# Runway Overrun During Rejected Takeoff
# Global Exec Aviation
# Bombardier Learjet 60, N999LJ
# Columbia, South Carolina
# September 19, 2008


## Accident Report

NTSB/AAR-10/02
PB2010-910402

**National Transportation Safety Board**

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National
Transportation
Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

**National Transportation Safety Board. 2010.** ***Runway Overrun During Rejected Takeoff, Global Exec Aviation, Bombardier Learjet 60, N999LJ, Columbia, South Carolina, September 19, 2008.*** **Aircraft Accident Report NTSB/AAR-10/02. Washington, DC.**

**Abstract:** This report describes the September 19, 2008, accident involving a Bombardier Learjet Model 60 (Learjet 60), N999LJ, which overran runway 11 during a rejected takeoff at Columbia Metropolitan Airport, Columbia, South Carolina, while operating as a 14 *Code of Federal Regulations* Part 135 unscheduled passenger flight. The captain, the first officer, and two passengers were killed; two other passengers were seriously injured.

The safety issues discussed in this report include the criticality of proper aircraft tire inflation; maintenance requirements and manual revisions for tire pressure check intervals; tire pressure monitoring systems; airplane thrust reverser system design deficiencies; inadequate system safety analyses by the Federal Aviation Administration (FAA) and Learjet; inadequate level of safety in the certification of changed aeronautical products; flight crew training for tire failure events; flight crew performance, including the captain's action to initiate an rejected takeoff after $V_1$, the captain's experience, and crew resource management techniques; and considerations for tire certification criteria. Safety recommendations concerning these issues are addressed to the FAA.

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# Acronyms and Abbreviations

| | |
|---|---|
| **AC** | advisory circular |
| **AFM** | airplane flight manual |
| **AMM** | aircraft maintenance manual |
| **ARFF** | aircraft rescue and firefighting |
| **ARP** | aerospace recommended practice |
| **ASRS** | Aviation Safety Reporting System |
| **ATIS** | automatic terminal information service |
| **ATP** | airline transport pilot |
| **AW** | advisory wire |
| **CAE** | Columbia Metropolitan Airport |
| **CAM** | cockpit area microphone |
| **CFR** | *Code of Federal Regulations* |
| **CRM** | crew resource management |
| **CSN** | cycles since new |
| **CVR** | cockpit voice recorder |
| **DER** | designated engineering representative |
| **EEC** | electronic engine control |
| **EUROCAE** | European Organization for Civil Aviation Equipment |
| **FAA** | Federal Aviation Administration |

| | |
|---|---|
| **FADEC** | full authority digital electronic control |
| **FBO** | fixed-base operator |
| **FDR** | flight data recorder |
| **FR** | *Federal Register* |
| **FSI** | FlightSafety International |
| **KIAS** | knots indicated airspeed |
| **kts** | knots |
| **MLG** | main landing gear |
| **msl** | mean sea level |
| **$N_1$** | engine fan speed |
| **NPRM** | notice of proposed rulemaking |
| **NTSB** | National Transportation Safety Board |
| **P/N** | part number |
| **PIC** | pilot-in-command |
| **POI** | principal operations inspector |
| **psi** | pounds per square inch |
| **QRH** | quick reference handbook |
| **QTR** | qualification test report |
| **RSA** | runway safety area |
| **RTO** | rejected takeoff |

| | |
|---|---|
| **RVDT** | rotary variable differential transformer |
| **S/N** | serial number |
| **SAFO** | safety alert for operators |
| **SB** | service bulletin |
| **SIC** | second-in-command |
| **SIR** | special investigation report |
| **SMS** | safety management system |
| **TC** | type certificate |
| **TCDS** | type certificate data sheet |
| **TEB** | Teterboro Airport |
| **TFM** | temporary flight manual |
| **TLA** | thrust lever angle |
| **TPMS** | tire pressure monitoring system |
| **TR** | temporary revision |
| **TSO** | technical standard order |
| **$V_1$** | takeoff decision speed |
| **$V_2$** | takeoff safety speed |
| **$V_r$** | rotation speed |
| **VOR** | very high frequency omnidirectional radio range |

# Executive Summary

On September 19, 2008, about 2353 eastern daylight time, a Bombardier Learjet Model 60, N999LJ, owned by Inter Travel and Services, Inc., and operated by Global Exec Aviation, overran runway 11 during a rejected takeoff at Columbia Metropolitan Airport, Columbia, South Carolina. The captain, the first officer, and two passengers were killed; two other passengers were seriously injured. The nonscheduled domestic passenger flight to Van Nuys, California, was operated under 14 *Code of Federal Regulations* Part 135. Visual meteorological conditions prevailed, and an instrument flight rules flight plan was filed.

The National Transportation Safety Board determines that the probable cause of this accident was the operator's inadequate maintenance of the airplane's tires, which resulted in multiple tire failures during takeoff roll due to severe underinflation, and the captain's execution of a rejected takeoff (RTO) after $V_1$, which was inconsistent with her training and standard operating procedures.

Contributing to the accident were (1) 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; (2) 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; (3) inadequate industry training standards for flight crews in tire failure scenarios; and (4) the flight crew's poor crew resource management (CRM).

The safety issues discussed in this report focus on criticality of proper aircraft tire inflation; maintenance requirements and manual revisions for tire pressure check intervals; tire pressure monitoring systems; airplane thrust reverser system design deficiencies; inadequate system safety analyses by the FAA and Learjet; inadequate level of safety in the certification of changed aeronautical products; flight crew training for tire failure events; flight crew performance, including the captain's action to initiate an RTO after $V_1$, the captain's experience, and CRM; and considerations for tire certification criteria. Safety recommendations concerning these issues are addressed to the FAA.

# 1. Factual Information

## 1.1 History of Flight

On September 19, 2008, about 2353 eastern daylight time,[1] a Bombardier Learjet Model 60 (Learjet 60),[2] N999LJ, owned by Inter Travel and Services, Inc., and operated by Global Exec Aviation, overran runway 11 during a rejected takeoff (RTO)[3] at Columbia Metropolitan Airport (CAE), Columbia, South Carolina. The captain, the first officer, and two passengers were killed; two other passengers were seriously injured. The nonscheduled domestic passenger flight to Van Nuys, California, was operated under 14 *Code of Federal Regulations* (CFR) Part 135. Visual meteorological conditions prevailed, and an instrument flight rules flight plan was filed.

Review of the cockpit voice recorder (CVR) transcript revealed that the flight crew received clearance instructions from the CAE ground controller at 2347:04 to taxi from the northeast fixed-base operator's (FBO) parking ramp to runway 11. After a short discussion with the first officer about which way to turn,[4] the captain, who was the pilot flying, turned the airplane left onto taxiway U. The controller provided an amended taxi clearance after noticing that the airplane had turned the wrong way.[5] The flight crew followed the amended taxi clearance, which involved back-taxiing the airplane on runway 11 and performing a 180° turn on the runway to position the airplane for takeoff.

At 2351:22, the captain briefed the RTO procedure and stated, "we've got plenty of runway so we'll abort for anything below eighty knots [kts] after V-one and before V-two[6] engine failure fire malfunction loss of directional control all the big things after V-two we'll go

[1] All times in this report are eastern daylight time unless otherwise noted and based on a 24-hour clock.

[2] Learjet engineering and certification documents refer to the airplane as Learjet Model 60 or L60. For brevity and consistency, this report refers to the Learjet Model 60 as "Learjet 60."

[3] An RTO may also be referred to as an aborted takeoff in some publications.

[4] The clearance was to taxi via taxiway U and cross the approach end of runway 23 to taxiway N, then taxiway A. The first officer replied to the controller, "okay Uniform November Alpha ah to one one." The captain stated to the first officer, "and hold short of two two I think it was," and the first officer replied, "I think he said…we could cross it." The captain stated, "oh did he?" and then asked, "and we're going right outta here, correct?" The first officer replied, "ah well I think we have to go left outta here don't we?"

[5] The controller stated that construction at the airport made it confusing for pilots to taxi. He indicated that the accident flight crew's initial taxi clearance would have required the crew to turn the airplane away from the takeoff runway, which the controller stated went "against normal."

[6] According to 14 CFR 1.2, $V_1$ is the maximum speed in the takeoff at which the pilot must take the first action (such as applying brakes, reducing thrust, or deploying speed brakes) to stop the airplane within the accelerate-stop distance, which is a calculated distance defined in 14 CFR 25.109. $V_1$ is also the minimum speed in the takeoff at which, after a failure of an airplane's critical engine, the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance. According to 14 CFR 25.107, $V_2$ is the takeoff safety speed that must provide at least a minimum specified climb gradient in the event of a loss of power in one engine.

ahead and take it into the air treat it as an in-flight emergency."[7] The first officer replied, "correct." The captain asked if the first officer had any questions, and the first officer asked, "reference the ah between eighty and ah V-one you're only ah aborting for the fire failure loss of directional control?" The captain replied, "yes," then added, "or an inadvertent thrust-, ah, T-R [thrust reverser] deployment." The first officer then stated, "that will ah cause the loss of directional control I guess," to which the captain replied, "exactly hah they go together." The first officer later stated, "well eh if the runway is long I abort but if it's short I kinda do different briefing depending on what the length of the runway is but we're pretty heavy so it's probably not a bad idea." The CVR transcript indicated that the flight crew continued performing pretakeoff checklist items and that the captain requested wind information.[8]

The captain initiated the takeoff roll, and, at 2355:00.1,[9] the first officer stated, "eighty knots. Crosscheck," to which the captain replied, "check." At 2355:10.5, the first officer reported, "V-one." About 1.5 seconds later, the CVR captured the beginning of a loud rumbling sound. Postaccident sound spectrum and airplane performance studies[10] indicated that the airplane's position on the runway at the onset of the loud rumbling sound corresponded with the location where the first main landing gear (MLG) tire fragments were found. Four-tenths second after the beginning of the loud rumbling sound, the first officer stated, "go," the captain stated something unintelligible, and, at 2355:13.0, the first officer stated, "go go go." The CVR recorded a sound similar to a metallic click, and, at 2355:14.0, the captain stated, "go?" Postaccident sound spectrum and airplane performance studies estimated that, about this time, the airplane's ground speed reached a peak of about 144 kts. The first officer then stated, "no? ar- alright. Get ah what the [expletive] was that?" The CVR recorded another metallic click sound, and, at 2355:17.0, the captain stated, "I don't know. We're not goin' though."

At 2355:18.4, another metallic click sound was recorded, and, at 2355:19.5, the captain stated, "full out." Postaccident performance studies indicated that the airplane was decelerating. Within 1 second, the CVR captured a sound consistent with the application of wheel braking, and, at 2355:21.6, the CVR captured a sound consistent with the nosewheel steering disconnect warning tone. Postaccident performance studies indicated that the airplane had then accelerated. About 7 seconds later, the first officer stated, "shut 'em off," and, at 2355:32.4, the first officer stated, "they're shut off they're shut off." At 2355:36.0, the first officer made a radio transmission on the CAE tower control frequency, saying, "roll the equipment we're goin' off the end." The CVR recording ended at 2355:41.1.

A controller in the CAE tower who observed the airplane's takeoff roll reported that the beginning of the takeoff roll appeared normal but that, when the airplane was part way down the runway, sparks appeared that seemed to be coming from the airplane's right MLG. One of the

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[7] The captain's briefing of the RTO criteria was inconsistent with Global Exec Aviation's training manual, which is discussed in section 1.17.2.1.

[8] At 2354:27, the captain asked the first officer to request a wind check from the controller. The controller stated, "wind zero seven zero at eight gust one four." The captain asked the first officer, "zero one zero at eight?" The first officer replied, "ah huh." The captain then stated, "'kay so pretty much straight down." Runway 11 has a magnetic heading of 110°.

[9] Times related to the takeoff sequence are reported to tenths of 1 second because of the speed at which events occurred.

[10] For further information, see sections 1.16.1 and 1.16.2.

two surviving passengers stated that, during the takeoff roll, the airplane was shifting and swaying back and forth all the way down the runway and that the airplane felt "out of control" from the start. The other surviving passenger reported that the airplane felt as if it blew a tire and that the airplane leaned to the right "almost like a wing had touched the ground."

The controller observed that the airplane went straight off the end of the runway. The airplane passed through the 1,000-foot runway safety area (RSA), 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 stated that, when the airplane struck the hill, the airplane stopped and exploded into a fireball. Both passengers stated that the nose of the airplane went up and down at least twice before final impact. Debris from all four MLG tires was found on the runway.

## 1.2 Injuries to Persons

**Table.** Injury Chart

| Injuries | Flight Crew | Cabin Crew | Passengers | Other | Total |
|---|---|---|---|---|---|
| Fatal | 2 | 0 | 2 | 0 | 4 |
| Serious | 0 | 0 | 2 | 0 | 2 |
| Minor | 0 | 0 | 0 | 0 | 0 |
| None | 0 | 0 | 0 | 0 | 0 |
| Total | 2 | 0 | 4 | 0 | 6 |

## 1.3 Damage to Airplane

The airplane was destroyed by impact forces and the postcrash fire.

## 1.4 Other Damage

Damage to airport property included some of the runway approach lighting, a localizer antenna array, and the airport perimeter fence. Concrete roadway right-of-way markers and a five-lane asphalt road were also damaged.

## 1.5 Personnel Information

The captain was hired by Global Exec Aviation on January 4, 2008, and the first officer was hired on August 8, 2008. According to Global Exec Aviation's director of operations, the accident flight was the crewmembers' second flight of the day, and they had previously flown together twice.

