet.

[34] Several smaller holes were punched through the left and right front windows.

passenger door open. According to ARFF personnel statements, no attempts were made to open the emergency hatch over the right wing. ARFF personnel stated that they were aware of the hatch's location and operation. ARFF personnel reported that the hole on the left side of the airplane provided sufficient access to the cabin and that entry through the hatch was not necessary.

WFD assisted with additional forced entry tools to enlarge the holes in the side cockpit windows, and to enlarge another hole located on the left side of the fuselage and forward of the wing. Additional water spray was used to protect the WFD firefighters who entered this hole to rescue the flight crew. The copilot was extricated from the cockpit about 20 minutes after ARFF units arrived and was transported to a hospital about 1541. The PF died before he could be extricated. The flight test engineer was found dead in the cabin near the cockpit bulkhead.

The ARFF S-2 truck was equipped with a penetrator nozzle, which can be used to pierce an airplane's fuselage to deliver water or foam inside the airplane. ARFF personnel stated that two firefighters were needed to prepare and operate the nozzle and hose. The ARFF chief stated that "only three ARFF personnel [were] on scene in first arrivals and they concentrated on knocking down the fire that was on both sides of the airplane." The chief stated that additional firefighters would have aided rescue efforts.

An ARFF captain/supervisor stated that the "tower provided us with no information…in the first three, four, five minutes at the scene. We knew nothing that was on there. We didn't even know if this was a commercial airplane, test airplane or whatever."

A fuel-fed vegetation fire was also extinguished. One ARFF officer was treated for smoke inhalation.

Emergency Response Training

At the time of the accident, multiagency drills at ICT were held quarterly and involved ARFF and law enforcement personnel, the Sedgwick County Fire and Sheriff's departments, and the Wichita fire and police departments.

ARFF personnel had received familiarization training on air carrier and military airplanes that use the airport. No similar training was provided for flight test airplanes based at the airport, which are frequently equipped with special features including ballistic-initiated spin recovery parachutes, forced entry locations, and pyrotechnic-operated emergency hatches.

At the time of the accident the Airport Authority's Airport Safety Division employed 24 people, who received law enforcement and ARFF initial and yearly recurrent training. Four people were assigned to ARFF duties and two were assigned to airport law enforcement duties for each 8-hour shift.

The Safety Board addressed ARFF staffing concerns when it issued Safety Recommendation A-01-65 to the FAA. Safety Recommendation A-01-65, issued on October 23, 2001, asked the FAA to "amend 14 *Code of Federal Regulations* 139.319 (j) to require a minimum Aircraft Rescue and Fire Fighting staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers." In a February 19, 2002, letter to the Safety Board, the FAA stated that it had asked the Aviation Rulemaking Advisory Committee (ARAC) Airports Issue Group to create an ARFF Requirements Working Group to examine ARFF staffing levels as part of an overall ARAC review of 14 CFR Part 139. On October 17, 2002, Safety Recommendation A-01-65 was classified "Open—Acceptable Response," pending results of the ARAC working group and implementation of the recommendation.

SURVIVAL ASPECTS

The airplane's configuration comprised pilot and copilot seats, a cockpit jump seat, and a flight test engineer station in the airplane cabin. The flight test engineer's station was located on the right side of the cabin. The seat was located adjacent to the emergency exit over the right wing. All crew seats were equipped with 5-point adjustable restraints. The pilots survived the impact sequence, but injuries and damage to the forward fuselage and cockpit prevented them from escaping unaided.

A manually operated, downward-opening main passenger door (with integral stairs) was located on the left side of the fuselage, aft of the cockpit. The main passenger door was found fully closed and latched. Safety Board staff examination revealed that the fuselage had buckled into the door, with evidence of shear and/or compression overload (skin wrinkles) on the forward fuselage and cabin door. Attempts by Safety Board investigators to open the door manually (with the inside and outside releases) were unsuccessful. The exterior handle was found out of its stowed position in a horizontal position; the handle could be moved 1.5 inches counterclockwise from the horizontal. Further investigation revealed that the mechanical fasteners that attach the aft center latch cam to the torque tube were sheared. The door's interior and latching mechanism exhibited evidence of a compressive overload to the door's lower tension rod and buckling damage to the door intercostals. An internal inspection of the door structure revealed damage to the forward part of the door stairs.

The airplane was equipped with an inward-opening, plug-type emergency exit hatch over the right wing. The exit can be opened from either inside or outside the airplane. The hatch was found in the closed and secured position. Postaccident examination determined that the exit was operational from the outside and inside.

The cockpit was not equipped with egress hatches. The airplane's windows were an integral part of the airframe structure and could not be opened. Pilot and passenger egress was through the forward passenger door or through the over wing hatch.

The flight engineer's station was located in the middle of the cabin near the right over-wing emergency hatch. Firefighters found the flight test engineer's seat in the forward cabin near the flight test engineer's body. The seat swivel adjustment was found locked in the forward facing position. The seat was separated by impact forces from its floor mounts and seatback vertical supports. The seat mounts were found attached to the floor seat track. No floor damage was found at the flight test engineer's station. There was no evidence of fire damage or sooting on the floor mounts. The restraint system was found attached to the seat by the tie down strap on the forward frame of the seat pan. The five point restraint system end fittings were found latched inside the release buckle. The left and right seat belts and shoulder harness straps were burned through. The seat was designed to withstand the following loads: 9 G forward, 4 G lateral, 4.65 G up and 8.1 G down.

TESTS AND OTHER RESEARCH

Airplane Performance

Safety Board staff conducted an airplane performance study as part of the accident investigation (see figure 2). According to FDR, CVR and flight test data, the nose gear strut was extended (before elevator input) as weight diminished on the nose gear about 0.5 second before rotation. Main gear liftoff occurred about 1449:50, as the airspeed reached 143 knots. FDR-derived data indicated that the PF used about 10° of nose-up elevator to initiate rotation, and main gear liftoff occurred about 1.2 seconds later, with a pitch angle of between 2.8° and 3.8°. The 10° nose-up elevator input was maintained for 0.8 second after liftoff until the pitch attitude reached 12°, according to FDR data. Pitch attitude continued to increase over the next 1.4 seconds, peaking at 20°, while nose-up elevator input decreased from 9° to 1° nose up. According to the FDR, the vane AOA reached 23°about 3.4 seconds after start of rotation. According to Bombardier, the airplane enters the stall warning region after reaching an AOA of 19°.

