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Challenger With Frost on Wings Enters Uncontrolled Roll on Takeoff

The report said that the judgment and concentration of the flight crew, who were aware of the wing contamination but did not have the aircraft deiced before departure, might have been impaired by the combined effects of a nonprescription drug, jet lag and fatigue.

FSF Editorial Staff

At 1207 coordinated universal time on Jan. 4, 2002, a Bombardier Challenger 604 began to roll left immediately after liftoff on Runway 15 at Birmingham (England) International Airport. The flight crew applied full opposite aileron control and full opposite rudder control, but the roll continued. The left winglet struck the runway shoulder, and the airplane struck the ground inverted and burned. The two pilots, an observer and two passengers were killed.

The U.K. Air Accidents Investigation Branch (AAIB) said, in its final report, that the accident investigation identified the following causal factors:

- "The crew did not ensure that [the aircraft's] wings were clear of frost prior to takeoff;
- "Reduction of the wing stall angle-of-attack, due to the surface roughness associated with frost contamination, to below that at which the stall-protection system was effective; [and,]
- "Possible impairment of crew performance by the combined effects of a nonprescription drug, jet lag [circadian desynchronosis] and fatigue."

The accident aircraft, manufacturered in 1999, was operated by Epps Air Service in Atlanta, Georgia, U.S. The aircraft had accumulated 1,594 flight hours and 797 cycles (takeoffs and landings).

The commander (pilot-in-command), 51, had an airline transport pilot (ATP) certificate and about 10,000 flight hours, including 800 flight hours in type. He was director of operations for Epps Air Service.

The second-in-command, 58, had an ATP certificate and about 20,000 flight hours, including about 800 flight hours in type.

The flight crew began duty in Atlanta at 0900 (0400 local time) the day before the accident. The aircraft departed from Atlanta at 1015. The crew flew the aircraft to two locations in Florida — Fort Myers and West Palm Beach — to pick up passengers.

"An additional company pilot, not qualified on the Challenger 604 and not forming part of the flight crew, was on board as an observer for transatlantic experience," the report said.

The aircraft departed from West Palm Beach at 1259 and was landed at the Birmingham airport at 2039. The aircraft was parked outside overnight. Frost conditions were categorized by ground-deicing personnel as severe, with 0.5-inch (12.7-millimeter) accumulation on wing surfaces.

"The aircraft was parked on the Western Apron while at Birmingham," the report said. "Over the night … the air temperature remained below zero, with a minimum temperature of minus 9 degrees [Celsius; 16 degrees Fahrenheit] at 0550 hours. Initially, the sky was clear, with increasing but variable

cloud cover after midnight. The surface wind overnight was southeasterly at about three knots.

"The two pilots and the observer spent the night in a local hotel. Records indicated that they checked in at approximately 2115 hours and had a meal and some alcohol between 2144 hours and 2315 hours before retiring to bed. The handling pilot [pilot flying (the second-in-command)] for the return to the [United States] made a phone call home at 0200 hours."

The handling pilot and the observer arrived at the airport at about 1040; the commander arrived at about 1100. The aircraft's auxiliary power unit (APU) was started at about 1050, and the aircraft was refueled between 1105 and 1140.

"At different times, each of the two crewmembers was seen to carry out an independent external inspection of the aircraft," the report said. "During the morning, various witnesses had seen frost/ice on the wing surfaces of N90AG [the accident aircraft]. Other aircraft had been deiced during the morning, with associated reports of severe to moderate ice accumulation."

The captain of a Canadair CRJ that had been parked overnight near the accident aircraft found frost on the CRJ that he estimated as 1.00 millimeter to 2.00 millimeters (0.04 inch to 0.08 inch) thick. The CRJ captain had the aircraft deiced before departure.

The report said that before the Challenger's engines were started, the cockpit voice recorder (CVR) recorded the following conversation:

> Commander: 'Got a (????) frost on the leading edge, on there, did you-all look at it?'
>
> Handling pilot: 'Huh?'
>
> Commander: 'D'you (????) that frost on the leading edge — wings?'
>
> Handling pilot: 'Did I feel 'em?'
>
> Commander: 'Yeah, did you-all check that out?'
>
> Handling pilot: 'Yuh.'

Investigators calculated that the aircraft's takeoff weight was 47,836 pounds (21,698 kilograms), which was less than the certificated maximum takeoff weight of 48,200 pounds (21,864 kilograms). The aircraft's center of gravity (CG) could not be calculated accurately.

