THRUST INTO

Tire debris disabled sensors, causing a Learjet 60 to accelerate during a high-speed rejected takeoff.

BY MARK LACAGNINA

The captain's decision to reject the takeoff after the airplane had accelerated beyond V_1 and electronic system damage that resulted in forward thrust being produced when reverse thrust was selected are among the issues discussed by the U.S. National Transportation Safety Board (NTSB) in its final report on the fatal crash of a Learjet 60 in Columbia, South Carolina, U.S., on Sept. 19, 2008.[1]

Based on findings that severely underinflated tires burst during the takeoff and shed debris into the wheel wells, damaging critical electronic sensors and hydraulic lines, the report also discusses the importance of, and

AN OVERRUN

The thrust reverser doors deployed, as shown here, but then were inadvertently stowed, and the engines produced nearly full forward thrust.

procedures for, maintaining proper tire inflation (see "Pressure Check," p. 30).

The accident occurred in visual meteorological conditions shortly before midnight during an attempted takeoff from Runway 11 at Columbia Metropolitan Airport. The Learjet, with six people aboard, overran the 8,601-ft (2,622-m) runway and the 1,000-ft (305-m) runway safety area (RSA) during the rejected takeoff (RTO). It then struck several objects before stopping against a roadside embankment. The airplane was destroyed by impact forces and an intense fire. Two passengers and the pilots were killed, and two passengers were seriously injured.

The report said that the probable causes of the accident were "the operator's inadequate maintenance of the airplane's tires, which resulted in multiple tire failures during [the] takeoff roll due to severe underinflation, and the captain's execution of an RTO after V_1, which was inconsistent with her training and standard operating procedures [SOPs]."

Moreover, the report said that contributing factors were "deficiencies in Learjet's design of and the Federal Aviation Administration's (FAA) certification of the Learjet Model 60's thrust reverser system, which permitted the failure of critical systems in the wheel well area to result in uncommanded forward thrust that increased the severity of the accident; the inadequacy of Learjet's safety analysis and the FAA's review of it, which failed to detect and correct the thrust reverser and wheel well design deficiencies after a 2001 uncommanded forward thrust accident; inadequate industry training standards for flight crews in tire failure scenarios; and the flight crew's poor crew resource management (CRM)."

The Learjet, which had accumulated 106 flight hours since its manufacture in 2006, was among nine airplanes operated by Global Exec Aviation, a charter-service provider and aircraft-management company based in Long Beach, California. The company employed 11 full-time pilots.

'Excellent References'

The captain, 31, was hired in January 2008. The company's director of operations told investigators that a simulator evaluation typically required for new hires was waived because of her excellent references. "Interviews with other pilots, a Learjet 60 proficiency-check evaluator and flight- and ground-training instructors who were familiar with the captain's flying and training in recent years revealed that none expressed any concerns about the captain's competence," the report said.

She had 3,140 flight hours, including 2,040 hours as pilot-in-command (PIC). She earned a Learjet 60 type rating in October 2007 and also held type ratings for the Cessna Citation 500 and Citation 650. She had 35 hours in the Learjet 60, with about eight hours as PIC. "In the 30 days before the accident, the captain had accumulated about 19 hours as second-in-command (SIC) in the Learjet 60 and about 15 hours as PIC in the Cessna CE-650," the report said.

The first officer, 52, was hired as a part-time pilot the month before the accident. He had about 8,200 flight hours, including about 7,500 hours as PIC. He had 300 hours in Learjet 60s, with 192 hours as PIC. He also held a Citation 500 type rating. The first officer was described by Global Exec Aviation's director of operations as "a well-experienced pilot with excellent piloting skills."

The pilots previously had flown together twice. Two days before the accident, they commuted on an airliner from Long Beach to Teterboro, New Jersey, where maintenance had been completed on a high-pressure bleed valve in the accident airplane. They conducted a 48-minute

Bombardier Learjet 60

Deliveries of the Learjet 60 midsize business jet began in 1993. Compared with its predecessor, the 55C, the 60 has more powerful engines, wing modifications to improve aerodynamic performance, upgraded avionics equipment, a longer fuselage and a larger baggage compartment.

The airplane can accommodate two pilots and eight passengers. The Pratt & Whitney Canada PW305A turbofan engines are flat-rated at 20.46 kN (4,600 lb) thrust. Maximum weights are 23,500 lb (10,660 kg) for takeoff and 19,500 lb (8,845 kg) for landing.