FDR data indicated that the airplane began an uncommanded right roll just before reaching peak pitch attitude. The CVR recorded the sound of the stick shaker at 1449:51, and the stick shaker sound continued for 2.2 seconds. During this time, a nose-down elevator input of about 14° was recorded, followed by a 5.5° nose-up elevator control input, consistent with pilot control inputs to correct the airplane's pitch and roll oscillations. The pitch attitude decreased to 4.3° nose up and the bank angle increased to about 80° right-wing down. During the next 3 seconds, the airplane rolled left to about wings level as the pitch attitude increased to 18° nose up. The vane AOA on the second pitch up was 26.4°. The second pitch up oscillation was followed by a second pitch down to -2°, and a right-wing down roll to 61°. This pitch down was followed immediately by a pitch up and roll back to wings level, reaching nearly level pitch attitude and 40° right-wing down at impact, according to FDR data. Peak nose-up elevator input at this time (1449:55) was about 16°.

The CVR recorded the intermittent activation of stick shaker, aural stall, and bank angle warnings beginning with the first pitch up to 20° until about 1 second before impact. After initial rotation, all elevator, rudder, and aileron inputs by the pilot were consistent with inputs to counter pitch and roll oscillations, according to FDR information. FDR data indicated a peak pitch rate of 8.4° per second. (The airplane's ADAS, which recorded test flight data at a higher sampling rate, indicated a pitch rate of 9.6° per second).

According to FDR data and information derived from the Safety Board staff's integration study of FDR data (flightpath integration), the airplane's peak airspeed was 170 knots. The flightpath integration indicated that the airplane's peak altitude was about 70 feet. FDR information indicated that the engines were operating at 90 percent fan speed until impact.

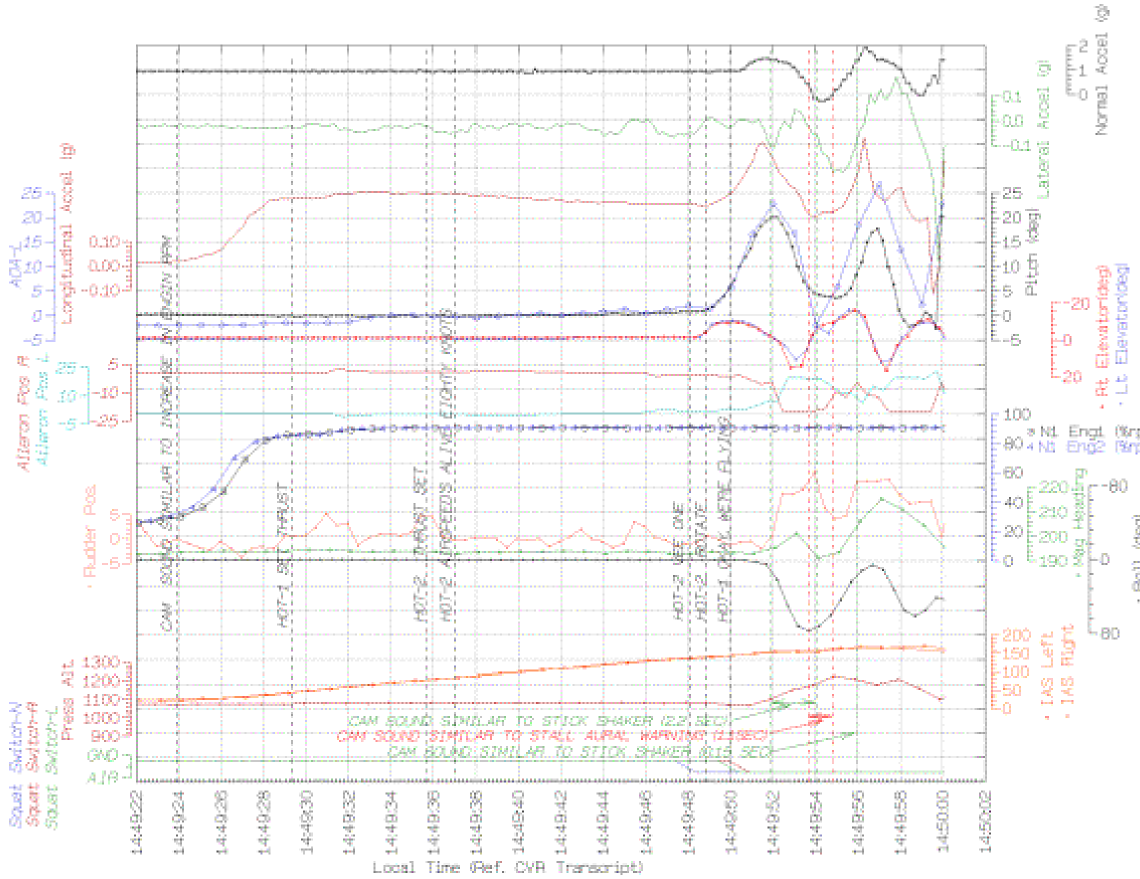

Figure 2.

Review of the Pilot Flying's Previous Takeoff Performance

Safety Board staff reviewed flight data to determine the peak pitch (rotation) rates per second during previous takeoffs performed by the PF.

Data showed a 7.2°-per-second rotation rate on a Challenger test flight on August 16, 2000. The airplane's ramp weight was 41,511 pounds and the c.g. was 31.0 percent MAC. Data also showed a 6.5°-per-second rotation rate on takeoff on a Challenger ferry flight from Barrow, Alaska, to Fairbanks, Alaska, on September 14, 2000, and a 6.0º-per-second rotation rate on takeoff from Fairbanks to Wichita on September 29, 2000, about 2 weeks before the accident. For the Fairbanks-to-Wichita flight, the airplane's ramp weight was 47,204 pounds and the c.g. was 35.5 percent MAC. The 35.5 percent MAC was the farthest aft c.g. that the PF had flown in the accident airplane, according to Bombardier flight test records. According to Bombardier flight test data, the stall protection system did not activate on these flights. The data indicated that the maximum pull control column force exerted by the PF during these operations was generally greater than 40 pounds. Bombardier stated that the stick force used by the accident pilot during the accident flight rotation "was near and within the upper limit of the normal range of stick forces, based on results from other pilots."

The accident pilot also flew the Global Express in the weeks before the accident. Flight 592, a Global Express BD-700-1A10 flight on September 22, 2000, showed a 8.3º-per-second pitch rate. A week earlier, on September 15, flight 589 showed a 6.8° rotation rate. A 5.8°-per-second pitch rate was recorded for flight 599, another Global Express, on October 4, 2000. The takeoff c.g. range for the Global Express was between 23 percent and 35 percent MAC.

Bombardier compiled additional takeoff data from 50 flights flown by other BFTC pilots, which included operational flights, certification test flights, and the accident flight (flight 535). According to Bombardier, the maximum pull control column force during normal operations was less than 40 pounds. The parameters examined were maximum pitch rate at rotation versus Mach number and c.g., and maximum control column forces at rotation versus c.g.