"The actual seating of the passengers and the positioning of the baggage could not be determined precisely … but with any seating combination, the aircraft would have been within the originally certificated normal weight and CG limits for takeoff," the report said.

The aircraft's originally certificated aft CG was 38 percent mean aerodynamic chord (MAC). After preliminary investigation of a Challenger 604 accident in October 2000 that indicated that fuel migration under acceleration or in climb might cause the aft CG limit to be exceeded, Transport Canada and the U.S.

Bombardier Challenger 604

Canadair was a subsidiary of General Dynamics Corp. when it was acquired by the Canadian government in 1976. The same year, Canadair acquired the rights to William P. Lear's LearStar 600; the company made several design changes — including a larger fuselage for more cabin space, a larger wing to accommodate more fuel and a T-tail — and renamed the twin-turbofan executive transport the Challenger 600. Deliveries began in 1980. Canadair, which was acquired by Bombardier in 1986, also used the Challenger design as the basis for a series of regional jets, which first entered service in 1992.

The Challenger 600, which has AlliedSignal (now Honeywell) ALF 502L-2 engines, was replaced in 1983 by the Challenger 601, which has General Electric CF34-3A engines and winglets. Production of the Challenger 601 was terminated in 1996.

The Challenger 604, which has the engineering designation CL-600-2B16, was introduced in 1995 with redesigned landing gear, carbon brakes and greater fuel capacity. The airplane has CF34-3B engines, each producing 8,800 pounds (3,992 kilograms) thrust.

The Challenger 604 accommodates two pilots and up to 19 passengers. Maximum takeoff weight is 48,200 pounds (21,864 kilograms). Maximum landing weight is 38,000 pounds (17,237 kilograms).

Maximum cruise speed is 0.83 Mach. Long-range cruise speed is 0.74 Mach. Maximum certified altitude is 41,000 feet. Maximum range with five passengers and fuel reserves is 4,077 nautical miles (7,551 kilometers).♦

Source: *Jane's All the World's Aircraft*

Federal Aviation Administration (FAA) in February 2001 issued airworthiness directives (ADs) requiring a reduction of the aft CG limit to 34.5 percent MAC for takeoff weights above 38,000 pounds (17,237 kilograms).[1]

The crew completed the "Pre-Start-up" checklist, started the engines and obtained clearance to taxi to the runway. The crew completed the "Pre-Take-off" checklist while taxiing the aircraft to the runway.

"When the anti-ice checklist item was reached, the handling pilot stated, 'We may need it right after takeoff,'" the report said.

The crew extended the flaps 20 degrees for takeoff and calculated the following target airspeeds: V_1 (decision speed), 137 knots; V_R (rotation speed), 140 knots; and V_2 (takeoff safety speed), 147 knots. They received takeoff clearance at 1207.

"During the takeoff roll, the sound of the nosewheel rolling over the runway centerline could be heard, which prompted the commander to tell the handling pilot, 'Get off that centerline,'" the report said. "The aircrew cross-checked their airspeed indications when the instruments started to register and at 100 knots, [and] the takeoff speeds (V_1, V_R, V_2) were called. The speeds called out on the CVR correlated closely with the FDR [flight data recorder] recorded airspeed values."

The takeoff appeared normal until the aircraft lifted off the runway two seconds after rotation at an indicated airspeed of 153 knots and with a nose-up pitch attitude of eight degrees.

"Immediately after liftoff, the aircraft started to bank to the left," the report said. "The rate of bank increased rapidly; and two seconds after liftoff, the bank angle had reached 50 degrees. At that point, the aircraft heading had diverged about 10 degrees to the left."

The left bank increased despite the crew's application of full-opposite aileron control and rudder control.

"As the bank angle continued to increase, progressively more aircraft nose-up elevator was applied," the report said. "Stick-shaker operation [stall warning] initiated 3.5 seconds after liftoff, and the recorders [i.e., CVR and FDR] ceased two seconds later. The aircraft struck the ground, inverted, adjacent to the runway. The last recorded aircraft attitude [about 5.5 seconds after liftoff] was approximately 111 degrees left bank and 13 degrees nose-down pitch; the final recorded heading was about 114 degrees."

The report said that the accident was not survivable. Autopsies indicated that the five occupants died instantaneously from multiple injuries. Toxicological examinations of the pilots detected diphenhydramine, a sedative antihistamine used in nonprescription cold medications, allergy medications and sleep aids.