### 1.5.1 Captain

The captain, age 31, held an airline transport pilot (ATP) certificate for multiengine land airplanes with type ratings for Cessna CE-500 (issued on June 18, 2005), Learjet 60 (issued on October 25, 2007), and Cessna CE-650 (issued on January 19, 2008) airplanes.[11] She held a first-class airman medical certificate issued April 29, 2008, with the limitation, "holder shall wear corrective lenses."

According to Global Exec Aviation employment records, the captain had accumulated about 3,140 hours total flight time, including about 2,040 hours pilot-in-command (PIC) time. She had accumulated about 35 hours in the Learjet 60 (about 8 hours of which were as PIC) and about 118 hours in the Cessna CE-650 (which were accumulated at Global Exec Aviation). Before the 2-day trip pairing that included the accident flight, the captain's most recent experience as PIC of a Learjet 60 was on August 16, 2008. 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. In the 90 days, 30 days, and 24 hours preceding the accident, the captain had logged about 67, 36, and 1.5 hours, respectively.

The captain completed Global Exec Aviation's initial new-hire training on January 4, 2008. Global Exec Aviation's director of operations stated that the captain came to the company with excellent references and had flown with and been recommended by a previous Federal Aviation Administration (FAA) principal operations inspector (POI) for the company. The director of operations stated that, because of the captain's references, the company did not give the captain a checkride in a simulator, even though the company typically gave a checkride to other potential new hires.

The captain's most recent recurrent simulator training was completed at a FlightSafety International (FSI) training facility on August 13, 2008, and her most recent recurrent ground training was completed on August 16, 2008. The captain's most recent line check was completed on May 6, 2008, and her most recent Learjet 60 proficiency check was completed on August 14, 2008. The evaluator who conducted the Learjet 60 proficiency check stated that the captain performed "very much" within standards and that the outcome of the checkride was never in doubt. He stated that the captain displayed good crew resource management (CRM) skills and had good command of the airplane.

Another Learjet 60 instructor who provided recurrent ground and simulator training to the captain at FSI described her as meticulous with good organizational skills. He recalled that, during training, the captain told him that she had not been in the Learjet 60 for some time; he stated that her first day of simulator training was a little rough during basic air work but that, by the end of that session, the captain was doing well. The instructor reported that the captain's second and third day of training went very well. He stated that his notes for the second day indicated "excellent CRM" and that he does not give that rating to many people. He stated that

[11] She also held second-in-command privileges for Cessna CE-560XL airplanes; a flight instructor certificate for instrument, single-engine, and multiengine land airplanes; commercial privileges for single-engine land airplanes; private privileges for single-engine seaplanes; and an aircraft dispatcher certificate.

the training included such abnormal scenarios as $V_1$ cuts and RTOs with an engine failure or a thrust reverser unlock.

Global Exec Aviation's director of operations, who had trained with the captain and had flown about 30 hours with her, described the captain as "laid back," which he considered "typical of a less experienced captain." He described her decision-making skills as excellent and conservative. He stated that he would work with her on being more vocal in her command authority but that she was "above normal" for a new captain.

A review of FAA records found no previous accidents, incidents, or enforcement actions. FAA records indicated that the captain received a notice of disapproval on August 11, 2006, for a practical test for the ATP certificate because of unsatisfactory performance in the nonprecision approach and circle-to-land procedures. She retested the same day and passed. On April 11, 1997, when the captain was a private pilot with about 192 total flight hours, she received a notice of disapproval for the practical test for the airplane instrument rating because of unsatisfactory performance of partial-panel very high frequency omnidirectional radio range (VOR) instrument approach procedures and instrument landing system instrument approach procedures. She was retested on April 14, 1997, and received a second notice of disapproval because of unsatisfactory performance of partial-panel VOR instrument approach procedures. She was retested on May 28, 1997, and passed. On November 14, 1997, when the captain had accrued about 252 total flight hours, she received a notice of disapproval for a practical test for the commercial airplane multiengine land certificate because of unsatisfactory knowledge of the national airspace system and airplane performance and limitations. (She subsequently passed the checkride for private pilot privileges for multiengine land airplanes on December 6, 1997, and she passed the checkride for the commercial certificate for multiengine land airplanes on September 1, 2004.[12])

### 1.5.2 First Officer

The first officer, age 52, held an ATP certificate for multiengine land airplanes with type ratings for Learjet 60 (issued on March 1, 2007) and Cessna CE-500 airplanes.[13] He held a first-class airman medical certificate issued July 18, 2008, with the limitations "must wear corrective lenses" and "possess glasses for near/intermediate vision." According to employment records from Global Exec Aviation and estimates from another employer[14] and a previous employer, the first officer had accumulated about 8,200 hours total flight time, including about 7,500 hours PIC time and about 300 hours in Learjet 60 airplanes (about 108 hours of which were as SIC). In the 90 days, 30 days, and 24 hours preceding the accident, the first officer logged about 42, 34, and 1.5 hours, respectively.

[12] According to the captain's résumé, in 1997, she was attending college and was not working in an aviation field that would require a commercial multiengine certificate. She subsequently gained flight experience and worked as a flight instructor in the years before her successful retest in 2004.

[13] He also held commercial privileges for single-engine land airplanes, rotorcraft/helicopters, and instrument helicopters.

[14] The first officer also began flying for another operator in August 2008. Global Exec Aviation's director of operations stated that he thought that the first officer had accepted a full-time position with another operator but that he was unsure of which one.

The first officer completed Global Exec Aviation's initial new-hire training on August 8, 2008. His previous employer, also a Part 135 operator, provided him with Learjet 60 flight training and his most recent Learjet 60 proficiency check, which was completed on March 13, 2008.[15] Global Exec Aviation's director of operations stated that the first officer was hired as a part-time pilot. A review of FAA records found no previous accidents, incidents, enforcement actions, or notices of disapproval.

Global Exec Aviation's director of operations had flown about 5 hours with the first officer and described him as a well-experienced pilot with excellent piloting skills. He stated that the first officer had good CRM skills and had no problem speaking up but that he was not overly assertive.

### 1.5.3 Flight Crew's 72-Hour History

Review of airline travel, cellular telephone, hotel, and company records provided information about the captain's and the first officer's nonwork activities during the 72 hours before the accident. These records revealed that, on Wednesday, September 17, 2008, both the captain and the first officer were passengers aboard a commercial flight that departed Long Beach, California, about 1238 Pacific daylight time en route to New York. They checked into hotel rooms in Secaucus, New Jersey, about 2200, and each requested hotel wake-up calls for about 0800 the next morning. Based on their respective telephone records, the captain had the potential for 6 hours of sleep, and the first officer had the potential for 7 hours of sleep, that night. The first officer's wife, who had communicated with him via telephone and text messaging, recalled that he had told her that noise at the hotel made it difficult to sleep.

On Thursday, September 18, 2008, both pilots left the hotel about 1000, taking the hotel shuttle to Teterboro Airport (TEB), Teterboro, New Jersey, where the accident airplane was parked. About 1200, they conducted a 48-minute test flight in the accident airplane to ensure that maintenance on a high-pressure bleed valve was effective.[16] About 1400, both the captain and the first officer checked into their rooms at a different hotel in Secaucus and were off duty until the next day. Based on their respective cellular telephone records, the captain had the potential for 7.5 to 9.5 hours of sleep, and the first officer had the potential for 9.75 hours of sleep, during the night before the accident.

On Friday, September 19, 2008 (the day of the accident), telephone activity for the captain showed numerous telephone calls and text messages, leaving three 1-hour uninterrupted periods. Telephone activity for the first officer indicated that he had one 1-hour and one 2-hour periods of uninterrupted time. Both the captain and the first officer checked out of the hotel about 2018 and traveled to TEB. They departed TEB in the accident airplane about 2142 and arrived at the Columbia Aviation ramp at CAE about 2310 to pick up the passengers.

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[15] Global Exec Aviation and the FAA accepted the training performed under his previous employer because both companies used the same training program and facility. The FAA can accept such training instead of training provided by the current employer if the FAA determines that the previous training was sufficient.

[16] The accident airplane had been at TEB since September 12, 2008, for maintenance after the valve became stuck in the open position during a flight.

## 1.6 Airplane Information

The accident airplane was powered by two Pratt & Whitney Canada PW305A high-bypass turbofan engines, each of which was rated at a maximum 4,600 pounds of thrust with a maximum nontransient forward engine fan speed ($N_1$) of 10,820 rpm, or 102 percent. The airplane's initial airworthiness certificate was dated December 14, 2006, and the airplane was configured with a seating capacity for two crewmembers and eight passengers. The accident airplane's empty weight was 14,755 pounds, its maximum ramp weight was 23,750 pounds, and its maximum takeoff weight was 23,500 pounds. According to performance calculations provided by Bombardier Learjet, given the accident flight conditions, $V_1$ would have been 136 kts indicated airspeed (KIAS),[17] $V_r$ (rotation speed) would have been 145 KIAS, and $V_2$ would have been 153 KIAS.

According to logbook information dated September 16, 2008, the airplane had accumulated 106 hours and 121 cycles since new (CSN). At the time of the accident, the airplane had accumulated an estimated 108.5 hours and 123 CSN.

### 1.6.1 Main Landing Gear Tires

The airplane was equipped with dual wheel and tire assemblies at each MLG position. Each MLG tire was a Goodyear Flight Eagle, part number (P/N) 178K43-1, size 17.5 x 5.75-8.[18] For use on the Learjet 60, the rated tire inflation pressure[19] was 220 pounds per square inch (psi). Applicable tire certification requirements are specified in 14 CFR 25.733 and FAA Technical Standard Order (TSO) TSO-C62c.[20] TSO-C62c specified various tire performance criteria, one of which was a maximum allowable air pressure loss of 5 percent per day for an airplane tire under normal operating circumstances. According to the Goodyear Qualification Test Report (QTR) 461B-3044-TL, the Goodyear Flight Eagle tire documented a daily pressure loss of about 2.2 percent.

Maintenance logs indicated that all four MLG tires were new when installed in December 2007 and had accumulated a total of 20 landings at the time of the accident. Flight history records showed that the airplane had flown 5 days during the 12-day period that preceded the accident. Interviews with personnel from all facilities that handled the accident airplane during that time period revealed that none had serviced or received a request to service the MLG tires. Global Exec Aviation's director of maintenance estimated that the tire pressures may not have been checked for about 3 weeks before the accident.

[17] KIAS refers to the airplane's speed as shown on the airspeed indicator.

[18] For the purpose of this report, "Goodyear Flight Eagle tire" refers to tire P/N 178K43-1, size 17.5 x 5.75-8, as specified for the Learjet 60.

[19] Rated pressure is the maximum inflation pressure to match the tire's load rating. Aircraft tire pressures are given for an unloaded tire; when the rated load is applied to the tire, the pressure increases by 4 percent as a result of a reduction in air volume. According to Learjet data, the allowable MLG tire pressure range for the Learjet 60 (based on its maximum takeoff weight of 23,500 pounds) would be 209 to 219 pounds per square inch gauge (gauge pressure).

[20] TSO-C62c was in effect at the time of certification; the current version is TSO-C62e, issued on September 29, 2006.

The Learjet 60 Aircraft Maintenance Manual (AMM) contained the minimum maintenance requirements for continued airworthiness in accordance with applicable regulations. Chapter 5 of the AMM, the contents of which related to the intervals for scheduled inspections, stated that the Learjet inspection program "also contains other inspections and individual stand-alone inspection checks, which must be accomplished at the specified intervals." Chapter 5 referenced tire pressure inspections under "Inspection Phase A5." The A5 inspection, which is due at 300-hour intervals, included Inspection Reference Number P1210055, which stated, "Nose and Main Tires – Check for proper inflation. (Refer to [chapter] 12-10-05)."

The contents of chapter 12 of the AMM related to technical specifications and descriptions of how to perform various maintenance tasks. Chapter 12-10-05, pages 301 and 302, contained the following guidance:

> Important inflation practices and tips are as follows: … Measure the cold tire pressure before the first flight of every day or every 10 day[s] on in-service tires [that] are not in use.… Do not underinflate the tire. An underinflated tire generally cannot be detected visually.

The AMM indicated that a tire should be replaced if found to have operated at an inflation pressure loss of 15 percent.

Other guidance calling for daily or regular checks of tire pressure was contained in a Learjet maintenance publication, *Aircraft Tire Care and Maintenance*, dated September 2001; a Learjet product support publication, *Everyday Maintenance of Tires and Brakes*, dated April 10, 2007; FAA Advisory Circular (AC) AC 20-97B, *Aircraft Tire Maintenance and Operational Practices*; and several Goodyear publications, including Goodyear Information Report 97001, *Learjet Tire Maintenance*, dated January 9, 1997, and an operator letter dated March 1999 referring to the availability of Goodyear's *Comprehensive Guide to Aircraft Tire Care and Maintenance*.

As shown in figure 1 below, to check tire pressures on the Learjet 60, the person performing the check must crouch or crawl under the wing of the airplane to gain access to the MLG tire pressure valves. The landing gear doors may conceal the valves for the outboard tires, requiring a person to lie on the ground to gain access.

**Figure 1.** Learjet factory technician checking inboard tire pressure (left image) and outboard tire pressure (right image).

### 1.6.2 Engine Power Control and Thrust Reverser System Control

The Learjet 60's control levers for commanding engine power for forward thrust are located on the cockpit pedestal. The level of engine power (measured as $N_1$) commanded by the pilot's positioning of the thrust levers for forward thrust is communicated electronically to the engine control components mounted on each engine. The Learjet 60 has no mechanical or cable-actuated connection between the cockpit thrust levers and the engines.