Bombardier computed maximum AOA (alpha) measured by the alpha stall vane during rotation as a function of Mach number. According to Bombardier, the maximum alpha stall vane angles recorded during operational takeoffs were about 14°. The maximum alpha stall vane angle values during abused certification takeoffs (that is, nonstandard takeoffs conducted for flight test purposes) were between 14°and 19°. The maximum alpha stall vane angle values for the accident pilot's operational takeoffs were between 15° and 17.5°. The maximum alpha stall vane angle for the accident flight was 23°. This angle was 4° above the normal setting for stick shaker activation, according to Bombardier.

In addition, Bombardier data indicated that the maximum pitch rates during operational takeoffs were 3.4º to 6.1º per second. Maximum pitch rates during abused (or nonstandard)[35] takeoffs during certification were between 3.5º and 7.0º per second. The maximum pitch rates for certification performance takeoffs were between 4.8º and 7.5º per second. The maximum pitch rates for operational takeoffs performed by the accident pilot were between 6.0º and 7.6º per second. As noted previously, the maximum pitch rate for the accident flight recorded by the onboard ADAS was 9.6º per second, according to recorded data.

Center of Gravity and Pitch Feel Sensitivity Studies

The Safety Board staff conducted c.g. and PFS sensitivity studies in an engineering flight simulator at Bombardier Aerospace facilities in Montreal as part of the accident investigation. The first c.g. study was conducted without pilots and used elevator values derived from the accident flight's FDR. The study indicated that with a c.g. of 37.9 percent MAC (the start of the takeoff roll), the alpha vane AOA did not reach the stick pusher value (for activation). At 40.5 percent MAC (the c.g. after rotation), the alpha vane AOA peaked about 5° beyond stick pusher value (see figure 3).[36]

[35] The takeoff demonstrations included early rotation (V_r minus 5 knots) with one engine inoperative; early rotation (V_r minus 10 knots, with a rapid rotation (or over rotation of 2º pitch) with all engines operating; and maximum pitch mistrim within the takeoff trim band with all engines operating.

[36] Simulator fidelity diminishes after entry into the stall.

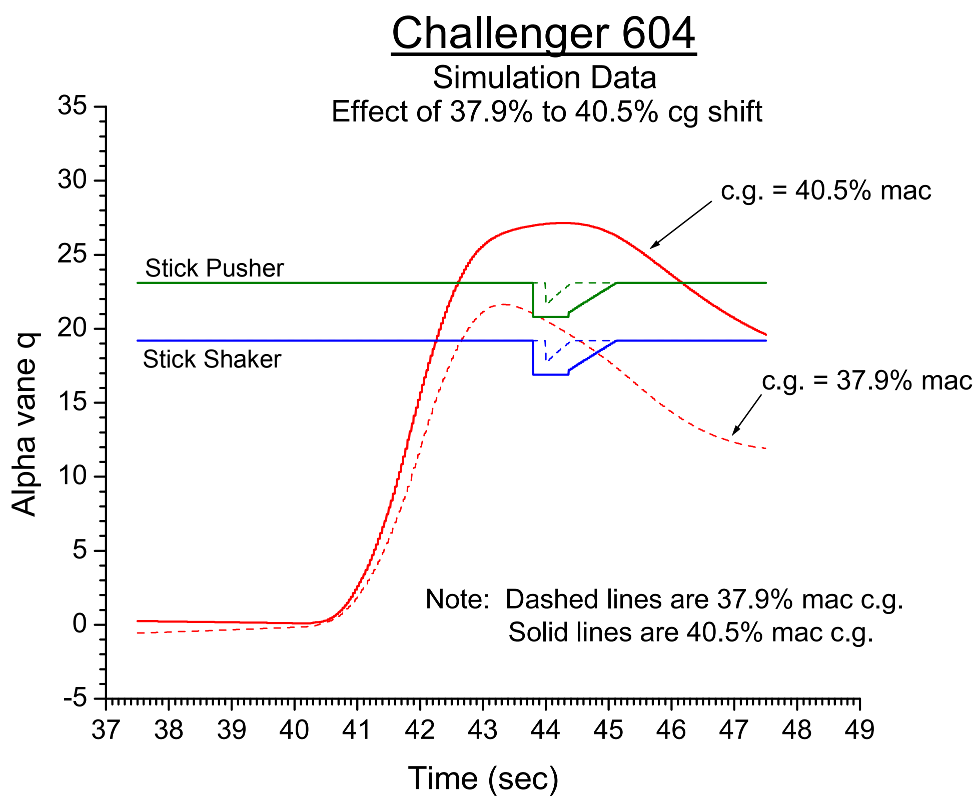

Figure 3. C.g. Sensitivity and Stick Shaker/Pusher Threshold Values

In a second c.g. study, an FAA test pilot and a Transport Canada test pilot, who were rated in the CL-604, performed takeoffs in the Bombardier engineering flight simulator to determine the effects of c.g. location on rotation rate (and the ability to capture the prescribed takeoff pitch attitude) and to examine whether there were perceptible differences between the handling characteristics of the modified PFS and the production PFS installed on in-service CL-604 airplanes. The pilots performed takeoffs with c.g. locations ranging from 35.0 percent MAC to 42.0 percent MAC. The pilots reported that aft c.g. positions caused them to rotate at a somewhat higher rate. The pilots noted that these effects were more noticeable when they used increased rotation rates (about 6° instead of the normal 3° rotation rate). When increased rotation rates were used, the pilots noted that the stick shaker frequently activated but only briefly. The pilots also indicated that the simulator was controllable at all c.g. locations using both normal and increased rotation rates.

In the PFS sensitivity study, each pilot performed takeoffs with either the modified or production PFS units. The c.g. was set at 40.5 percent MAC for each takeoff. The pilots reported no handling differences between the modified PFS and the production PFS units.

Safety Board staff and Bombardier also conducted simulation studies to determine how the pilot's elevator inputs during the accident would affect pitch rates at different c.g.

configurations. The simulations indicated that the pilot's elevator inputs produced a pitch rate of 5.5° per second at 35 percent MAC and a rate of 10.5° per second at 40.5 percent MAC (the c.g. the accident pilot encountered after rotation).

PFS Unit Examinations

The PFS units (model Nos. TY2614 and TY1741) recovered from the airplane were examined at TRW Aeronautical Systems, Lucas Aerospace, United Kingdom, under the supervision of the United Kingdom Air Accidents Investigation Branch. A visual and x-ray examination was performed and no anomalies were noted except for smoke discoloration. No anomalies were found during manufacturer-conducted tests before delivery, during acceptance tests in Wichita before installation of the units on the accident airplane, or during postaccident acceptance testing.