"Examination of the luggage removed from the wreckage site revealed a number of medications within the baggage belonging to the crew," the report said. "In the handling pilot's bag, there was a quantity of 'Excedrin PM — aspirin-free'; this medication contains 500 milligrams of acetaminophen [pain/fever reducer] and 38 milligrams of diphenhydramine citrate per tablet."

Research conducted by the pathologist who performed the autopsies and by a psychologist indicated that the pilots' judgment and decision making likely were impaired by diphenhydramine, jet lag and fatigue.

The pathologist said that diphenhydramine can cause drowsiness, blurred vision, dizziness and nausea, and can impair short-term memory and attention. The effects of diphenhydramine are amplified by alcohol.

"Why both these men should be taking diphenhydramine is open to speculation," the pathologist said. "It is possible that the handling pilot had a cold or similar upper-respiratory-tract infection and was taking diphenhydramine. Had the commander developed a similar cold, the handling pilot may have shared his medication with him. It is equally possible that both men had taken this drug to aid sleep and prevent jet lag. There is no way of knowing why they took this medication. In my opinion, the most likely explanation is that they took the drug to aid sleep."

The psychologist said that the five-hour time difference between Atlanta and Birmingham would have affected the quality of rest obtained by the crew on the night before the accident.

"The evidence suggests that they retired to bed some time after 2336 but [that] they could well have had difficulty initiating sleep before 0200," the psychologist said. "Although the alcohol [that the crew consumed the evening before the accident] may have assisted with initiating sleep, it may also have disrupted later sleep. The overall effect on the morning of [the accident] is likely to have been a significant degree of fatigue that conceivably could have impaired judgment or reasoning."

The report said that many nonprescription medications containing diphenhydramine are sold "over the counter" in the United States in packaging displaying warnings about avoiding alcohol but displaying no warnings about driving or operating machinery.

"In the U.K., similar drugs [are] more difficult to obtain and have additional warnings on the packaging," the report said.

The report cited recommendations by the U.S. National Transportation Safety Board (NTSB) in January 2000 based on investigations that found use of medications to be causal or contributory in accidents that occurred in all modes of transportation in the United States.[2] NTSB made the following recommendations to FAA:

- "Establish, with assistance from experts on the effects of pharmacological agents on human performance and

alertness, procedures or criteria by which pilots who medically require substances on the U.S. Department of Transportation's list of approved medications may be allowed, when appropriate, to use those medications when flying. (A-00-4)"

[FAA in March 2001 told NTSB that publishing a list of medications approved for use by airmen would be inappropriate. "The medical certification process now in place at the FAA requires airmen to secure permission to fly while using reported medication," FAA said. "Because the FAA believes that all drugs taken for a medical reason have a potential to affect aviation piloting performance adversely, this process takes into account the drug and dosage level, the medical condition being treated and the potential for adverse response to any given medication or combination of medications."]

- "Develop, then periodically publish, an easy-to-understand source of information for pilots on the hazards of using specific medications when flying. (A-00-5)"

  [FAA in March 2001 told NTSB that "developing and updating an easy-to-understand source document for medication would present a formidable and labor-intensive task of questionable benefit." FAA said, "Airmen have access to the Civil Aeromedical Institute's (CAMI) Web site, which contains information on medications detected in pilots by the FAA's Toxicology and Accident Research Laboratory. The information available on the CAMI Web site includes prescription medications detected in pilots, along with the notes on the impact of these medications on an airman's ability to perform flight duties. The FAA also publishes a list of common, over-the-counter medications and their hazards to aviators, which is distributed to pilots."]

- "Establish and implement an educational program targeting pilots that, at a minimum, ensures that all pilots are aware of the source of information described in Safety Recommendation A-00-5 regarding the hazards of using specific medications when flying. (A-00-6)"

  [FAA in March 2001 told NTSB that "ongoing educational programs … adequately address the hazards of medication and flying." FAA said, "These educational programs include distribution of medical publications to aviation medical examiners (AMEs) to make available to airmen, providing material to AMEs for presentation to airmen at flight safety meetings [and] providing FAA support for training airmen at aviation events and activities."]

[NTSB has classified Recommendations A-00-4, A-00-5 and A-00-6 as "open," with "unacceptable response" from FAA.]

NTSB made the following recommendation to the U.S. Food and Drug Administration (FDA): "Establish a clear, consistent, easily recognizable warning label for all prescription [medications] and over-the-counter medications that may interfere with an individual's ability to operate a vehicle. Require that the label be prominently displayed on all packaging of such medications. (I-00-5)" [The "I" indicates that this is an "intermodal" recommendation.]