**Figure 2.** Captain's side view of Learjet 60 thrust levers (at idle) and thrust reverser (piggyback) levers. To illustrate lever movement, one thrust reverser lever is in the stowed position, and the other is lifted to command reverse thrust (arrow shows direction lever moves when lifted from the stowed position).

The airplane's thrust reverser system, which is designed to help stop the airplane on the ground, is also electronically controlled. The thrust reverser system responds to the pilot's positioning of the thrust reverser levers (also known as "piggyback" levers because they are located on top of the thrust levers) by using electronic signals to command reverse thrust functions. See figure 2 (at right) for the captain's side view of Learjet 60 thrust levers and thrust reverser levers.

The Learjet 60's thrust reversers are designed with two half-shell doors on each engine that form the engine's aft nacelle when stowed (forward thrust configuration). When deployed (reverse thrust configuration), the thrust reverser doors redirect the flow of engine fan air and exhaust gases forward to provide a deceleration force to assist with ground braking. (See figure 3 below, which depicts a Learjet 60 with thrust reversers deployed.) Although the use of reverse thrust can reduce the distance needed to stop the airplane, most of the stopping power is provided by the wheel brakes.[21]

Both the thrust levers and the thrust reverser (piggyback) levers share some common mechanical components in the cockpit pedestal that move whenever a pilot manipulates either the thrust levers or the thrust reverser levers. The shared components depend on microswitches to detect which levers the pilot is using for commanding either forward or reverse thrust. (The following two sections describe the shared components and the basic system functions for forward and reverse thrust during normal operations; section 1.6.2.3 describes the fail-safe logic criteria and system responses to detected anomalies.)

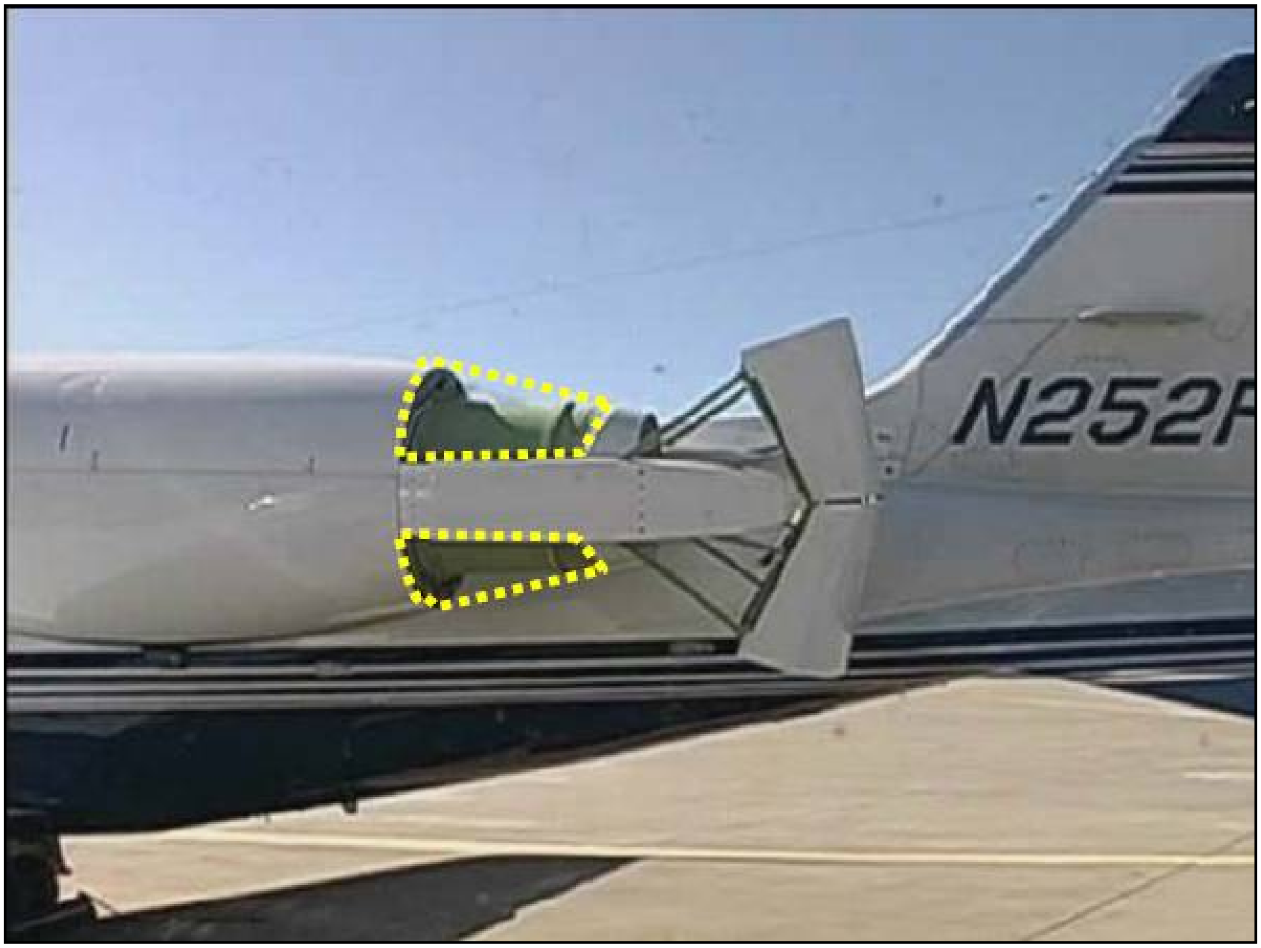


**Figure 3.** Learjet 60 with thrust reversers deployed. The dotted yellow lines show the stowed position for the doors.

[21] The FAA's master minimum equipment list for the Learjet 60 (upon which operators' minimum equipment lists are based) allows an operator to fly the airplane with inoperative thrust reversers for up to 10 days, during which time a maintenance lockout pin is installed in the reversers to prevent use.

### 1.6.2.1 Commanding Forward Thrust

To command forward thrust, a pilot positions the cockpit thrust levers (one per engine) to a desired engine power setting (such as takeoff, maximum continuous thrust, or cruise power). As the pilot moves the thrust levers, a mechanical linkage on each thrust lever rotates the input shaft on a rotary variable differential transformer (RVDT) in the cockpit pedestal for each lever. As the RVDTs' input shafts rotate, each RVDT electronically provides information about the changing thrust lever angle (TLA) to the electronic engine control (EEC) computer for the corresponding engine. The EECs interpret the TLA information and provide corresponding electronic signals to each engine's full authority digital electronic control (FADEC) components.[22] Based on the signals received from the EECs, the FADEC components, which perform functions including thrust management and compressor surge control, regulate engine output to provide the level of engine power commanded by the pilot. In the case in which the EECs provide the logic signals that forward thrust has been commanded, the FADEC components regulate engine power according to the forward thrust power schedule.

### 1.6.2.2 Commanding Reverse Thrust

To command reverse thrust, a pilot positions the engine power levers to idle power, then lifts the thrust reverser (piggyback) levers to the deploy position. When the thrust reverser levers are lifted to the deploy position, a mechanical linkage on each lever (the same linkage used by each thrust lever when forward thrust is commanded) rotates the input shaft on each respective RVDT; microswitches (one for each thrust reverser lever) detect that the reverser levers are lifted and send an electronic request for the thrust reversers to deploy.

While the thrust reverser doors on both engines begin to move from stowed toward the deployed position, balk solenoids in the throttle quadrant (one for each lever) momentarily prevent the pilot from moving the thrust reverser levers further until the thrust reversers fully deploy. Once the doors are fully deployed, each balk solenoid releases, allowing the pilot to further lift the thrust reverser levers to command increased reverse thrust.

The EECs respond to the pilot's movement of the thrust reverser levers by signaling the FADEC components to set engine power in accordance with the reverse thrust power schedule. The reverse thrust power schedule is a function of both TLA (set by the pilot through positioning of the reverse thrust levers to command any amount of reverse thrust up to full reverse thrust) and the airplane's indicated airspeed when less than 100 kts. Slower indicated airspeed will result in less thrust.[23]

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[22] According to Pratt & Whitney Canada, the FADEC is a dual-channel system made of several components to control the engine's thrust. The main control system components are the thrust lever, EEC, and the hydromechanical fuel metering unit. The FADEC system regulates each engine's high-pressure rotor speed ($N_2$) and low-rotor (fan) speed ($N_1$) in response to the pilot-operated TLA, ambient conditions, other pilot-selected inputs, and aircraft discrete inputs.

[23] According to the Pratt & Whitney Canada PW305 Customer Training Manual, engine power provided for reverse thrust for an airplane traveling at 100 kts would be about 85 percent of takeoff $N_1$, whereas engine power for an airplane traveling 0 to 40 kts would be about 50 percent of takeoff $N_1$.

#### 1.6.2.3 Thrust Reverser System Logic Criteria

The thrust reverser system requires specific input from various sensors on the airplane, which provide input into the logic control functions that prevent certain operations when specific criteria are not met. The thrust reverser system logic criteria are designed to protect against inadvertent thrust reverser deployment during flight and to prevent the engines from producing high levels of thrust while the reverser doors are in transit.

For the thrust reverser doors on each engine to fully deploy when commanded and to remain deployed, the EECs must receive input from the squat switches, which are sensors mounted on each MLG assembly, signaling that the airplane is on the ground.[24] In addition, each engine's thrust reverser doors must fully open to change the electrical state of the switches for the balk solenoids to release the thrust reverser levers. In addition, the thrust reverser levers' microswitches (located in the cockpit pedestal with each respective RVDT) must indicate that the reverser levers are lifted before the EECs will signal the FADEC components to use the reverse thrust engine power schedule.

In the event of a scenario in which almost any of the thrust reverser logic requirements are not met, the thrust reversers are designed to stow. Learjet engineering personnel indicated that the uncommanded stowage of the thrust reversers in the event of any system loss or malfunction is part of a fail-safe design that ensures that a system anomaly cannot result in a thrust reverser deployment in flight, which could adversely affect the airplane's controllability. The design is intended to reduce the pilot's emergency procedures workload and prevent potential mistakes that could exacerbate an abnormal situation.[25]

## 1.7 Meteorological Information

Automatic terminal information service (ATIS) information V (victor) was current at the time of the accident. According to the CVR transcript, the first officer advised the ground controller before taxi that the crew had obtained ATIS V, which indicated that winds were from 060° at 10 kts, visibility was 10 miles with clear skies below 12,000 feet above mean sea level (msl), the temperature was 21° C, the dew point was 13° C, and the altimeter setting was 30.23 inches of mercury.

## 1.8 Aids to Navigation

No deficiencies with navigational aids were noted.

[24] The squat switches signal "ground mode" upon sensing that the MLG is partially compressed to support the airplane's weight.

[25] Both Learjet and FAA personnel noted that designing the thrust reversers to fail to the stow position prevents a pilot from having to perform the procedures of isolating which engine had a faulty thrust reverser, correctly increasing thrust on the opposing engine to counteract the other's reverse thrust, and then shutting down the engine with the faulty thrust reverser. In multiengine airplanes, numerous accidents have occurred when pilots identified and shut down the wrong engine.

## 1.9 Communications

No ground or airplane communications equipment deficiencies were noted.

## 1.10 Airport Information

CAE is located about 5 miles southwest of Columbia at an elevation of about 236 feet msl. Runway 11/29, which has a grooved asphalt surface, is 8,601 feet long and 150 feet wide. The RSA beyond the departure end of runway 11 is 1,000 feet long and 500 feet wide. At the time of the accident, several taxiways and runway 5/23 were closed for construction. Runway and taxiway closure information was available in Notice to Airmen 08-75 and was included in the ATIS V broadcast.

CAE is certificated under 14 CFR Part 139 and maintains aircraft rescue and firefighting (ARFF) capabilities at index C.[26] At the time of the accident, CAE had four firefighting personnel on duty 24 hours a day and three ARFF vehicles (Redbird 6, 9, and 10). Each vehicle was a 1500-series crash truck that carried at least 1,500 gallons of water and 200 gallons of foam concentrate. Redbird 10 also carried 700 pounds of dry chemical agent.

## 1.11 Flight Recorders

The airplane was equipped with a Universal model 1603-02-12 CVR, which is a solid-state unit that records 2 hours of digital audio information. Examination of the CVR showed structural and fire damage on the outer case. Removal of the damaged outer case exposed the inner crash-protected memory case, which showed no structural or fire damage.

Download of the digital information at the National Transportation Safety Board's (NTSB) laboratory in Washington, D.C., revealed that the CVR captured both a two-channel recording of the last 2 hours of operation and a separate four-channel recording of the last 30 minutes of operation. The 2-hour recording captured one channel of poor-quality[27] audio information from the cockpit area microphone (CAM) and one channel of good-quality[28] audio information from the captain's and the first officer's audio panels combined. The 30-minute recording captured good-quality audio information from the captain and the first officer and

[26] CAE is an index C airport based on five or more average daily departures of aircraft having a length of at least 126 feet but less than 159 feet. To meet index C capabilities, two or three ARFF vehicles are required that contain a total of 3,000 gallons of water and commensurate quantities of aqueous film-forming foam. In addition, ARFF apparatus must carry either 500 pounds of sodium-based dry chemical, halon 1211, clean agent, or 450 pounds of potassium-based dry chemical agent.

[27] The NTSB uses five categories to classify the levels of CVR recording quality: excellent, good, fair, poor, and unusable. A poor-quality recording is characterized by fragmented phrases and conversations, and extensive passages of conversations may be missing or unintelligible.