COMPANY INFORMATION

Company History and Organizational and Flight Test Structure

Bombardier was a Canadian manufacturer of ground and water transportation equipment before it purchased Canadair on December 23, 1986. The company purchased Learjet Corporation on June 29, 1990. Test development activity for the Learjet line continues at the BFTC.

At the time of the accident, Bombardier Aerospace comprised eight manufacturing plants located in five cities, two aircraft parts distributions centers, four approved maintenance organizations in four cities, and four approved training organizations in two cities.

At the time of the accident, a manager of flight test operations and safety was assigned to BFTC operations. His duties included providing administrative operational support to engineering flight test personnel, ensuring compliance with U.S. Federal Aviation Regulations and Canadian Aviation Regulations for pilot currency and qualification tracking, managing flight logs, dispatching, and piloting test flights. The manager of flight test operations and safety was the only person assigned to the BFTC's safety department.

At the time of the accident, the manager of flight test operations and safety reported directly to the vice president of flight test at BFTC, who in turn reported to the vice president of engineering. The vice president of flight test at BFTC was on the same organizational level as the vice presidents of engineering at the Toronto, Belfast, Wichita, and Montreal operations. He was also on the same management level with the vice presidents of program management for product development in Montreal, the director of quality assurance in Montreal, and the vice president of the Tucson Completion Center.[37] According to Bombardier, the manager of flight test operations and safety

[37] According to International Civil Aviation Organization Circular 247-AN/148, Section 3.10, a safety program "should be administered by an independent company safety officer who reports directly to the highest level of corporate management." The Safety Board, the FAA, and industry safety groups have also recommended that the safety officer be independent and report directly to top management. Safety Recommendation A-94-201 asked the FAA to require all carriers operating under Part 121 and Part 135 to "establish a safety function, such as outlined in Advisory Circular (AC) 120-59, "Air Carrier Internal Evaluation Programs." AC 120-59 stated that an evaluation program, which includes audits, inspections and evaluations, should be an "independent process that organizationally has straightline reporting responsibility to top management." The AC added that "this management

currently reports to the vice president of flight test at BFTC and the executive vice president for engineering and product development at company headquarters in Montreal.

Company Flight Test Accident and Incident History

Before the accident flight, Bombardier and Learjet experienced two fatal accidents (including a 1980 accident involving a Canadair CL-600), two nonfatal accidents and one incident.

On April 3, 1980, a Canadair Limited CL-600 was destroyed during stall testing near California City, California.[38] The pilot was killed, and the copilot received minor injuries. The flight test engineer was not injured. According to statements from the surviving pilot and flight test engineer, the flight crew was troubleshooting a noise associated with stalls conducted during previous flight test activities. Airplane control was lost during the stall, and the emergency spin recovery parachute was deployed. According to the copilot and flight test engineer, who were able to bail out, attempts to jettison the parachute were not successful and airplane control was never recovered.

On July 26, 1993, a Canadair CL-600-2B19 was destroyed during lateral and directional stability testing near Byers, Kansas.[39] The two test pilots and flight test engineer were killed. The probable cause of the accident was determined to be the "captain's failure to adhere to the agreed upon flight test plan for ending the test maneuver at the onset of pre-stall stick shaker, and the flight crew's failure to assure that all required switches were properly positioned for anti-spin chute deployment. A factor which contributed to the accident was the inadequate design of the anti-spin chute system which allowed deployment of the chute with the hydraulic lock switch in the unlocked position."[40]

On April 25, 1997, a Canadair BD700-1A10 landed wheels-up following avionics testing at Toronto, Canada. The test crewmembers were not injured. A Canada Transportation Safety Board (TSB) investigation determined that the flight crew did not lower the landing gear and had not followed a landing checklist. The aural gear warning had been disarmed during the flight test and not re-armed by the pilots following the test.

[safety] position should be above the level that directly supervises work accomplishment or procedural development and should have direct contact with the chief executive officer or equivalent." Safety Recommendation A-94-201 was listed "Closed—Acceptable Alternate Action" after the FAA issued Joint Flight Standards Bulletins (HBAT 99-19 and HBAW 99-16) to FAA principal inspectors that provided guidance for the development of a comprehensive safety department and the suggested functions, qualifications, and responsibilities for a director of safety position.

[38] The description for this accident, LAX80FA073, can be found on the Safety Board's Web site at <http://www.ntsb.gov>.

[39] The description for this accident, CHI93MA276, can be found on the Safety Board's Web site at <http://www.ntsb.gov>.

[40] As a result of this investigation and an unrelated flight test accident involving a Lockheed C-130, the Safety Board issued Safety Recommendation A-94-101, which asked the FAA to inform members of the flight test community about the circumstances of these accidents. Specific to the Byers, Kansas, accident, A-94-101 urged that "all companies involved in flight test of airplanes with anti-spin parachute systems … incorporate a design feature that would prevent the parachute from deploying if the jaws securing the parachute to the airplane are open." According to Bombardier, the spin chute system has been redesigned to prevent the chute's deployment before it is secured to the airplane.

On October 27, 1998, a Learjet 45 was destroyed after colliding with a pickup truck parked next to the runway during water ingestion testing near Wallops Island, Virginia.[41] The copilot and flight test engineer received minor injuries. The probable cause of the accident was determined to be the "failure of the pilot to obtain/maintain alignment with the water pool, which resulted in a loss of control. Factors in the accident were the inadequate preflight planning of the flight test facility and the airplane manufacturer which resulted in hazards in the test area and the subsequent collision of the airplane with a vehicle."

Bombardier also reported a flight test-related incident that occurred on July 21, 2000, when a Global Express BD-700-1A10 experienced an elevator jam following its first production test flight. The flight crew used a combination of thrust and pitch trim to maintain airplane control. The flight crew managed to free the right-hand elevator and landed at Lester B. Pearson International Airport in Toronto, Canada. A company investigation revealed that an unflagged rigging pin was not removed before the flight.[42]

Company Training

At the time of the accident, Bombardier production and experimental test pilots attended initial and recurrent flight training at a company-owned or a commercial flight training facility that is structured for operational flying, such as charter and private operations. No test scenarios were presented during these courses. Three-week initial training comprised 2 weeks of ground school and 1 week of simulator training. One day of line-oriented flight training was provided during simulator training.

Company flight test training is on-the-job, according to Bombardier's senior engineering test pilot. Flight test maneuvers are demonstrated to pilots, and the maneuvers are then performed by the pilot in training. Bombardier sends its test pilots and flight test engineers to a 2-week flight test short course at a civilian flight test school. Between 33 percent and 40 percent of flight test personnel had received military training or had attended a civilian test pilot school before being hired.