[FDA in February 2000 told NTSB that new regulations on labeling of over-the-counter medications that might interfere with a person's ability to operate a vehicle require the following warning statement in at least six-point type size[3] and in a consistent location: "Be careful when driving a motor vehicle or operating machinery." NTSB has classified Recommendation I-00-5 as open, with unacceptable response from FDA. NTSB told FDA that "requiring very general cautions such as 'be careful' in the extremely fine print of (over-the-counter) medication labels [does not meet] the intent of our recommendation."]

The report said that investigators did not determine how much frost was on the Challenger or where the frost was located. No frost deposits were found on the aircraft wreckage.

"It was probable that any frost deposits present on N90AG at takeoff would have been removed by the effects of impact, shock loading and/or heating that occurred during the accident, and/or by the effects of the extinguishant used during the fire fighting operation," the report said.

The pilots' preflight conversation about frost on the aircraft and witness reports of frost on the aircraft indicate "that there was frost contamination on at least some of the wing surfaces," the report said.

Exhaust from the APU, which was operated slightly more than one hour, likely caused some asymmetry in frost contamination of the aircraft, the report said. The APU in a Challenger is installed in the rear equipment bay; APU exhaust gas is expelled through a port beneath the right engine pylon; vanes direct the exhaust gas away from the engine nacelle and fuselage. The accident aircraft's APU exhaust flow likely was affected by a slight tail wind.

"During the investigation, a Challenger pilot noted that he had experienced two occasions when ice and frost on the right wing had melted when the aircraft had been parked in a light tail wind with the APU running," the report said.

The accident flight was conducted under U.S. Federal Aviation Regulations (FARs) Part 91 [*General Operating and Flight Rules*]. Part 91.527 states that takeoff is prohibited with "any frost adhering to the wings or stabilizing or control surface, unless that frost has been polished to make it smooth." Part 135 [*Commuter and On-demand Operations*] has a similar provision (Part 135.227).

"During the investigation, attempts were made to determine the definition of 'polished frost' and, indeed, how to polish frost," the report said. "Nothing was found, and the conclusion was that the explanation could have been lost in aviation history. …

The concept of 'polished frost' is particularly inappropriate and potentially dangerous to modern aircraft types and detracts from the importance of strictly observing the clean-wing principle."[4]

The report said that the clean-wing principle is espoused in the Challenger 604 flight manual, which states, "Takeoff must not be attempted if snow, ice or frost are present in any amount on the wings and tail surfaces of the airplane."

U.K. Civil Aviation Authority (CAA) Civil Aviation Publication 512 [*Ground De-icing of Aircraft*, 1 December 1985] includes the following information:

> Any deposits of ice, snow or frost on the external surfaces of an aircraft may drastically affect its performance. This can be due to reduced aerodynamic lift and increased aerodynamic drag resulting from the disturbed airflow over the aerofoil surfaces, or due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges and micro-switches, or by the ingestion of ice into the engine. Furthermore, since the in-flight de-icing system may not become effective until the aircraft is established in the climbout, the measures taken to remove frozen deposits on the ground must also be such as to provide adequate protection during the initial stages of flight.

The report said that the accident aircraft's ice-detection system was not designed to provide "an effective crew warning of pre-takeoff frost contamination of the wings and did not do so." The system comprises vibrating cylindrical probes on each side of the forward fuselage; when a vibration-frequency change equivalent to an ice thickness of about 0.02 inch (0.51 millimeter) occurs, the system generates a master-warning light, an aural warning (chime) and an "ICE" message on the engine-indicating and crew-alerting system (EICAS).

"It was unknown whether the thickness and coverage of the frost had been sufficient to trigger the aircraft ice-detector system," the report said. "Had this been the case, a flight deck warning should have occurred when N90AG was first electrically powered up. At this time, however, a very large number of transient start-up warnings would have been triggered, and an 'ICE' warning would not have stood out among the rest."

The Challenger has a "supercritical" wing design, which, compared with non-supercritical wing designs, has less camber, a larger leading-edge radius, less curvature of the upper surface and a concave section in the rear part of the lower surface. The wing has no leading-edge devices (e.g., slats).

"At cruise conditions, the profile maintains supersonic flow over a larger part of the upper, suction, surface of the aerofoil that is then decelerated toward the rear by a weak shock wave," the report said. "As well as improving aerodynamic efficiency, the design allows a thicker wing section for a given aircraft critical Mach number [at which airflow separation and buffeting can occur, and shock waves can form], providing a more efficient wing structure and additional wing-tank-fuel capacity compared to previous types of high-speed aerofoils."