Balanced field length for takeoff is 5,450 ft (1,661 m). Maximum rate of climb at sea level is 4,500 fpm, or 1,240 fpm with one engine inoperative. Maximum operating speeds are 340 kt at Flight Level (FL) 200 (approximately 20,000 ft), 0.81 Mach at FL 370 and 0.78 Mach above FL 430. Maximum operating altitude is FL 510. Range with reserves is 2,493 nm (4,617 km).

The Learjet 60 remained in production until 2007, with 314 built before the model was replaced by the 60XR, which has a redesigned cabin, upgraded avionics and other improvements.

Sources: Bombardier Aerospace, *Jane's All the World's Aircraft*

test flight of the Learjet that day and departed from Teterboro the next day at 2142 local time for a positioning flight to Columbia, where they were to pick up the passengers for a charter flight to Van Nuys, California.

The pilots' mobile telephone records indicated that fatigue may have played a role in the accident, but this was not confirmed by investigators. The records showed that on the night before the accident, the captain "had the potential for 7.5 to 9.5 hours of sleep" and that the first officer "had the potential for 9.75 hours of sleep," the report said. Records for the next day indicated that there were few and relatively brief periods in which the pilots did not use their mobile telephones before leaving the hotel at 2018.

Lack of Focus

The Learjet arrived in Columbia at 2310. Surface winds were from 060 degrees at 10 kt, visibility was 10 mi (16 km), the sky was clear, and the ambient temperature was 21° C (70° F) when the passengers were boarded. Runway 05/23 was closed for construction.

The report pointed to several examples of ineffective CRM, including lack of accuracy about RTO criteria during the captain's preflight briefing, exchanges of incorrect and unchallenged information between the pilots, incorrect readbacks of air traffic control instructions and a wrong turn while taxiing. Neither pilot appeared to be "particularly focused," the report said. "The captain's casual tone and lack of leadership, and the flight crew's inattention to details foreshadowed elements of the crew's subsequent performance in responding to the [takeoff] anomaly."

The pilots apparently did not conduct weight-and-balance calculations. "Although postaccident estimates indicated that the airplane's maximum gross weight may have been exceeded by up to 300 lb [136 kg], there is no evidence that weight-and-balance issues contributed to the accident," the report said.

Among the airspeeds set for takeoff from Columbia were 136 kt for V_1 and 145 kt for rotation. The report said that the crew had been taught — and the company's SOPs specified — that "because of the high risk of runway overrun and other dangers, rejecting a takeoff at speeds greater than V_1 should be performed only when airplane control is seriously in doubt."

'Loud Rumbling Sound'

The captain, the pilot flying, began the takeoff at 2355. Less than two seconds after the first officer made the V_1 callout, the cockpit voice recorder (CVR) recorded a "loud rumbling sound," and the airplane veered right. The sound was attributed to fragments of the right

outboard tire, which failed first, striking the bottom of the airplane.

The first officer said, "Go." The captain, who had regained directional control after the swerve, said something unintelligible, and the first officer said, "Go, go, go."

Airspeed had reached a peak of 144 kt when the captain said, "Go?" She had reduced power briefly but then increased power for about one second before reducing it again.

"No?" the first officer said. "All right. Get, ah, what the [expletive] was that?"

"I don't know," the captain replied. "We're not going, though." She then said "full out," likely indicating deployment of the thrust reversers, and applied wheel braking.

'Startle Factor'

Investigators found no sign that the Learjet was not controllable. Attempting to explain why the captain did not follow her training and SOPs, the report said that she likely was startled by the airplane's swerve, the sound of the tire fragments striking the airplane and the vibration of the airframe caused by the burst tires.

The "startle factor" does not exist in simulated training scenarios but "in the real world … can increase the stress levels of the pilot, resulting in an incorrect decision being made," the report said. "Many other pilots have misinterpreted tire anomalies and responded by initiating an unnecessary RTO after V_1."

The thrust reverse malfunction caused the engines to produce high forward thrust, and the Learjet, which had been decelerating, began to accelerate.

The first officer radioed the airport traffic controller, saying, "Roll the equipment. We're going off the end." The CVR recording ended less than four seconds later — 41 seconds after the takeoff was initiated.

The report said that after overrunning the RSA, the Learjet "struck airport lighting and navigation antennas, and descended a steep downhill slope before striking a lighting pole and the perimeter fence. The airplane then struck a concrete highway marker post, crossed a five-lane road and struck a second concrete post and an embankment on the far side of the road."

The controller told investigators that the airplane "exploded into a fireball" after coming to a stop.