The company's chief test pilot at the time of the 1993 Byers, Kansas, accident told Safety Board investigators that flight test training was conducted as an apprenticeship. He stated that pilots learned maneuvers and procedure by observing from the jumpseat or second pilot seat. The chief test pilot stated that pilots did not receive external test pilot training and that they did not use the company's simulator for flight test training.

Postaccident interviews with Bombardier flight test employees indicated that no formal safety training meetings were conducted. Safety issues were presented during all-hands meetings. Several test pilots stated that they were not familiar with details of previous Bombardier flight test accidents and would like to be provided flight test incident and accident information.

[41] The description for this accident, IAD99FA008, can be found on the Safety Board's Web site at <http://www.ntsb.gov>.

[42] The description for this accident, TSB Occurrence No. A00O0150, can be found at the TSB Web site at <http://bst.gc.ca>.

Company Flight Test Procedures

Bombardier's flight test operational and safety policy manual, *Bombardier Flight Test Standards and Procedures 3000* (BFTC 3000), was published on October 10, 1996, and revised (with revision A) on December 14, 1998. Parts of the manual were incorporated into FAA Order 4040.26, "Aircraft Certification Service Flight Safety Program,[43] which established flight test briefing, risk assessment, and risk management procedures. Neither FAA nor Transport Canada regulations required Bombardier to have a flight test policies and procedures manual.

The 1996 BFTC 3000 manual did not require a test hazard analysis (THA) document, which addresses hazards, their causes, their effects, minimizing procedures, corrective action, and relevant remarks. Revision A contained provisions for hazard identification and risk reduction. Bombardier's chief of flight test operations and safety stated that the document was not used in Bombardier's sustaining programs at the time of the accident but that it was a phased-in program that had been implemented in the company's developmental (experimental) programs, such as the RJ 700 program.[44]

Both documents list risk levels of high, medium, and low for flight maneuvers or flight conditions. A high risk level indicates a high probability of an incident or accident involving severe damage to equipment and/or injury to personnel. Approval for high risk flights must be received from Bombardier's vice president for flight test or the engineering flight test director.

High risk test flights include new prototype flight testing. The manual states that such tests will be defined high risk "until an operation envelope covering stability and control, engine operation…[has] been defined." The tests included "all flight testing for the expansion or definition of limits appropriate to stability and control, flutter, performance, maximum airspeed and engine operation, testing that could result in loss of all engines, flight control failures, high speed 'upset' tests, initial stall tests, [and] stall tests with adverse c.g., aerodynamic, configuration, or component changes." High risk test flights also included "evaluation of unproven components in critical systems or the airplane in critical environments (e.g. high altitudes, high or low speeds, braking systems, flight controls, life support)…, structural demonstrations at limit values, … takeoff performance with actual engine shutdown, maximum brake energy test, maximum rudder sideslips, high altitude depressurization [or] any flight test, which, in the opinion of the test pilot-in-command and/or a representative of the engineering discipline responsible for the flight test to be conducted, warrants consideration as high risk."

A medium risk level indicates the probability of an incident or accident combined with moderate damage to equipment and/or injury to personnel. According to the manual, these tests "require more than routine supervision." Such flights must be approved by the Lear/Canadair program manager or the chief of flight test operations and safety. Medium risk flights include, "loss of one engine, including fuel starvation due to negative or lateral G, extreme attitudes, testing where close visual chase is required, flight outside of the current normal flight and/or operational envelope…, operating at minimum usable fuel [and] intentional single engine shutdowns."

[43] FAA Order 4040.26 was initially published in 1997 and was revised on March 23, 2001.

[44] The Challenger 604 was considered to be under the sustaining program because the airplane had been certified. The accident flight was considered experimental because it was to test an unproven change to the airplane.

A risk level of low indicates that there is a low probability of incident or accident combined with minimal damage to equipment and/or injury to personnel, according to the manual. The risk assessment authority for these flights is the PIC.

Bombardier's safety risk assessment process is described in BFTC 3000 Revision A as follows:

8.5.2 Steps in Deliberate Safety Risk Management

a. **Hazard Identification:** Hazard identification begins with the preparation of the test requirements document…and [conducting] a preliminary hazard analysis. This analysis is a list of hazards that could occur and result in mishaps/incidents/accidents. This preliminary hazard analysis is developed using experience, scenario thinking, archives, and similar techniques.

8.5.5 The Safety Risk Assessment Process

a. **Aircraft Configuration:** All test aircraft will be configured in accordance with Bombardier Aerospace, Transport Canada, or the Federal Aviation Administration directives as appropriate for the conduct of the test.

b. **Crew:** All flight crews on the test or chase aircraft will be qualified and current IAW [in accordance with] BFTC 3000 prior to the start of the test.

c. **Briefings:** All test personnel will participate in pre test briefings.

d. **The Completed Safety Risk Assessment** will be briefed prior to each flight. The Safety Risk Assessment format will vary IAW program directives. However, each completed Safety Risk Assessment is required to contain the following information.

1) Decision Authority Signature
2) Risk Assessment
3) Hazard Identification (Not required for low risk flights)[45]
4) Risk Reduction (Not required for low risk test flights)[46]

Surveillance of the Bombardier Flight Test Facility

Under a bilateral agreement with the United States, Transport Canada has direct regulatory oversight of the BFTC facility. However, there are no Canadian or U.S. regulations specific to the conduct of flight test operations. The last Transport Canada inspection of the BFTC facility before the accident was conducted on November 5, 1999. A full-time, on-sight Transport Canada inspector was not assigned to the BFTC facility until after the accident.

[45] According to the BFTC 3000 manual, hazard identification "begins with the preparation of the test requirements document," which includes "a preliminary hazard analysis." The manual states that the preliminary hazard analysis "is developed using experience, scenario thinking, archives, and similar techniques."

[46] The BFTC 3000 manual lists risk reduction measures to be conducted before the flight, including consideration of whether or not "this configuration (aerodynamic or systems) [has] been flight-tested."

As part of initial certification and subsequent modification programs, Transport Canada test pilots and flight test engineers are involved with BFTC management and flight test crews during certification tests to validate company compliance. FAA and JAA flight test crews also fly with BFTC flight test crews to validate Transport Canada certification of new and modified airplanes. Although not defined as regulatory oversight of the operation, the activities provide and opportunity to observe company operations, according to Transport Canada.

The FAA's MIDO and Wichita Aircraft Certification Office (ACO), located at ICT, provide oversight for the manufacture and certification of Learjet airplanes manufactured at the Bombardier Learjet facility in Wichita. The Wichita MIDO also issues special flight authorizations for Bombardier-Canada airplanes based on limitations developed by Transport Canada. Although the FAA's Wichita ACO is located at ICT, the FAA's ACO in Valley Stream, New York, has certification oversight for the CL604 and other aircraft manufactured by Bombardier in Canada. The New York ACO has no direct regulatory oversight responsibility of Bombardier airplanes manufactured in Canada and test flown in Wichita. However, according to the manager of the New York ACO, FAA certification personnel are authorized to validate Canadian certification test points.