[28] A good-quality recording is characterized by crew conversations that are easily and accurately understandable with only a few words that are unintelligible.

poor-quality information from the CAM (each on separate channels).[29] The airplane was not equipped with a flight data recorder (FDR).[30]

## 1.12 Wreckage and Impact Information

Examination of the debris path from the runway to the main wreckage site revealed that the initial wreckage debris on the runway consisted of fragments from the right outboard MLG tire. In immediate proximity following the initial tire debris (along the airplane's direction of travel), tire skid marks and gouging on the runway surface crossed the runway centerline at an angle from left to right before generally realigning with the runway heading and continuing straight off the departure end into a swath of ground scars and debris that extended to the main wreckage.

The identified debris extended down the runway in the following order (with some overlap): right outboard MLG tire (some fragments of which were found coated with hydraulic fluid), airplane landing light, airplane pieces, right inboard MLG tire, left inboard MLG tire, and left outboard MLG tire. Fragments of the MLG wheel sets were found strewn along the debris path with few tire fragments attached; all four MLG wheel and brake assemblies showed grinding and friction damage on the bottom, with the most severe damage evident on the right outboard wheel. The left and right squat switches were found in the grass at the end of the runway, separated from their respective MLG struts.

The airplane came to rest on a 25° to 30° embankment on the east side of a five-lane road. The top and right side of the fuselage were burned away to about the level of the cabin floor. The aft fuselage forward of the vertical stabilizer was mostly consumed by fire, particularly beneath the fuselage fuel tank location. Both engines and their mounting structures were fire damaged. The left engine's thrust reverser doors were in the stowed position. Remnants of the thrust reverser door actuating mechanism from the right engine (which sustained more fire damage than the left) were in locations consistent with the stowed position. Postaccident examination of the engines revealed that their combustor sections contained organic debris; thermal damage to the airplane's engine diagnostic system precluded memory data extraction.

## 1.13 Medical and Pathological Information

The Lexington County, South Carolina, Office of the Coroner performed autopsy examinations on the captain, the first officer, and two passengers. The cause of death for both the captain and the first officer was reported as smoke and fume inhalation and thermal injuries, and a contributing factor for both was blunt force trauma. The cause of death for the two passengers was reported as injuries resulting from blunt force trauma. The two survivors received second- and third-degree burns.

[29] The fourth channel did not contain (and was not required to contain) any audio information.

[30] According to 14 CFR 135.152(a), the requirement for an FDR does not apply to multiengine, turbine-powered airplanes configured with fewer than 10 passenger seats, excluding any required crewmember seat.

The FAA's Civil Aerospace Medical Institute performed toxicology testing on samples from the captain and the first officer. The toxicology reports for the captain and the first officer indicated that the samples tested negative for ethanol and a wide range of drugs, including major drugs of abuse (marijuana, cocaine, phencyclidine, amphetamines, and opiates). Twenty percent carboxyhemoglobin saturation (carbon monoxide), 1.8 (µg/mL) cyanide,[31] and 0.03 (µg/mL, µg/g) diphenhydramine[32] were detected in the captain's blood.[33] Diphenhydramine was also detected in her liver. Twenty-five percent carboxyhemoglobin saturation, 2.07 (µg/mL) cyanide, and 0.036 (µg/mL, µg/g) diphenhydramine were detected in the first officer's blood. Diphenhydramine was also detected in his liver and urine, and ibuprofen[34] was detected in his urine.

## 1.14 Fire

According to statements from the passengers and witnesses, a fire erupted in and around the airplane when it came to rest at final impact. CAE ARFF responders received the alert of the accident via the crash phone and radio from the airport communication center. All three ARFF vehicles and all four ARFF personnel on duty arrived at the scene within 5 minutes of notification and found that the entire length of the airplane and sections of the highway were on fire. The fire was under control about 10 minutes after the first ARFF crews arrived. Mutual aid response was provided by Lexington County and the Town of Cayce. Burn lines consistent with a fuel fire extended downhill from the wing and fuselage fuel tanks, across the road toward the airport fence, and along the gutter of the road.

## 1.15 Survival Aspects

The captain was seated in the left cockpit seat, and the first officer was seated in the right cockpit seat. According to the two surviving passengers, the two fatally injured passengers were seated in the forward cabin, one in the forward-facing seat on the left and the other on the side-facing divan on the right. The two survivors were seated in the aft forward-facing seats.

The captain's seat five-point restraint system buckle was found with four of the five buckles fastened; the crotch-strap buckle was not located in the wreckage. The first officer's five-point restraint system buckle was found with all five buckles fastened. None of the identified seat belt buckles from the cabin were found fastened (not all buckle components from the cabin were located).

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[31] Carbon monoxide and cyanide levels can result from smoke inhalation.

[32] Diphenhydramine is an over-the-counter antihistamine with sedative effects that is often used to treat allergy symptoms (commonly known by the trade name Benadryl®) or as a sleep aid (commonly known by the trade name Unisom®).

[33] The condition and specific anatomical sources of the blood samples from both the captain and the first officer were not reported.

[34] Ibuprofen is an over-the-counter pain reliever and fever reducer commonly known by the trade name Motrin®.

### 1.15.1 Survivors' Descriptions of Crew-Provided Safety Information

The passenger who was seated in the aft forward-facing seat on the right recalled that, before the airplane taxied, the captain asked the passengers if they knew where the seatbelts were and told them that the fire extinguisher and the snacks were in the back. The passenger stated that he did not hear the "usual" safety briefing but noted that the captain told them where the exits were and stated, "you have all done this before." He stated that he did not think that the captain's briefing sounded very professional. He recalled that he fastened his seatbelt but indicated that he did not notice what the other passengers did with their seatbelts. He stated that he assumed that they used them because he was familiar with their travel habits, and they typically used their seatbelts on every flight.

The other surviving passenger, who was seated in the aft forward-facing seat on the left, stated that the pilots did not provide a safety briefing and that he did not remember hearing any specific language about the location of the exits. He recalled that one of the pilots made a comment that he interpreted to mean that the pilot considered the passengers to be frequent fliers who were familiar with safety briefings. He stated that he fastened his seatbelt but not very tightly.

### 1.15.2 Survivors' Descriptions of Exiting the Airplane

The passenger in the aft right seat stated that, as soon as the airplane came to a stop, fire erupted in the cabin. He stated that he remembered being told that there was an exit near him and that he turned around went to the aft exit door (on the right) and "did what it said to do." He stated that he did not remember if there were instructions or arrows on the exit that showed how to open it but stated that he opened it without difficulty and jumped out onto the wing of the airplane. He recalled that he went through more fire outside the airplane; ran away from the airplane; and saw, within 5 seconds, the airplane burst into bigger flames. He stated that, as he ran, he pulled off his burning clothes.

The passenger in the aft left seat stated that the airplane went up and back down "hard" and that, before the airplane's final "very, very hard" impact, he saw something or someone fly up and hit the ceiling in the forward cabin. He stated that he may have been unconscious for a few seconds but that he saw the other passenger get up and yell, "we gotta go! We gotta go!" He indicated that he did not know that there was an exit behind him but that the other passenger "went right to it," opened it, and leapt "straight out into a wall of flames." He stated that he went to the exit, stayed to the left to try to avoid the fire, and jumped out. He indicated that, when he landed on the ground, he was on fire and began rolling to put out the fire himself.

### 1.15.3 Postaccident Examination of Airplane Exits

The airplane's main passenger boarding door, a type I exit of a clamshell design with upper and lower doors,[35] was located at the left forward cabin. The exterior handle and the interior lower handle were found at the accident site in the closed/locked position, and the door pins were found in the extended/locked position. The fuselage was deformed at the aft bottom area of the door frame, and the lower door could not be opened; the upper door latch was operable with effort.

A type III escape hatch was located in the lavatory area in the rear cabin on the right, above the lavatory's seat.[36] The lavatory and escape hatch area were separated from the cabin by two wooden partitions (extending from floor to ceiling) on each side of the airplane with a sliding, wooden "pocket" door in the middle that, when open, stowed into the left partition. The charred remains of this pocket door were found consistent with it having been in the open (stowed) position; the hatch and the surrounding fuselage were destroyed by fire. The escape hatch handle and one pin-type latch were found in the debris in the open (unlatched) position.

## 1.16 Tests and Research

### 1.16.1 Sound Spectrum Study

The NTSB performed a sound spectrum study to examine a 50-second segment of audio (from 2354:42 to 2355:32) captured on the CVR by the CAM in the near-final moments on the recording. The sound spectrum study used the audio signals as a basis for calculating the accident airplane's engine $N_1$ and ground speed.

#### 1.16.1.1 Engine N1

The calculated engine $N_1$ values were used to plot a curve of the airplane's $N_1$ as a function of time, as shown in figure 4 on the following page. Breaks in the curve indicate times during which clearly discernible engine sounds were absent, which likely resulted from other sounds obscuring the engine sound signal.

[35] A type I exit, according to 14 CFR 25.807(a)(1), is a floor-level exit with a rectangular opening of not less than 24 inches wide by 48 inches high, with 8-inch maximum corner radii.

[36] A type III exit, per 14 CFR 25.807(a)(3), is a rectangular opening of not less than 20 inches wide by 36 inches high, with 7-inch maximum corner radii and with a step-up inside the airplane of 20 inches or less. The step-down outside the airplane may not exceed 27 inches for exits located over the wing.

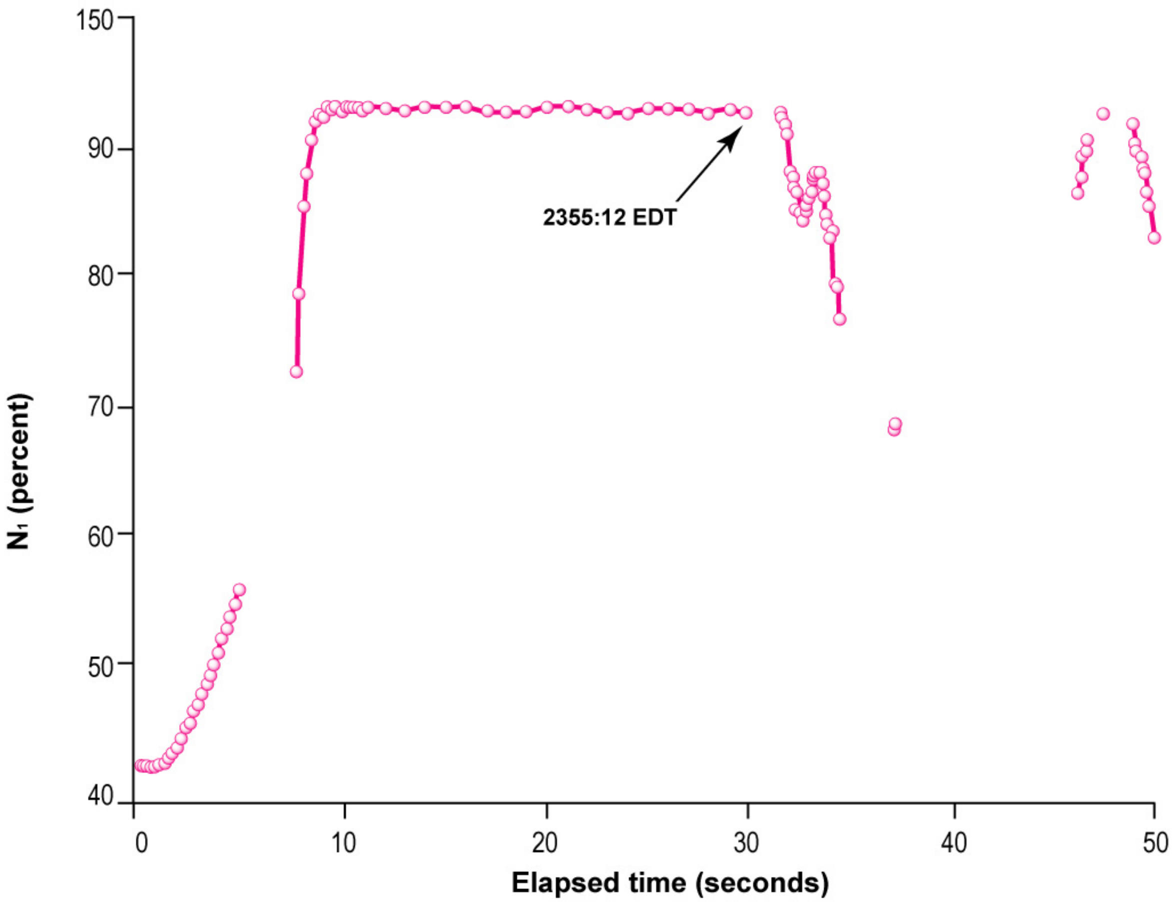


**Figure 4.** Engine $N_1$ calculated as a function of elapsed time into the takeoff roll (time of the start of the loud rumbling sound is shown).

As shown in figure 4, from 2354:42, the calculated engine $N_1$ increased to a peak within 10 seconds and then remained constant near that peak level (about 93 percent) for the next 20 seconds until 2355:12, when a distinct noise burst (corresponding with the beginning of a loud rumbling sound) was recorded. After the noise burst, from 2355:14 to 2355:16, there was noticeable wavering of engine $N_1$; during this 2-second period, $N_1$ decreased from about 93 percent to about 84 percent and then increased back up to about 88 percent before finally decreasing below about 76 percent, at which point engine noises became only intermittently discernible. At 2355:19, engine $N_1$ was about 68 percent. In the final 4 seconds of analyzed audio (beginning at 2355:28), discernible engine noises corresponded with an $N_1$ rising through about 86 percent to about 93 percent before decreasing again to about 83 percent.