The survivors, who were in the aft seats, escaped through the emergency exit in the lavatory, which is in the rear of the cabin. Both men sustained second- and third-degree burns.

Diphenhydramine, an allergy remedy and sleep aid, was detected in samples from the bodies of both pilots. The report said, however, that there was insufficient evidence to determine if the use of this drug — or

The thrust reverse levers are hinged to, and atop, the thrust levers.

possibly fatigue — had impaired their performance.

Sensors Disabled

The report said that the tires had burst during the takeoff because of sidewall overdeflection and that tire fragments thrown into the wheel wells had struck and disabled components of the thrust reverser system, as well as hydraulic lines.

The Learjet 60's engines and thrust reverser system are controlled electronically, with no "mechanical or cable-actuated connection between the cockpit thrust levers and the engines," the report said. To select reverse thrust, the pilot moves the thrust levers to the idle stops and then lifts and pulls the thrust reverse levers, which are hinged to, and atop, the thrust levers.

Microswitches detect which levers the pilot is using. When the thrust reverse levers are lifted, electronic signals command the thrust reverser doors to deploy. The two half-shell doors, which form the top and bottom of the aft portions of the engine nacelles when stowed, move aft and join together to form barriers that redirect the engine fan airflow and exhaust gases forward, thus producing "reverse thrust."

Among safeguards against inadvertent deployment of the thrust reversers during flight are squat switches on each main landing gear assembly. When the gear is extended and the assemblies are compressed to support the airplane's weight, the squat switches signal the electronic engine control (EEC) system that the airplane is in "ground mode," allowing the thrust reversers to deploy.

The deceleration that occurred after the captain called "full out" indicates that the thrust reversers initially operated normally. However, the CVR then recorded the nosewheel steering disconnect warning tone, an indication that the mode status had changed from ground to air.

The investigation determined that one or both squat switches had been disabled during the accident sequence. "Debris found on the runway and other physical evidence show that the MLG [main landing gear] area where system components were mounted sustained damage from the shedding tire fragments," the report said.

The false air mode indication caused the thrust reversers to stow and triggered an EEC logic shift and a change from the reverse-thrust power schedule to the forward-thrust power schedule. The engines began to produce forward thrust at near takeoff power when the Learjet was about 2,500 ft (762 m) from the end of the runway. Reducing thrust would have required moving the thrust reverse levers to the stowed position — an action that is counterintuitive during an RTO, the report said.

Airspeed was more than 100 kt when the airplane overran the RSA. Because wheel braking effectiveness was compromised by the burst tires and by hydraulic system damage, "it was not possible to determine whether or not the flight crew could have safely stopped the airplane on the runway (or within the RSA) had the airplane not developed the uncommanded forward thrust," the report said.

Design Change Needed

The Columbia accident was similar to an accident that occurred on Jan. 14, 2001, when a Learjet 60 struck two deer shortly after touchdown at Troy (Alabama, U.S.) Municipal Airport.[2] The investigation revealed that deer fur lodged in a squat switch, rendering it inoperative. The thrust reversers stowed, and the EEC switched to a forward-thrust schedule. Despite heavy wheel braking, the airplane overran the 5,010-ft (1,527-m) runway. Both pilots were seriously injured.

The airplane manufacturer introduced an emergency procedure for inadvertent thrust reverser stowage after the 2001 accident, but the FAA did not require modification of the system design to prevent uncommanded production of forward thrust during an RTO.

A redesign of the thrust reverser system and training Learjet 60 pilots to recognize inadvertent thrust reverser stowage were among several recommendations generated by the Columbia accident investigation (*ASW*, 8/09, p. 10). The FAA has responded in part by publishing Safety Alert for Operators 09017, which outlines best practices for recognizing and responding to cockpit indications of inadvertent or uncommanded thrust reverser stowage during an RTO or a landing in a Learjet 60 or 60XR.

This article is based on NTSB Accident Report AAR-10/02: "Runway Overrun During Rejected Takeoff; Global Exec Aviation; Bombardier Learjet 60, N999LJ; Columbia, South Carolina; September 19, 2008." The full report is available at <ntsb.gov/Publictn/A_Acc1.htm>.

Notes

1. U.S. Federal Aviation Regulations Part 1.2 defines V_1 as follows: "V_1 means the maximum speed in the takeoff at which the pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes) to stop the airplane within the accelerate-stop distance. V_1 also means the minimum speed in the takeoff, following a failure of the critical engine at V_{EF}, at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance." (V_{EF} is "the speed at which the critical engine is assumed to fail during takeoff.")
2. NTSB Accident Report ATL01FA021.