The report said that a supercritical wing typically does not stall symmetrically; a high roll rate occurs, and aileron input is ineffective in controlling the roll until angle-of-attack (AOA) is reduced sufficiently to recover from the stall.

"The fuselage AOA at which N90AG began to roll to the left after liftoff was estimated from the FDR data as 7.8 degrees," the report said. "This was 5.3 degrees lower than the 13.1-degree fuselage AOA at which … an uncontaminated wing would stall."

The report said that "the relatively low level of roughness associated with frost contamination [reduced] the stall AOA to below those at which the stick-shaker, the stall warnings and/or the stick-pusher would activate."

Investigators found that components of one of the two AOA sensors that were part of the accident aircraft's stall-protection system (SPS) were worn and were not operating properly.

"The SPS fault did not contribute to the accident," the report said. "However, correct operation of the SPS system in many circumstances is clearly vital."

Based on the findings of the accident investigation, AAIB made the following recommendations:

- "[FAA] and all authorities who follow FAA practice [should] delete all reference to 'polished frost' within their regulations and ensure that the term is expunged from operations manuals;
- "Bombardier Aerospace [should] include the following specific limitation within appropriate aircraft manuals: 'Wings and tail surfaces must be completely clear of snow, ice and frost prior to takeoff';
- "The [U.K CAA should] require the following specific statement within the limitations section of the flight manuals of aircraft with a significant susceptibility to ice contamination: 'Wings and tail surfaces must be completely clear of snow, ice and frost prior to takeoff,' and communicate this recommendation to other civil airworthiness authorities responsible for the primary type certification of new aircraft types;
- "[FAA should] act upon [NTSB] Recommendations A-00-4, A-00-5 and A-00-6, and, in particular, review the guidance given to flight crew about the dangers of using nonprescription medication;
- "[FAA should] take measures to encourage action by the [FDA] in line with [NTSB] Recommendation I-00-5,

to ensure that over-the-counter medication contains appropriate warnings on any associated potential dangers in operating aircraft;

- "Bombardier Aerospace [should] reassess the fault tolerance of the [SPS] for the Challenger 604 and other aircraft models with a similar system and the measures aimed at verifying its integrity in service; [and,]

- "[FAA and the European Joint Aviation Authorities should] review the current procedural approach to the pre-takeoff detection and elimination of airframe ice contamination and consider requiring a system that would directly monitor aircraft aerodynamic surfaces for ice contamination and warn the crew of a potentially hazardous condition."♦

[FSF editorial note: This article, except where specifically noted, is based on U.K. Air Accidents Investigation Branch Aircraft Accident Report No. 5/2004 (EW/C2002/1/2). The 74-page report contains illustrations and appendixes.]

Notes

1. The U.S. National Transportation Safety Board (NTSB) said, in Aircraft Accident Brief NTSB/AAB-04/01, that the accident occurred at 1452 local time on Oct. 10, 2000, during an experimental test flight in Wichita, Kansas, U.S. The Challenger 604 was being used to test a modified pitch-feel simulator and was required to have an aft center of gravity (CG) for the test. The aircraft banked right on takeoff and struck terrain. The pilot and flight-test engineer were killed; the copilot received serious injuries and died 36 days after the accident. NTSB said that the probable cause of the accident was "the pilot's excessive takeoff rotation during an aft [CG] takeoff, a rearward migration of fuel during acceleration and takeoff and consequent shift in the airplane's aft CG to aft of the aft CG limit, which caused the airplane to stall at an altitude too low for recovery."

2. NTSB. Safety Recommendation A-00-4 through -6. Jan. 13, 2000. NTSB said that drug impairment was a cause or a factor in 72 fatal aircraft accidents between 1987 and 1995.

3. One point is a unit of type measurement equal to 1/72 inch (approximately 1/3 millimeter). This note is printed in 8.5-point type; the text of this article is printed in 10-point type.

4. U.S. Federal Aviation Administration Advisory Circular (AC) 20-117, *Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing*, published Dec. 17, 1982, discusses the "clean-aircraft concept." U.S. Federal Aviation Regulation Part 121.629 (governing air carrier operations) says, "No person may take off an aircraft when frost, ice or snow is adhering to the wings, control surfaces, propellers, engine inlets or other critical surfaces of the aircraft or when the takeoff would not be in compliance with [the operator's FAA-approved ground deicing/anti-icing program]." Part 121.629 provides for FAA-approved operating specifications allowing takeoffs with frost under the wing in the area of fuel tanks.

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