### 1.16.1.2 Airplane Ground Speed

The data derived from the sound spectrum analysis for the sound produced by the tires rolling over the runway grooves (the spacing of which was measured) were used in calculating airplane ground speed. These calculated ground speed values were used to plot a curve of the airplane's ground speed as a function of time, as shown in figure 5 on the following page. Breaks in the curve indicate times during which clearly discernible tire-rolling sounds were absent, which likely resulted from other sounds obscuring the tire sound signal.

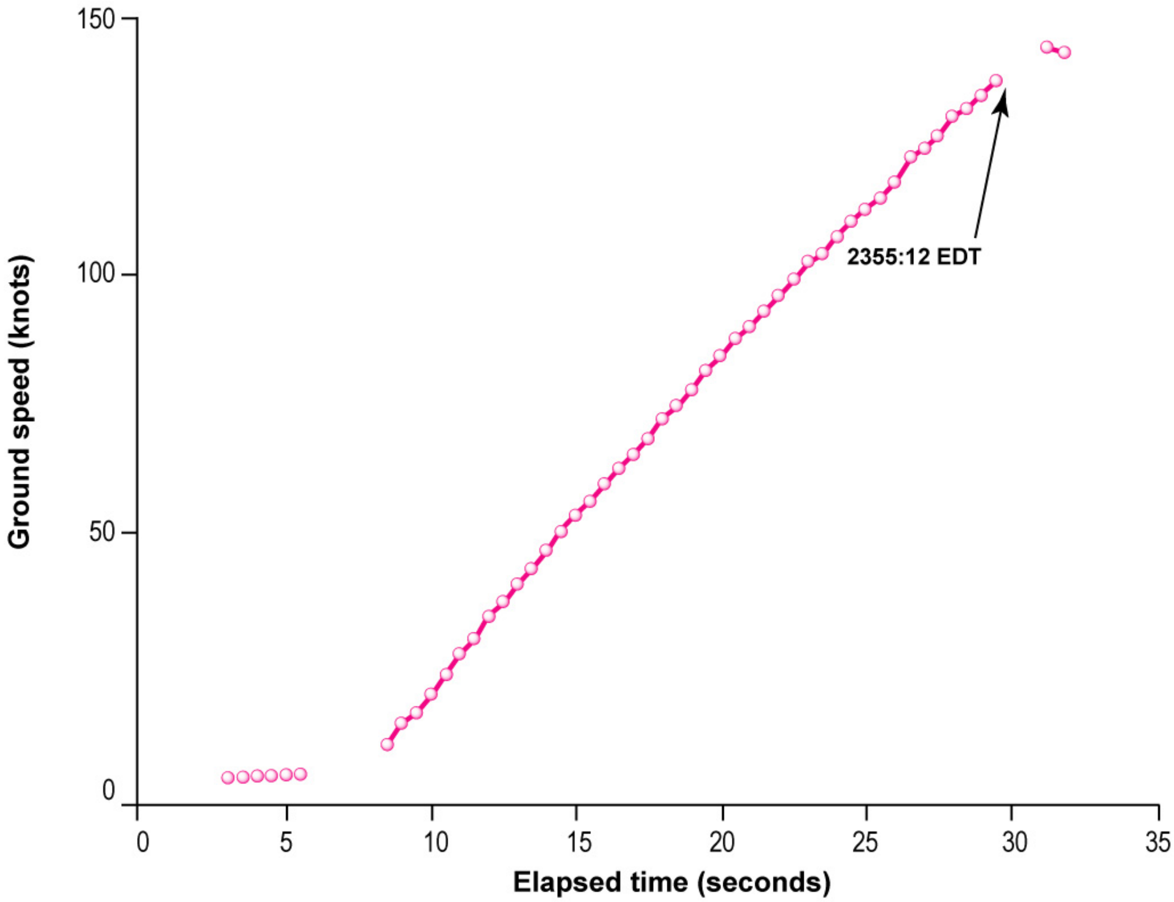


**Figure 5.** Airplane ground speed calculated as a function of elapsed time into the takeoff roll (time of the start of the loud rumbling sound is shown).

As shown in figure 5, the airplane's ground speed increased from about 5 kts about 8 seconds into the recording (at 2454:50) to about 138 kts at the time that the rumbling sound began at 2355:12. The sound spectrum analysis of airplane ground speed ends a few seconds later; tire-rolling sounds beyond that time were not clearly discernible. The analysis indicated a peak ground speed of about 144 kts.

### 1.16.2 Airplane Performance Study and Map Overlay

The airplane's position on the runway at the time that the CVR began recording usable sound spectrum data is not precisely known; however, radio communications and wreckage debris locations on the runway provided a basis for estimating the airplane's initial position. Plotting this estimated position on a map of CAE provided an initiation point. Other time-stamped information, such as calculated ground speed, engine $N_1$ values (in rpm), and flight crew comments, was then correlated with the airplane's position plots on the CAE map, and mapped wreckage debris information was added. The result provided a graphical depiction of the relative progression of events throughout the takeoff roll to impact, a segment of which is shown in figure 6.

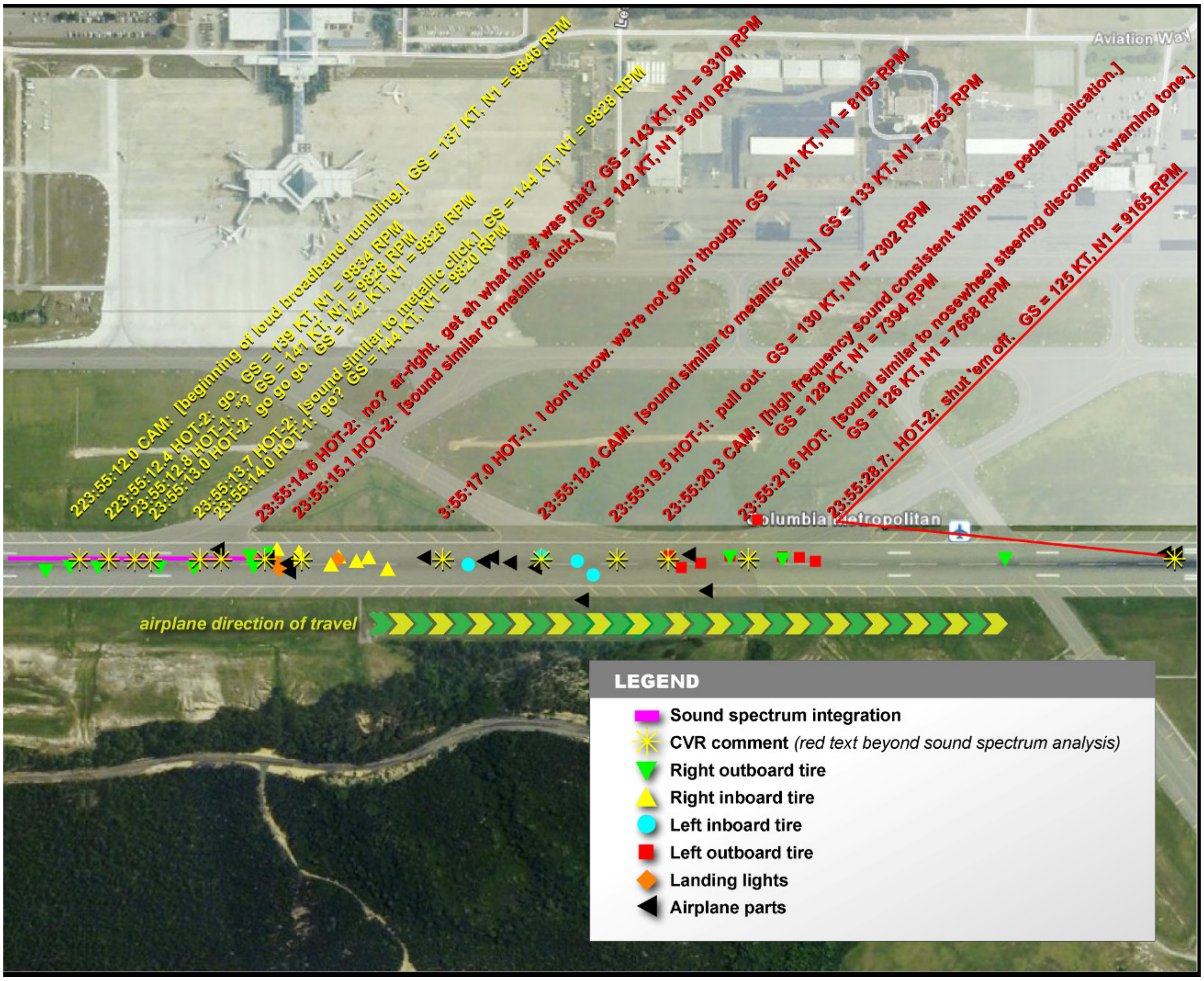


**Figure 6.** Map of Columbia Metropolitan Airport showing integrated sound spectrum data, cockpit voice recorder comments, and wreckage locations plotted.

The sound spectrum study speed analysis ends at 2355:14 (when sound signatures are no longer clearly discernible); information derived from the integration of that portion of the sound spectrum is shown in pink. CVR comments, engine $N_1$, and ground speed from the same timeframe are shown in yellow text. For the purpose of positioning the remaining CVR comments in the approximate locations where they occurred, the airplane performance study further extrapolated the airplane's ground speed to 2255:31 through a visual examination of the sound spectrum illustration. This extrapolated information is shown in red text. Wreckage and tire debris found on the runway are also shown as marked.

### 1.16.3 Main Landing Gear Tires

#### 1.16.3.1 Basic Design and Function

Transport-category aircraft tires, such as those installed on the Learjet 60, operate at high inflation pressures[37] and have a thick-walled construction made up of three main materials: rubber, fabric (primarily the flexible nylon ply material that gives tires their strength), and the steel bead wires. Transport-category aircraft tires are designed to withstand intermittent (taxi, takeoff, and landing) operations in severe operating conditions, such as under the airplane's heavy load requirements and at high speeds. Each intermittent use of the tires is typically brief and followed by lengthy periods of relief from the loads and/or high speeds while the aircraft is in flight or parked. When an aircraft tire is in use, both heavy weight and high speed contribute to the strong forces that act on it.

An aircraft tire in use can generate high temperatures within its structure in part because of the amount that the materials can flex in response to inflation pressure and loading. Aircraft tires perform properly only when they have the correct inflation pressure and are not overloaded. Proper inflation and loading result in an acceptable amount of sidewall deflection. Sidewall overdeflection occurs when a tire is operated while underinflated or overloaded. When a tire's sidewalls overdeflect at the bottom of each rotation, the excessive flexing of the rubber can result in fatigue of the reinforcing fibers and the generation of higher internal temperatures at a faster rate than would be generated in a properly inflated, properly loaded tire. High temperatures can degrade the physical properties of the tire's rubber compounds and melt the nylon threads in the plies; such damage can lead to tire failure.

#### 1.16.3.2 Reconstruction and Examination of Accident Airplane's Main Landing Gear Tires and Wheels

Pieces of the right outboard tire, which were the first debris found on the runway, were identified as fragments of the tire's sidewall. About 80 percent of the tire was reconstructed. Both sidewalls showed damage around the entire circumference of the tire; the damage had a ragged appearance and was located at a generally uniform distance from the wheel rim, as shown in figure 7 on the following page.

Both the inboard right tire and the inboard left tire showed similar sidewall damage (on one sidewall each). The outboard left tire, fragments of which were the farthest down the runway, had a more torn and shredded appearance than the other three tires and showed extensive tearing through its layers. One fragment of this tire, about 19 inches in circumferential length, showed sidewall damage.

[37] In contrast, the tires used on many single-engine general aviation airplanes are not of a high-pressure tire design; those tires carry a load that is about proportionate to what automotive tires carry and have inflation pressures and wall thicknesses similar to the tires used in automotive applications.

**Figure 7.** Reconstruction of the right outboard main landing gear tire showing outboard sidewall damage. Arrows depict the generally uniform location of the damage.

The characteristics of the sidewall damage observed on all four of the accident airplane's tires were consistent with a photograph in a Goodyear publication showing typical heat damage sustained from sidewall overdeflection and flexing fatigue.[38] Goodyear engineers and the Goodyear publication noted that previous tire testing found that aircraft tire sidewall damage from flexing fatigue is predominantly consistent with taxi-cycle operations while the tire is

[38] *Aircraft Tire Care and Maintenance*, The Goodyear Tire & Rubber Company Publication 700-862-931-538 (Akron, Ohio: The Goodyear Tire & Rubber Company, 2002, rev. 10/2004), <http://www.goodyearaviation.com/resources/tirecare.html> (accessed February 15, 2010).

underinflated; Goodyear testing showed that as little as 5-percent underinflation greatly reduces the fatigue life of transport-category aircraft tires.

Because either underinflation or overloading can result in tire sidewall overdeflection, tire testing data for both scenarios were reviewed. According to estimated static load deflection charts created during the investigation for the accident tires, the amount of underinflation needed for a loaded tire to produce the type of overdeflection damage observed on the accident airplane's tires (specifically, the damage location on the sidewall) would be about 36-percent underinflation. Alternatively, testing data showed that the amount of overload needed for a properly inflated tire to produce the amount of overdeflection consistent with the sidewall damage observed on each of the accident airplane's tires would be about 12,200 pounds.