Transport Canada Postaccident Audit of Bombardier's Wichita Facility

After the accident, Transport Canada conducted a Special Purpose Audit at the BFTC from October 25 to 27, 2000. The audit report commended Bombardier "for documenting procedures for the safe conduct of flight tests [the standards and procedures manual 3000]" but that "the audit revealed that the company management does not always enforce the provisions of the manual." The audit report stated that Bombardier project directives authorize specific BFTC engineers to "develop and approve developmental and experimental modifications specific to the flight test aircraft that can have significant effects on safety." The report noted that "documentation or specific procedures were unavailable to demonstrate that other engineering disciplines, potentially affected by the modification, provided sufficient analysis to support safe operation of the aircraft."[47]

In addition, the audit report stated that the "chief of flight operations and safety at BFTC is an unusual position in that it combines the 'Safety Manager' function with that of 'Operations Manager, which due to their functions have conflicting or incompatible roles."

The audit report noted that BFTC has a "well documented safety risk management [SRM] process" but that the SRM process did not address several areas. According to the report, these areas included the following:

a) The risk level of a particular flight test activity is assigned prior to the expected effect of the minimizing or mitigating procedures. The hazard associated with using a[n] SRM tool that assigns risk level without taking

[47] In a November 27, 2003, letter to the Transportation Safety Board of Canada (forwarded to the Safety Board), Bombardier challenged several conclusions and observations contained in Transport Canada's postaccident audit. The company stated that it had "challenged Transport Canada … and provided substantial proof that the subject documentation and procedures were readily available and that the required engineering oversight for the safe conduct of flight testing was beyond reproach." In addition, Bombardier claimed that the audit "lacked specifics" and that "many of its findings were refuted by Bombardier." Corrective actions were also taken, according to Bombardier, including having the safety manager report directly to the executive vice president of engineering on safety issues and to the vice president of flight test on day-to-day issues.

into account the effectiveness of the risk reduction procedures is that the residual risk of a test could actually be higher than perceived;

b) Low risk tests require no risk reduction, or identification of mitigation procedures. This is contrary to one of the basic principles of flight test safety, which is quoted in Section 8.5.1 of BFTC S&P 3000, ‘Accept no unnecessary risk’; and

c) Low risk tests are defined as ‘all test flying not described as high or medium risk’. There are lists of what are considered high and medium risk tests. The implication is that if it is not listed in the high or medium lists, then it must be low, without any analysis being performed.

d) The procedures in place have the potential, particularly in situations of time pressure, to over rely on the TDS [test definition sheet] generated risk analysis. Under such circumstances, further in-depth analysis of the risk associated with the particular test might be warranted.

The audit report concluded that “it was evident that the level of activity at BFTC was very high and is predicted to continue at this pace. The tempo of operations continues to place working pressures that have the potential [to] affect flight safety.”

ADDITIONAL INFORMATION

The wreckage was released and all retained components were returned to Bombardier Incorporated. The FAA, Bombardier and General Electric were parties to the investigation. The TSB assigned a technical adviser to the investigation. Transport Canada provided technical personnel and resources throughout the investigation, including assistance in FDR/CVR readouts and Bombardier simulator tests.

Normal Takeoff Procedures

According to the Bombardier Aerospace *Challenger 604 Operations Reference Manual*, the PF rotates to 14° at 3º per second after the “rotate” call from the PNF. The same rotation rate is used for an abnormal takeoff (engine failure after V_1) but with a reduced pitch attitude of 10°. The rotation rate value listed in the *Challenger 604 Operations Reference Manual* is based on an industry average for transport-category aircraft takeoff profiles.

Flight Test Safety Standards

During the investigation, Safety Board staff examined flight test standards and programs developed by the FAA, the U.S. military, and the civilian National Test Pilot School. FAA certification test pilots attend an initial 6-week standardization course at a civilian test pilot school and receive 2 weeks of recurrent training. The course covers helicopter and fixed-wing flight test fundamentals, flight test safety, and flight test crew resource management (CRM). According to the FAA, the majority of FAA test pilots had received formal test pilot training from a military test pilot school before being hired, although the FAA also hires test pilots who have at least 1 year of industry flight test experience. FAA test pilots validate test points that have already been performed by airplane manufacturers.

The aircraft certification flight safety program established in FAA Order 4040.26 requires FAA management personnel who participate in safety management training to disseminate lessons learned to those involved in certification and to receive CRM training. The order also formalized procedures for the formal assessment of flight test risks and the acceptance of residual risks when signing the type inspection authorization or test plan. The order defined risk management as follows:

> The process by which an assessment is made of the risks involved during a flight test, the establishment of mitigating procedures to reduce or eliminate the risks, and a conscious acceptance of the residual risks. Risk assessment is normally done by a safety review process in which a flight test plan is reviewed by project and non-project personnel in order to draw out potential hazards and recommend mitigating (or minimizing) procedures. Experience has shown that knowledgeable non-project personnel who are similarly involved in other projects provide valuable contributions to this process. They can identify areas that may have been overlooked by the project team (aircraft manufacturer vs. limited flight test experience), and flight crew currency in both the test method(s) and aircraft type.

U.S. Air Force Flight Test Center (AFFTC) Instruction 91-5, “AFFTC Test Safety Review Process,” directs the application of system safety principles to the planning and conduct of all AFFTC and other designated test programs. It states that safety planning and technical planning are integral and that a “smart test team” will interweave technical and safety issues throughout the project planning process. The document emphasizes the identification and elimination/control of test hazards, the preparation of safety-related forms that include a THA, and the importance of safety and technical reviews.

The National Test Pilot School publication, “Flight Test Training: Luxury or Necessity?” addressed the benefits and efficiency of training for flight test pilots and engineers. This publication summarized an FAA test pilot’s views as follows:

> In general, on-the-job trained personnel are usually quite good at what they do; but their abilities are dependent on what they have been shown in the past. Flight testers who have learned on-the-job usually demonstrate very little capability to move into new areas of testing because they haven’t been taught the fundamental philosophy of flight test. This is particularly noticeable in the area of test safety and the incremental approach to test flying.

ANALYSIS

General

The captain and first officer were properly certificated and qualified in accordance with applicable Federal regulations and company requirements.

The airplane was operating in accordance with a Canadian flight permit and a special use authorization issued by the FAA and was properly equipped to conduct flight tests. Examination of the flight controls, the modified PFS units, and the airplane's engines and systems found no evidence of pre-impact malfunction.

Visual meteorological conditions prevailed. Weather was not a factor in the accident.