Other damage observed on fragments from each of the accident airplane's tires included blue to purple heat discoloration indicative of moderate to severe heat damage. According to the Goodyear publication, blue tinting appears at temperatures from 210° to 230° F. Microscopic examination of fragments from all four tires revealed that the tires' nylon fibers (which are generally soft and fabric-like when undamaged) had melted and resolidified into single strands that had a stiffness resembling that of broom bristles. The Goodyear publication noted that the melting point of nylon is greater than 400° F. Rubber reverts to an uncured state and loses strength and adhesion at temperatures from 280° to 320° F, then becomes hard and dry at temperatures from 355° to 390° F.

Fragments from all four tires showed abrasion and rub marks on the inner liner and heat damage to the rubber and nylon fibrous cord materials. Goodyear engineering personnel and investigators experienced in tire failure examinations noted that, although heat and rolling distance could affect the start of wrinkling, they were not aware of wrinkling or liner damage ever occurring in aircraft tires that had been properly inflated.

The tires showed no evidence of impact, puncture, or adhesive-separation damage. Examination of the wheels and brakes showed no evidence of overheating or brake lock-up,[39] and none of the wheels' eutectic fuse plugs, which are designed to melt if the wheel temperature reaches about 390° F, leaked when tested. The right outboard wheel assembly had no flanges remaining, and the left outboard wheel assembly retained nearly full height on the outboard flange. The threaded tire inflation valve bodies on two of the wheels (left inboard and right outboard) could be removed by finger torque (the specification for installation required 190 inches-pounds); the inflation valve bodies of the other two wheels were found more tightly secured. The internal mechanisms of the four tire inflation valves did not leak when tested.

### 1.16.3.3 Tire Pressure Data Collected from In-Service Airplanes

The average daily pressure loss for Learjet 60 tires reported in the QTR, which is within the 5 percent allowed by TSO-C62c, is comparable to the daily loss rate for tires on many other

[39] Evidence indicated that the wheel brakes stopped rotating after sustaining mechanical damage associated with runway contact.

transport-category airplanes. The NTSB reviewed tire pressure information collected from various sources for the purpose of gaining insight into industry practices related to tire pressures and maintenance for in-service transport-category airplanes. The information included historical data from 2005 to 2009 and tire pressure and maintenance practice information collected from two FBOs and eight commercial operators. The data collection was not intended (or sufficient) for performing statistical analyses.

The collected data showed that most of the tires sampled were inflated to within 10 percent of their rated pressure, which was typically within maintenance limits. However, some tires were operated at inflation values well below the limits that the respective AMMs specified for tire replacement. During the data collection, nearly all maintenance providers interviewed mentioned that use of the AMM was required by each operator's FAA-approved operations specifications. One FBO operator indicated that some AMMs do not call for mandatory tire pressure checks as part of scheduled maintenance and that he believed that weekly tire pressure checks were generally good practice.

A review of AMMs for the Cessna CE-650 and the Dassault Falcon 50 (airplane types also operated by Global Exec Aviation) found that the AMMs were organized similar to the Learjet 60 AMM; the reference to daily tire pressure checks was found in chapter 12 of each. The Dassault airplane flight manual (AFM) for pilots also contained a reference to chapter 12 of the AMM for tire pressure check information.

### 1.16.4 Thrust Reverser System

#### 1.16.4.1 Ground Tests and Engineering Review

The Learjet 60 is equipped with cockpit annunciator lights that indicate the status of the thrust reverser system to the pilots. Ground tests were performed using a Learjet 60 that was specially equipped to simulate possible anomalies that could affect the thrust reverser system's logic functions, and the test airplane's cockpit annunciator lights were monitored throughout the testing.

In the cockpit, the thrust reverser system has a total of six annunciators (two columns of three annunciator lights each, with one column per engine). The annunciators for each engine include the green TR ARM light, which illuminates when the thrust reverser system is armed and available for use if commanded;[40] the amber TR UNLOCK light, which illuminates when the thrust reverser doors are unlocked and in transit; and the white TR DEPLOY light, which illuminates when the thrust reverser doors are in the fully deployed position. When the thrust reverser doors on each engine are fully deployed, the amber TR UNLOCK lights extinguish.

[40] The TR ARM lights remain illuminated when the airplane is on the ground at idle engine power and any time that the TR UNLOCK or TR DEPLOY lights are illuminated. During taxi operations, the green TR ARM lights extinguish when the engine power levers are moved to a position greater than the idle-thrust position.

During one test, the airplane was on the ground (with squat switches in ground mode) with the thrust reversers deployed and at idle thrust. While the airplane remained on the ground, the test equipment switched the squat switch status to air mode, thus creating a situation in which the logic requirements to maintain thrust reverser deployment were no longer being met. As a result, the thrust reverser doors stowed, the TR DEPLOY light extinguished, the TR UNLOCK light illuminated, and the TR ARM light flashed for less than 2 seconds before all thrust reverser system annunciators extinguished. The EECs, upon receiving the input that the thrust reversers were stowed and that the squat switches were signaling air mode, shifted logic and signaled the FADEC components to change the engine thrust output from the reverse thrust power schedule to the forward thrust power schedule. (In the test airplane's configuration, the thrust changed from ground idle speed to flight idle speed.)

In this situation, the EECs would transition from the reverse thrust power schedule to the forward thrust power schedule during about a 2-second transition through idle power. During the entire sequence, the thrust reverser levers in the cockpit would remain in the reverse thrust idle position (as selected by the pilot) while the engines produced forward thrust. Because both the thrust reverser levers and the forward thrust levers share common RVDTs (one for the left engine and one for the right engine), the EECs, which receive TLA information from the RVDTs, would signal the engines to produce a level of forward thrust that generally corresponds with the level of reverse thrust commanded; that is, a pilot commanding full reverse thrust (for maximum deceleration of the airplane) would instead receive high levels of forward thrust (accelerating the airplane) according to the forward thrust power schedule.[41] To reduce the forward thrust in such a situation in a Learjet 60, a pilot would need to move the thrust reverser levers out of the commanded reverse thrust position and place them in the stowed position, consistent with the "Inadvertent Stow of Thrust Reverser After a Crew-Commanded Deployment" procedure described in section 1.16.4.3.

### 1.16.4.2 Accidents and Incident Involving Thrust Reverser System Anomalies

***April 1994 accident during landing (Learjet 60 prototype test flight)***

On April 6, 1994, a prototype Learjet 60 airplane (a modified Learjet 55) was involved in a landing accident during a test flight. After the airplane landed with a suspected flat tire, the pilot's application of the thrust reversers produced no deceleration, and the airplane went off the end of the runway. Postaccident examination found that both right MLG tires were flat and that the right MLG strut was damaged.

***June 1998 incident during rejected takeoff***

In June 1998, a Learjet 60 was involved in an incident during an RTO at Washington Dulles International Airport, Chantilly, Virginia. According to the pilot's report submitted to the National Aeronautics and Space Administration's Aviation Safety Reporting System (ASRS), both right MLG tires failed during the takeoff roll, and tire and brake assembly damage led to

[41] For any given TLA, the forward thrust power schedule results in higher engine power than the reverse thrust schedule, and the maximum possible reverse TLA is less than full forward TLA.

severed hydraulic brake lines and squat switch wiring. The airplane's thrust reversers stowed during the attempted RTO, and the airplane went off the left side of the 11,500-foot runway near the end.

During interviews with Learjet 60 pilots, one pilot provided contact information for another captain that he believed had experienced a thrust reverser incident; a 2009 interview with that captain revealed that he was involved in the 1998 incident that was recorded in the ASRS. During the interview, the captain recalled that the airplane had four new MLG tires just installed and that he had completed two uneventful flights in the airplane on the day of the incident. He recalled that, for the incident takeoff, the airplane was loaded to near maximum takeoff weight and that the taxi route for takeoff was long. He stated that, fairly early in the takeoff roll and well before $V_1$, he heard a loud bang that he felt certain was a blown tire because he had experienced a blown tire before. He described the event as a "very violent explosion" that created holes in the flaps and damage to the right side of the fuselage.

***January 2001 accident during landing***

On January 14, 2001, a Learjet 60 went off the end of a runway after a collision with deer during landing at Troy Municipal Airport, Troy, Alabama.[42] The pilots, who were critically injured, reported that the thrust reversers failed to operate. The airplane's thrust reversers were found stowed, and the squat switch on the left MLG showed damage and evidence of deer impact. An NTSB sound spectrum study performed on the airplane's CVR recording revealed that, after the airplane touched down, $N_1$ increased to a speed higher than what could be achieved on the reverse thrust power schedule.

#### 1.16.4.3 Approved Modifications After 2001 Landing Accident

On November 20, 2003, Learjet issued an AFM revision that changed the name of the "Inadvertent Stow of Thrust Reverser During Landing Rollout" abnormal procedure to "Inadvertent Stow of Thrust Reverser After a Crew-Commanded Deployment" and moved it to the emergency procedures section. In addition, on February 21, 2005, Learjet issued Service Bulletin (SB) 60-78-7 (the latest revision of which was dated May 1, 2006), which advised Learjet 60 owners and operators of a modification that Learjet was installing on in-production airplanes (including the accident airplane) and that could be retrofitted to in-service airplanes.[43] The SB noted that the purpose of the modification, which incorporated the airplane's existing wheel speed detection system into the thrust reverser logic,[44] was "to reduce the possibility of inadvertent stowing during thrust reverser operation." The SB modification was not required by the FAA.

[42] The report for this accident, NTSB case number ATL01FA021, is available at the NTSB's website at <http://www.ntsb.gov/ntsb/query.asp>.

[43] The SB applied to airplanes with serial numbers (S/N) 60-002 through -276. New-production airplanes, starting with S/N 60-277, were equipped with the modification. The accident airplane was S/N 60-314.

[44] The wheel speed sensors were already installed on the airplane as part of the autospoiler system. The wiring for both the wheel speed sensors and the squat switches is routed along the MLG struts.

The modification added the wheel speed sensor input to the thrust reverser logic, thus providing a redundant ground signal intended to help ensure that the thrust reversers would remain deployed in the event of the loss of a squat switch ground signal after landing. The wheel speed sensor signal would provide redundancy after the airplane's squat switches had been in air mode for at least 2 minutes, beginning within 50 seconds of the ground/air transition.

### 1.16.5 Certification of the Learjet 60 as a Changed Aeronautical Product

The Learjet 60 was certificated on January 15, 1993, under 14 CFR Part 25 (the airworthiness standards for transport-category airplanes). The Learjet 60 was added as the most recent model in a series of derivative models (or "changed aeronautical products") that were approved and added to Learjet type certificate (TC) A10CE, which was originally issued for the Learjet 24 on March 17, 1966. Performance and basic specifications for the models on TC A10CE vary widely. The Learjet 24 has maximum gross takeoff weight of 13,000 pounds, can be configured for up to 8 people (2 crew and 6 passengers), a maximum altitude of 41,000 feet, and a maximum range of 1,266 miles; in comparison, the Learjet 60 has nearly twice the maximum gross takeoff weight, a configuration option for up to 10 people (2 crew and 8 passengers), a maximum altitude of 51,000 feet, and a maximum range of 2,768 miles. The Learjet 60 also has a different wing and fuselage than earlier models and includes a large fuel tank in the aft fuselage. All but two Learjet models (the Learjet 23 and the Learjet 45) were certificated using TC A10CE.

The certification basis for changed aeronautical products allows an aircraft manufacturer to introduce a derivative model as a design update on a previously certificated aircraft and add the changed product onto an existing TC. The FAA approves such changes if it finds that the changes are not significant enough to warrant application for a new TC. This process enables a manufacturer to introduce derivative aircraft models without having to resubmit the entire aircraft design for certification review. The manufacturer can use the results of some of the analyses and testing from the original type certification to demonstrate compliance, in which case the regulations that were in effect on the date of the original TC apply.

Title 14 CFR 21.101 specifies the requirements for demonstrating airworthiness compliance for changed aeronautical products; the current revision of the regulation differs from the one that applied to the certification of the Learjet 60.[45] According to the revision of 14 CFR 21.101, which became effective on September 16, 1991, the certification basis for the Learjet 60 required, at the discretion of the FAA, compliance with either the regulations cited in the original TC (issued in 1966) or applicable regulations in effect on the date of the application. The exceptions related to compliance with different versions of and amendments to the regulations are specified on the Learjet 60's type certificate data sheet (TCDS).[46]

[45] See section 1.18.4 for the current requirements.

[46] Specifically, the Learjet 60 is certificated under 14 CFR Part 25, effective February 1, 1965, as amended by amendments 25-1 through -73, with specified exceptions. The TCDS specifies sections of the regulation and amendment levels that apply.

The Learjet 60's certification basis did not require compliance with some of the regulatory revisions for aircraft certification that were in effect in 1993 (when the Learjet 60 was introduced), which would apply to new aircraft models certificated on new TCs. For example, the Learjet 60's compliance with 14 CFR 25.1309, which related to failures of equipment, systems, and installations, was based primarily on the original version of the regulation.[47] A revised and more extensive version of 14 CFR 25.1309, including amendment 25-41, (which became effective September 1, 1977, for newly certificated aircraft) did not fully apply to the Learjet 60.[48]

According to Learjet and FAA personnel, during the changed product certification process, Learjet informs the FAA about proposed design changes from the initial concept and throughout the design's progress. As Learjet develops the design change, company senior engineers, recognized by the FAA as designated engineering representatives (DERs), review the change. FAA certification engineers in Wichita, Kansas, meet regularly with Learjet engineering staff, and the final design must be approved by the FAA.

During a 1981 certification review of the Learjet 25,[49] the FAA provided comments about the practice of applying the original certification basis to derivative airplanes. The FAA noted that the original certification basis for fail-safe criteria of flight critical systems, defined in 14 CFR 25.629, requires that the criteria address "only reasonably probable single failures and malfunctions," whereas the revised requirements of 14 CFR 25.629 and 25.1309 require the analyses to address all single and other combinations of failures not shown to be "extremely improbable." The FAA concluded that "it is necessary that flight critical systems meet these more stringent requirements to ensure safety." The FAA stated that "the current regulations in the system installation area (14 CFR 25.672, 25.1303, and 25.1309) should be applied to all new model airplane certifications and derivative certification airplanes where equivalent safety is not ensured by the application of the old regulations."

#### 1.16.5.1 Thrust Reverser Control Design

The Learjet 60 was the first Learjet model to be equipped with a fully electronic thrust reverser control. Learjet incorporated the electronic control system on the Learjet 60 to take advantage of design improvements made possible by computer control of the engines. In this design, the pilots could move the power levers to detents for specific modes of flight, such as takeoff and cruise. The microprocessor controls could then make continual adjustments to reduce fuel consumption and pilot workload.

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[47] The original version of 14 CFR 25.1309 states that equipment, systems, and installations must be designed and installed to ensure that they perform their intended functions under any foreseeable operating conditions and to prevent hazards to the airplane if they malfunction or fail.

[48] According to the Learjet 60's TCDS, only the airplane's electronic flight instrument system was required to comply with this revised version of the regulation.

[49] None of the Learjet 25 design characteristics under FAA review were related to the systems examined in this investigation. For more information, see FAA. Type Certification Decision Document, Learjet Special Certification Review, Supplement 1, April 30, 1981 (Kansas City, Missouri: FAA Central Region, Office of the Regional Counsel).

The fail-safe concept for the Learjet 60 thrust reverser system design was intended to protect against deployment of thrust reversers in flight. To achieve this protection, the logic criteria were such that any system failures or anomalies would result in the stowage of the thrust reversers. An uncommanded stowage of the thrust reversers in the Learjet 60 does not result in a corresponding movement of the cockpit thrust reverser levers. Such lever movement is not a regulatory requirement but was inherent in older Learjet models (also on TC A10CE) and most other airplanes that are equipped with mechanical thrust reverser control systems. With mechanical systems, cables physically connect the cockpit thrust reverser levers to the thrust reversers and engine power control units; thus, any uncommanded stowage of the thrust reverser doors would result in a corresponding movement of the levers in the cockpit and a corresponding reduction in engine thrust. Certification and test flights for the Learjet 60 were conducted without the use of thrust reversers (and without the reverser credit for calculating takeoff and landing runway length).

#### 1.16.5.2 Protection of Equipment in Wheel Wells

According to 14 CFR 25.729, any equipment that is essential to safe operation of the airplane and that is located in wheel wells "must be protected from the damaging effects of … a bursting tire, unless it is shown that a tire cannot burst from overheat, and … a loose tire tread, unless it is shown that a loose tire tread cannot cause damage." The Learjet 60's compliance with this requirement is recorded on a checklist that referenced a report that had originated during development of the Learjet 54. That report stated that two fuse plugs are installed in each main wheel to prevent overheating explosions and that tire burst tests had been conducted to demonstrate results for adjacent structure.

The investigation found that two hydraulic lines in each wheel well of the Learjet 60 did not have the protection of a restrictor, making it possible to lose the hydraulic supply if those tubes were breached. In addition, a review of Learjet service history found that tire bursts in some airplanes resulted in extensive damage, both in the wheel well and beyond the MLG tires' plane of rotation.

### 1.16.6 Comparison of Certification Criteria for Learjet 45 and Learjet 60

The Learjet 45 was certificated on a new TC (T00008WI) on September 22, 1997, under 14 CFR Part 25, as amended by amendments 25-1 through -77. The Learjet 45's compliance with 14 CFR 25.1309 is based on amendment 25-41, effective September 1, 1977 (unlike the Learjet 60, for which compliance is based primarily on the original version of the regulation). The more recent revision to the regulation, as applicable to the Learjet 45, states that airplane equipment, systems, and installations must be designed to ensure that they perform their intended functions under any foreseeable operating condition and that any failure that would prevent the continued safe flight and landing of the airplane is extremely improbable. The regulation also states that warning information must be provided to alert pilots to unsafe system operating conditions and to enable them to take appropriate corrective action. Compliance with the design criteria must be shown by analysis that considers possible modes of failure, including damage from external sources and the probability of multiple or undetected failures.

### 1.16.6.1 Thrust Reverser System Design

The Learjet 45 is equipped with a fully electronic thrust reverser control. The Learjet 45's system is designed to electronically duplicate the thrust reverser lever movement and engine power reduction inherent in the older mechanical systems. Specifically, the Learjet 45's thrust reverser control electronically triggers the cockpit thrust reverser levers to move to the stowed position and the engine thrust to idle if an abnormal condition results in the stowage of reverser doors while the cockpit thrust reverser levers are raised.

### 1.16.6.2 Protection of Equipment in Wheel Wells

With the exception of the Learjet 45, the MLG is similar throughout the series of Learjet airplane models and is based on similarities to the initial 1960s models that had been certificated before more stringent regulatory requirements existed. Components in the wheel wells of the Learjet 45 have protective plating and revised routing that provide more protection. Differences in the Learjet 45's and the Learjet 60's protection of system components in the MLG well, for which 14 CFR 25.1309 applies, are illustrated in figure 8 below, which shows protection in the inboard aft corner of the MLG wheel well for each airplane. Notable is the white shield that protects the Learjet 45's hydraulic and electrical system components, whereas components in the Learjet 60 are more exposed.

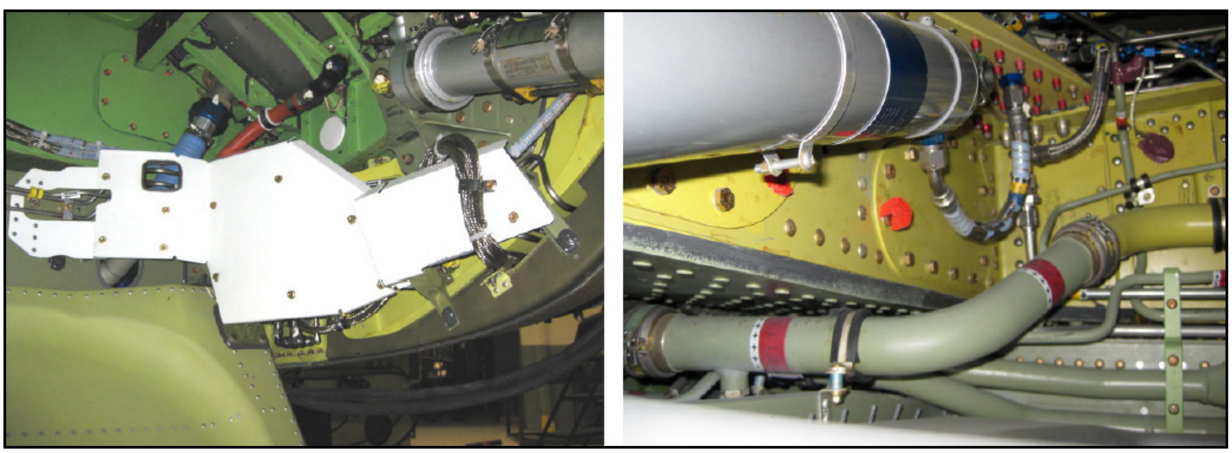

**Figure 8.** Inboard aft corner of the left main landing gear wheel well for the Learjet 45 (left) and the inboard after corner of the right main landing gear wheel well for the Learjet 60 (right).

## 1.17 Organizational and Management Information

Global Exec Aviation, based in Long Beach, California, was established in 2002 to provide on-demand charter services using managed airplanes. At the time of the accident, the company operated nine airplanes: two Gulfstream GIVs, three Gulfstream GIIIs, a Falcon 50, a CE-650, the accident airplane, and a Cessna 441.[50] Global Exec Aviation began operating the

[50] At the time of the accident, the Cessna 441 was grounded by a supplemental inspection document.

accident airplane, which was listed on the company's operations specifications, under 14 CFR Part 135 for on-demand charter flights in August 2008 after having previously managed the airplane for its owner for 14 CFR Part 91 flights. Global Exec Aviation had 20 employees, including 11 full-time pilots. The company also used part-time pilots for some flight operations.

### 1.17.1 Main Landing Gear Tire Maintenance and Checks

According to its operations specifications, Global Exec Aviation was required to comply with the Learjet AMM, and the company's director of maintenance stated that he referred to the AMM when determining what scheduled maintenance needed to be performed and when. He stated that he did not know how often the Learjet 60's tire pressures were supposed to be checked. He indicated that there is no requirement to record tire pressure checks and that the company does not document them.

Global Exec Aviation's director of operations stated that Learjets occasionally blow tires just like any other jet and that Bombardier Challenger jets have a requirement for daily pressure checks in the AFM but that the Learjet does not. He stated that the pilots never check the tire pressures and are not trained to do so and that no such procedures are in place. At the time of the accident, the exterior preflight procedure indicated that the flight crew should "check" the MLG wheels, tires, and brakes. The airplane's AFM indicated that the crew should check the "condition" of those components. The director of maintenance indicated that, if pilots suspected any problem with a tire while on a trip, they would call him as they would with any other maintenance issue.

The Learjet 60 pilots and instructors interviewed stated that preflight tasks involved visually inspecting the tires for general condition, such as excessive wear, sidewall bulges, or visible tire cord. All but one pilot interviewed stated that tire underinflation would be difficult to determine visually (one thought that "significant" underinflation could be visually detected). All but one of the Learjet 60 pilots and instructors interviewed stated that checking tire pressure was a maintenance function and that they were neither trained nor expected to check tire pressure at any time.

### 1.17.2 Pilot Training and Standard Operating Procedures

Global Exec Aviation provided its pilots with company indoctrination training; all other ground training, simulator training, and checks were provided by FSI in Tucson, Arizona. Global Exec Aviation pilots received the same FAA-approved Basic Bombardier Learjet 60 Training Program that FSI provided to other operators; Global Exec Aviation did not have any additional operator-specific training.

Flight crew procedure checklists for the Learjet 60 are published in the Bombardier Learjet 60 AFM, which is an FAA-approved manual that contains the normal, abnormal, and emergency procedures for the airplane. The Learjet 60 Crew Checklist and the Quick Reference Handbook (QRH) list the procedures in a cockpit-ready reference checklist format.

#### 1.17.2.1 Rejected Takeoff

According to Global Exec Aviation's operations manual, the pilot flying is responsible for conducting a takeoff briefing before each takeoff. The manual stated, in part, that the briefing may be "full" or "abbreviated" at the discretion of the pilot in command:

> Generally, a full briefing will be conducted for the first flight of the day for a particular crew pairing. A full briefing will include the following:
>
> a. abort procedure prior to $V_1$,
> b. procedure to be followed in case of a problem after $V_1$,
> c. minimum safe altitude for flap retraction / running checklists,
> d. emergency return plan,
> e. and the normal takeoff plan (initial departure procedure, altitude, squawk, and departure frequency).
>
> An abbreviated briefing will include the words "standard brief" and will include letters c through e above.

Global Exec Aviation's operations manual, the Learjet 60 AFM, the Learjet Pilot Manual, the Learjet Training Manual, and the FSI Learjet 60 Pilot Training Manual all contained guidance for pilots to determine if an RTO was necessary. All of the guidance was based on engine failure scenarios. The Global Exec Aviation training program manual and the FSI Learjet 60 Pilot Training Manual contained illustrations depicting the procedures for rejecting a takeoff due to engine failure below $V_1$ and for continuing a takeoff due to engine failure at or above $V_1$. The Bombardier Learjet 60 Pilot Training Guide stated that the pilot flying should reject the takeoff "for any abnormality observed" before the airplane reaches 90 kts and that, between 90 kts and $V_1$, the takeoff should be rejected for "engine failure, engine fire, loss of directional control, thrust reverser deployment, [or] catastrophic failures." The guide further stated that, if an engine fails above $V_1$ speed, "the takeoff will normally be continued." The Global Exec Aviation Part 135 Training Program Manual (Appendix Learjet 60) indicates that the pilot flying is to remove his/her hand from the thrust levers at the time of the $V_1$ callout by the pilot not flying.

Interviews with Global Exec Aviation pilots, other Learjet 60 pilots, and instructors indicated that all used nearly identical criteria to determine whether to reject a takeoff. Generally, they stated that, during the low-speed regime up to 80 kts, takeoff would be rejected for any abnormal or emergency event and that, during the high-speed regime up to $V_1$, takeoff would be rejected for only an engine fire, engine failure, thrust reverser deployment, or loss of directional control (which, according to some, included abnormal acceleration or deceleration). The consensus was that, at speeds above $V_1$, the takeoff would be continued.