Pilot Actions and Weight and Balance Shift

According to FDR information and calculated performance data, the airplane's maximum pitch rate after rotation was 9.6° per second, an extremely rapid pitch rate which was approximately three times greater than the average 3° per second pitch rate recommended in the *Challenger 604 Operations Reference Manual.* Safety Board staff review of the PF's previous takeoff performance indicated that he had commanded excessive pitch rates during several takeoffs in the months before the accident, including 6.5°- and 6°-per-second pitch rate takeoffs in the Challenger from Barrow and Fairbanks, Alaska, a month before the accident; a 7.2°-per-second rotation rate on a Challenger test flight on August 16, 2000; and a 8.3°-pitch-rate takeoff in a Global Express on September 22, 2000.

The amounts of fuel in the airplane's center, three-in-line auxiliary fuel tanks were not isolated from each other, which allowed fuel to move freely through pipes between tanks, especially during acceleration and rotation. Postaccident calculations determined that the c.g. moved aft as the airplane accelerated down the runway as fuel shifted rearward in the auxiliary fuel tanks, tail tanks, and wing tanks. By the time the airplane reached a pitch attitude of 13.8° 20 seconds after the start of the takeoff roll, the airplane's c.g. increased to at least 40.5 percent MAC, according to Safety Board staff calculations. Although fuel some migration is normal and expected in all airplanes, the CL-604's center fuel tank design allowed for significant fuel migration above the range accounted for in the airplane's certified c.g. range limits. Safety Board staff also considered a scenario that did not include fuel migration. Simulation testing indicated that without the fuel migration factor, the airplane's c.g. would have been sufficiently forward to prevent the airplane from pitching up sufficiently to trigger the airplane's stall protection system.

Thus, the aft c.g., including the c.g. change during the takeoff phase, combined with the high pitch attitude and pitch rate commanded by the pilot, resulted in stall and loss of control. Moreover, the aft c.g. and the aggressive pitch control inputs by the pilot eliminated the safety margin that the c.g. limit and the lower pitch rate guidance of 3° per second were intended to provide. Safety Board staff and Bombardier simulation studies indicated that either restoring the c.g. margin or reducing the pitch rate to 3° per second would have provided an adequate safety margin.

Based on FDR data, flight data of the PF's previous takeoffs, and postaccident fuel migration and shift calculations, it is evident that the pilot's pitch control, combined with unanticipated aft c.g. (fuel) shift during acceleration, resulted in an excessive rotation rate and an unexpected and faster pitch rate after liftoff, which caused the airplane to stall. The FAA and Transport Canada issued ADs after the accident addressing the issue of fuel migration (lowering the aft c.g. limit) and the potential for exceeding the airplane's aft c.g. limit during acceleration or climb.

FDR data indicated that the stick pusher activated twice (following two pitch up oscillations) after the airplane's pitch angle reached the stick shaker and stick pusher activation thresholds, and that the pilot made elevator inputs to counter the downward pitch angle induced by the stick pusher. During this time, the CVR recorded the sounds of stick shaker, aural stall and bank angle warnings. Based on this data, it is evident that the second combination of stall, stick pusher activation and subsequent up elevator inputs by the pilot occurred at an altitude too low for recovery when the airplane was experiencing wide excursions in pitch attitude and roll.

As noted previously, postaccident examination determined that the modified PFS units, which were to be tested during the flight, were not a factor in the accident.

Flight Test Oversight

Safety Board staff examined Bombardier's flight test operations, company procedures, and safeguards to minimize risk. At the time of the accident, Bombardier was phasing in a new flight test procedures manual, which included significant changes and additions in the areas of flight test preparation, hazard identification and analysis, and risk reduction. However, the changes had not yet been implemented in the Challenger sustaining program. Although the Challenger program was defined as a sustaining program because the airplane had received prior certification, the flight was nevertheless experimental because it was designed to test a component change that affected the airplane's handling qualities.

During the investigation, it was determined that the accident flight's risk assessment was subject to several interpretations. For example, the accident flight was assessed as a low risk test flight by Bombardier's manager of flight test operations and safety, who stated that the determination was made because the airplane was operating within its c.g. range and because "the modification was stabilizing." A Transport Canada test pilot later came to the same conclusion. However, an FAA test pilot concluded that the flight was a medium risk flight because it involved the modification of a flight control system. This disparity in risk assessment underscores the importance of a formal safety review and THA standard, especially when there are competing assessments. Even if the changes to PFS units were considered minor and ultimately judged not to pose a medium risk, it is noted that the risk assessment was made minutes before the flight and did not take into account that the changes were to a flight control system that was to be tested in flight for the first time during a complex maneuver.

Pilot selection and crew pairing are also part of the flight test safety equation. According to Bombardier, test flight training is on-the-job. Although on-the-job flight test training is a common industry practice, several airplane manufacturers (including Bombardier) and flight test schools have implemented an incremental approach to flight test training. This approach includes a gradual increase in flight test complexity during on-the-job training and the pairing of newly hired flight test pilots with an experienced flight test pilot before the new hires are allowed to conduct test flights as PICs. It is noted that the accident pilot, whose experience was largely in routine, entry-level operational and production testing, rather than flight testing, was assigned as PIC to test airplane control performance and airplane handling qualities in a complex flight test maneuver that he had never flown. The copilot, who was an experienced test pilot in other airplanes, was assigned second-in-command duties to familiarize himself with the Challenger, not to demonstrate flight test procedures and maneuvers that were unfamiliar to the accident pilot.

During its investigation, Safety Board staff reviewed test flight safety information from several sources, including the FAA, U.S. Air Force and the National Test Pilot School. The sources recommend developing THA worksheets for test flights, which include information on potential hazards, risk minimizing procedures, or emergency procedures. Briefing a test flight with a THA helps pilots focus on the specific risks involved in a test flight and helps to minimize the risk of complacency. Bombardier did not use these worksheets for preflight test briefings.

Neither the flight test card nor the preflight briefing for the accident flight called for a "build-up" of the flight test maneuver to be flown. A typical build-up for such a maneuver would have called for a gradual entry into the maneuver, at lower speeds and at a more stable c.g. location, before executing the prescribed maneuver at higher speeds and G forces and aft c.g. configurations. The preflight briefing also did not include a discussion about test maneuver techniques or about what procedures to follow in the event of a problem or failure in the modified systems to be tested. Pitch rate targets were also not discussed in the context of an aft c.g. test flight. Although the accident flight was to be conducted within the airplane's aft c.g. limit, the c.g. was near the aft limit and should have been briefed to increase awareness of pitch rate performance in this configuration.

Safety Board staff review of Bombardier flight data from 50 flights flown by BFTC pilots, including several senior test flight and management pilots, indicated that pilots routinely commanded pitch rates that were more than double the recommended rate of 3° per second during operational takeoffs. Company flight operations data, collected from every Bombardier test flight and archived, is not reviewed as part of an overall company flight operations quality assurance program. Therefore, this high pitch rate practice, and its potential for hazard, was not identified by senior Bombardier management.

Finally, despite experiencing three fatal and two nonfatal accidents during product development, Bombardier did not have a safety manager who reported directly to senior management at headquarters in Montreal, did not conduct regular safety meetings, and did not maintain a "lessons learned" safety database accessible to flight crews.

Based on its review of Bombardier's flight test operations and other relevant safety programs, the investigation determines that Bombardier's oversight of its flight test program was inadequate because risk assessment procedures in place for the Challenger program were not followed and because a more comprehensive risk assessment program, which would have required a more timely and thorough risk assessment of the accident flight, had not been implemented for the Challenger test program, although it had been used for 2 years in the company's RJ 700 program. Further, it is evident from the investigation that Bombardier's operation of its flight test program was deficient because the preflight briefing was inadequate, because a relatively inexperienced flight test pilot was chosen for a flight that involved a complex maneuver he had never flown (and in an aft c.g. configuration greater that he had ever flown), because a build-up for the accident flight was not considered, and because the company failed to identify a history of its pilots' practice of high rotation rate takeoffs, which becomes even more critical in airplanes configured with aft c.g.'s. Finally, it is evident from the investigation that Bombardier's safety program was deficient because the safety manager at the time of the accident did not report directly to senior management. However, it should be noted that the BFTC safety manager now reports directly to senior management in Montreal and that Revision A of BFTC 3000 is now used for the Challenger program.

Transport Canada and FAA Oversight of Flight Test Programs

Under the terms of a bilateral agreement, Transport Canada had direct regulatory oversight of Bombardier's BFTC operations involving the company's Canadian-manufactured airplanes, although the last inspection of the facility was conducted nearly a year before the accident. Although Transport Canada assigned a full-time inspector to the BFTC facility after the accident, there was very little surveillance of the facility's flight test operations at the time of the accident. Further, there are no Canadian or U.S. regulations specific to the conduct of flight test operations. Neither FAA nor Transport Canada regulations require Bombardier, or other flight test operations, to have a flight test policies and procedures manual.

It is evident from the investigation that Bombardier is developing and using its *Flight Test Standards and Procedures 3000* manual, but Transport Canada's audit observation indicated that the company did not always enforce the provisions of its own manual. Thus, Transport Canada and the FAA are only monitoring a largely voluntary program. The flight test operations and the corporate safety culture they require would benefit from the adoption of Transport Canada- and FAA-approved flight test standards and procedures. It should be noted that Transport Canada is currently considering regulations to require the use of an approved flight test operations manual and is implementing additional procedures to improve regulatory oversight of flight test operations, including those at BFTC.

Survival Factors

The emergency response to the accident site was timely, with two ARFF vehicles and three firefighters arriving at the scene within 90 seconds of the crash. However, there were not sufficient ARFF personnel equipped with protective gear in the immediate response to fight the fires and perform a rescue. The first responders to the scene, two ARFF fire trucks and three ARFF personnel, initiated a mass application of water and firefighting agent to extinguish the fuel-fed, exterior fire, which had engulfed the fuselage. The firefighters stated that they could hear the pilots calling for help after the large exterior fires had been extinguished. Two of the three personnel were occupied in their vehicles with firefighting activities, according to ARFF officials. Firefighters stated that additional personnel during the initial response would have allowed them to suppress the cockpit fire more quickly.

During its investigation of a runway overrun accident involving a McDonnell Douglas MD-82 in Little Rock, Arkansas, in 1999,[48] the Safety Board examined whether a passenger who needed to be rescued from the wreckage would have survived if sufficient ARFF personnel had been available to perform a rescue. In a situation similar to the Challenger accident, rescue efforts could not be conducted effectively until off-airport firefighters arrived at the scene. Although the Safety Board could not determine whether the passenger would have survived if more ARFF personnel had been available, it expressed concern that Federal regulations did not ensure that ARFF units would be staffed at levels sufficient to conduct simultaneous firefighting and rescue activities.[49] As a result, on October 23, 2001, the Safety Board issued Safety Recommendation A-01-65 to the FAA. Safety Recommendation A-01-65 asked the FAA to "amend 14 *Code of Federal Regulations* 139.319 (j) to require a minimum Aircraft Rescue and Fire Fighting staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers."[50]

The flight test engineer's station was located in the middle of the cabin. The flight test engineer's body was found forward near the cockpit bulkhead. He had suffered severe blunt force injuries. The flight test engineer's seat frame was found near his body with the 5-point latch buckled. The lap belts were found burned through. Damage to the seat, the seat floor mounts and the injuries sustained by the flight test engineer indicate that scenario three, that the flight test engineer's seat failed, is the most likely. Based on seat damage, evidence of seat frame separation in overload and the lack of similar separation of instrument racks near his seat, it is evident that the flight test engineer's seat separated during the impact sequence, and that his injuries were consistent with a lack of restraint.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of this accident was the pilot's excessive takeoff rotation, during an aft center of gravity (c.g.) takeoff, a rearward migration of fuel during acceleration and takeoff and consequent shift in the airplane's aft c.g. to aft of the aft c.g. limit, which caused the airplane to stall at an altitude too low for recovery. Contributing to the accident were Bombardier's inadequate flight planning procedures for the Challenger flight test program and the lack of direct, on-site operational oversight by Transport Canada and the Federal Aviation Administration.

---

[48] National Transportation Safety Board, *Runway Overrun During Landing, American Airlines Flight 1420, McDonnell Douglas MD-82, N215AA, Little Rock, Arkansas, June 1, 1999*, Aircraft Accident Report NTSB/AAR-01/02 (Washington, DC: NTSB, 1999).

[49] The Safety Board had similar concerns during its investigation of an emergency landing of Air Tran flight 913 in Greensboro, North Carolina, on August 8, 2000, because of dense smoke in the cockpit. The Safety Board concluded that if the passengers and crew had not been able to evacuate, there would not have been enough ARFF personnel to enter the airplane and rescue occupants. The description for this accident, DCA00MA079, can be found on the Safety Board's Web site at <http://www.ntsb.gov>.

[50] In a February 19, 2002, letter to the Safety Board, the FAA stated that it had asked the ARAC Airports Issue Group to create an ARFF Requirements Working Group to examine ARFF staffing levels as part of an overall ARAC review of 14 CFR Part 139. On October 17, 2002, Safety Recommendation A-01-65 was classified "Open—Acceptable Response," pending results of the ARAC working group and implementation of the recommendation.