Global Exec Aviation's director of operations stated that the company used a Boeing video that discussed statistical safety on high-speed RTOs. He stated that the message communicated by the video was "do not do high-speed aborts." Boeing's video, *Takeoff Safety*, states that an RTO beyond $V_1$ should only be attempted if the ability of the airplane to fly is in serious doubt. The video notes that taking the airplane into the air to deal with the problem offers pilots several advantages over an RTO, including reduction of airplane gross weight, ability to use landing flaps, more time to analyze the situation, ability to prepare for vibration and directional control problems on landing, and the availability of more runway on landing to allow the airplane to stop, increasing the margin of safety. The video further indicated that, if an RTO is initiated 2 seconds after $V_1$, an airplane will exit the end of the runway (based on a balanced field length)[51] at 50 to 70 kts.[52]

At the time of the accident, the abnormal procedures section of the QRH contained the checklist for use in the event of an RTO. The "Aborted Takeoff" procedure checklist included the following: "1. Brakes – APPLY, 2. Thrust Levers – IDLE, 3. Spoilers – EXT [extend], 4. Thrust Reversers – AS REQ'D [as required]."

At the time of the accident, the Bombardier Learjet 60 Crew Checklist and the QRH contained the emergency procedure, "Inadvertent Stow of Thrust Reverser After a Crew-Commanded Deployment," to be used in the event of an uncommanded stowage [53] of the engine thrust reversers. The first two steps of the procedure's checklist were enclosed in a box to indicate that the procedures "should be memorized for crew accomplishment without reference to the procedure." These two steps were the following: "1. Maintain control with rudder, aileron, nosewheel steering, and brakes, [and] 2. Both Thrust Reverser Levers – STOW." The checklist also included the note that "failure to move the thrust reverser levers to stow will result in forward thrust ranging from idle to near takeoff power, depending on the position of the thrust reverser levers."

#### 1.17.2.2 Pretakeoff Passenger Briefing

According to 14 CFR 135.117, before takeoff, passengers must be provided with an oral briefing that includes the following: prohibition of smoking, use of safety belts, seatback position for takeoff and landing, location and means for opening the passenger entry door and emergency exits, location of survival equipment, use of overwater equipment and supplemental oxygen, and the location and use of fire extinguishers. According to Global Exec Aviation's operations manual, the PIC is responsible for ensuring that all passengers receive the briefing as soon as possible after passenger loading. Neither 14 CFR 135.117 nor Global Exec Aviation's operations manual require any particular verbatim briefing content.

The initial portion of the CVR recording was of insufficient quality to determine the content of any briefing that may have been provided. At 2336:32, the CVR captured a sound consistent with the cabin door closing, followed by a voice captured by the captain's side CAM that stated, "I briefed 'em all." At 2340:39.6, the CVR captured a sound similar to a seatbelt

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[51] AC 120-62, *Takeoff Safety Training Aid*, defines balanced field length as the runway length (including the RSA, if applicable) at which, for the airplane's takeoff weight, the engine-out accelerate-go distance equals the accelerate-stop distance. Critical field length is defined as the minimum runway length (including the RSA) required for a specific takeoff weight, which may be the longer of the balanced field length, 115 percent of the all-engine takeoff distance, or the length established by other limitations, such as ensuring that $V_1$ is less than or equal to $V_r$.

[52] See Boeing *Takeoff Safety Video* Appendix 3-E.

[53] "Uncommanded stowage," which is synonymous with the QRH term "inadvertent stow," occurs when the logic requirements to maintain thrust reverser deployment are lost, resulting in the stowage of the thrust reversers after a crew-commanded deployment.

chime, and, at 2345:14, the first officer called for the checklist item, “seatbelt, no smoking,” to which the captain replied, “is, ah, on.”

#### 1.17.2.3 Airplane Weight and Balance Calculations

According to its operations specifications, Global Exec Aviation was authorized to use only the actual passenger weights (or the solicited passenger weights plus 10 pounds for each passenger) and the actual weight of all carry-on, checked, planeside-loaded, and heavy bags when determining aircraft weight and balance. The company used Ultra-Nav software and an American Aeronautics Plotter to calculate airplane loading and center of gravity. According to 14 CFR 135.63(d), the PIC of each flight must carry the weight and balance manifest on board the airplane. (The manifest for the accident flight was not located.) One of the passengers stated that neither pilot weighed any of the passengers or asked them their weight.

The weight and balance manifest for the accident flight was not identified in the wreckage, and postcrash fire damage to the baggage precluded obtaining actual baggage weight. Fueling records showed that the airplane received 835 gallons of fuel minutes before departing on the accident flight; given the flight plan filed by the crew, about 7,800 pounds of fuel was on board. This information, combined with an estimated weight for the baggage and catering supplies and standard estimated adult weights for the two flight crewmembers and four passengers, indicates that the airplane’s weight at takeoff may have ranged from about 23,590 to about 23,800 pounds.[54]

### 1.17.3 Federal Aviation Administration Oversight

The FAA flight standards district office in Long Beach, California, was responsible for the oversight of Global Exec Aviation. The FAA POI assigned to the company had been its POI since November 2007 and was previously the assistant POI.

A review of the FAA’s National Program Tracking and Reporting Subsystem records revealed that, in the 60 months before the accident, the FAA performed numerous inspections of Global Exec Aviation, including the following: 17 aviation education and safety promotion inspections, 44 organizational certification inspections, 2 aircraft and equipment inspections, 153 airmen certification oversight inspections, 38 surveillance inspections, and 5 investigation inspections. Sixteen records for the accident captain and one for the first officer pertained to routine oversight inspections and contained no remarkable comments. In 2007, the FAA performed a special emphasis operational control inspection[55] of Global Exec Aviation with

[54] This estimate includes a pretakeoff fuel burn of 150 pounds, as indicated in the airplane operating manual. As referenced previously, the airplane’s maximum allowable ramp weight and takeoff weight were 23,750 and 23,500 pounds, respectively.

[55] FAA Notice 8900.16, *Special Emphasis Inspection: Operational Control* (issued on August 17, 2007), directed POIs to inspect all Part 135 certificate holders to ensure compliance with operational control policies, procedures, and prohibitions. The inspections resulted from Safety Recommendation A-06-67, which stemmed from the NTSB’s investigation of a February 2, 2005, accident in Teterboro, New Jersey, involving a Bombardier Challenger CL-600-1A11 that was operated under a suspect charter arrangement. For more information, see

satisfactory results. A review of FAA safety performance analysis system records showed one entry for Global Exec Aviation, which recorded that its operations specifications were amended on August 15, 2007, to reflect the addition of a minimum equipment list for the Learjet 60.

## 1.18 Additional Information

### 1.18.1 Takeoff Safety Training Aid

In 1994, the FAA published AC 120-62, *Takeoff Safety Training Aid*, to provide guidance to "minimize, to the greatest extent practical, the probability of RTO-related accidents and incidents." The AC, which applies to Part 121 operators, states that "many of the principles, concepts, and procedures described apply to operations under [14 CFR] Parts 91, 129, and 135 for certain aircraft, and are recommended for use by those operators when applicable."

The AC provides recommended elements for air carrier ground training programs that state, in part, that the training should,

> ensure thorough crew awareness in at least the following topics: (1) Proper RTO and takeoff continuation procedures in the event of failures; (2) Potential effects of improper procedures during an RTO, (3) Guidelines on rejecting or not rejecting a takeoff in the low and high speed regimes; (4) Assigned crewmember duties, use of comprehensive briefings, and proper crew coordination.

The AC also provides recommended elements for air carrier flight training programs and pilot evaluations that state, in part, that simulator scenarios should include the following conditions and procedures: "demonstration of the proper and appropriate crew responses for engine failure, tire failure, nuisance alerts, and critical failures that affect the ability to safely continue the takeoff in both the high and low speed regimes."

Section 2 of AC 120-62, "Pilot Guide to Takeoff Safety," addresses various aspects of the go/no-go decision-making process in response to various anomalies and provides the following cautions:

> The infrequency of RTO events may lead to complacency about maintaining sharp decision making skills and procedural effectiveness. In spite of the equipment reliability, every pilot must be prepared to make the correct Go/No Go decision on every takeoff--just in case.

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National Transportation Safety Board, *Runway Overrun and Collision, Platinum Jet Management, LLC, Bombardier Challenger CL-600-1A11, N370V, Teterboro, New Jersey, February 2, 2005*, Aircraft Accident Report NTSB/AAR-06/04 (Washington, DC: NTSB, 2006).

> Do not attempt an RTO once the airplane has passed $V_1$ unless the pilot has reason to conclude the airplane is unsafe or unable to fly. This recommendation should prevail no matter what runway length appears to remain after $V_1$.

With respect to tire failures, section 2 includes the following guidance:

> Tire failures may be difficult to identify from the flight deck and the related Go/No Go decision is therefore not a simple task. A tire burst may … cause the airplane to pull to one side, or can cause the entire airplane to shake and shudder…. A pilot must be cautious not to inappropriately conclude, under such circumstances, that another problem exists.… Degradation of control can occur, however, as a result of heavy pieces of tire material being thrown at very high velocities and causing damage to the exposed structure of the airplane and/or the loss of hydraulic systems.

Section 2 also notes that rejecting a takeoff from high speeds with a failed tire is risky, especially if the airplane is near maximum gross weight:

> The chances of an overrun are increased simply due to the loss of braking force from one wheel. If additional tires should fail during the stop attempt, the available braking force is even further reduced. In this case, it is generally better to continue the takeoff.

## 1.18.2 Postaccident Safety Action

### 1.18.2.1 Learjet Tire Servicing Advisory Wire

On October 13, 2008, Bombardier Learjet issued advisory wire (AW) 32-045, *Tire Servicing*, applicable to all Learjet airplanes. The AW advised maintenance and operations personnel that proper tire inflation cannot be determined visually and that underinflation can result in overload of the adjacent tire, as indicated in chapter 12 of the AMM. The AW noted that proper tire servicing should be accomplished in accordance with the AMM and recommended that cold tire pressure should be checked before the first flight of every day or every 10 days on tires installed on airplanes that are not operated daily.

### 1.18.2.2 Federal Aviation Administration Safety Alert for Operators

On February 24, 2009, the FAA issued safety alert for operators (SAFO) 09005, “Dangers of Improperly Inflated Tires,” to emphasize to all aircraft operators, especially those operating Learjet 60s, the importance of proper tire inflation. The SAFO referenced the accident, stated that the operators’ personnel must understand the dangers of improper tire inflation, and recommended that tire pressures be checked using the manufacturer's recommended intervals and procedures.[56]

### 1.18.2.3 Learjet Revisions to Flight and Maintenance Manuals

#### 1.18.2.3.1 Temporary Flight Manual Change, Revised Procedures

On March 9, 2009, Bombardier Learjet issued an FAA-approved temporary flight manual (TFM) change applicable for Learjet 60 and 60XR airplanes. TFM 2009-03 provided amendments to the AFM that established the limitation that "nose and main tire pressures must be checked within 96 hours (not flight hours) prior to takeoff" using the procedures listed in chapter 12 the AMM. The revision included a note to check tire pressures on airplanes parked more than 10 consecutive days and provided a table of allowable tire pressure ranges based on maximum takeoff weight. The TFM change added tire pressure checks to the AFM's normal preflight procedures and provided expanded information for the abnormal procedures section to help flight crews recognize that a malfunction of the thrust reverser system can result in forward thrust.

Specifically, the TFM revised the "Aborted Takeoff" procedure, amending step 4 to read "Thrust Reversers – Deploy if necessary. Check for DEP [deploy] indications on the EIS [engine indication system] page" and adding the following step: "If none of the [thrust reverser] lights are illuminated, both Thrust Reverser Levers – Stow." The TFM also added a note and a warning to the "Aborted Takeoff" procedure and changed a note to a warning in the "Inadvertent Stow of Thrust Reverser After a Crew-Commanded Deployment" procedure. The notes provided information on the normal sequence of the thrust reverser annunciators, and both warnings stated that "a damaged squat switch (or other failures) may cause the thrust reverser auto stow system to activate … resulting in forward thrust, ranging from idle to takeoff power.… If this occurs, thrust reverser levers must be stowed immediately." The warnings detailed the effect of squat switch failure on the thrust reverser annunciators and emphasized in bold text that "the absence of any [thrust reverser annunciator] lights indicates forward thrust."

#### 1.18.2.3.2 Temporary Revision to Maintenance Manual

On March 18, 2009, Learjet issued temporary revision (TR) 12-16 to the Learjet 60 AMM. TR 12-16 moved the preflight tire pressure check recommendation to the front of the chapter and indicated that tire pressure checks must be taken per the revised AFM limitation (within 96 hours before flight). TR 12-16 included the procedure to use when checking for proper tire inflation and indicated that the checks must be documented. On May 29, 2009, the FAA issued a notice of proposed rulemaking (NPRM) to adopt a new airworthiness directive to require that the Learjet 60 AMM and AFM be revised as referenced in Learjet's TFM change and TR 12-16.[57] On July 30, 2009, the NTSB provided comments in support of the proposed rule but indicated that the rule should be expanded to cover other airplanes.

[56] On June 12, 2009, the FAA issued a revised version, SAFO 09012, which contained editorial revisions.

[57] 74 *Federal Register* (FR) 25682-25684 (May 29, 2009).

#### 1.18.2.4 Federal Aviation Administration Legal Interpretation That Learjet 60 Tire Pressure Checks Are Preventive Maintenance

In correspondence dated January 8, 2009, Learjet requested that the FAA provide a legal interpretation of "applicable rules in 14 CFR Parts 43, 91, and 135 pertaining to whether a pilot of a transport-category aircraft may check tire pressure during a normal preflight inspection." On February 26, 2009, the FAA's assistant chief counsel for regulations responded that checking the tire pressure on a Learjet 60[58] airplane is preventive maintenance and not a simple preflight task. The FAA stated that such checks involve high air pressure and require a calibrated gauge that must be used properly to ensure correct readings.

Title 14 CFR 43.3(g) allows pilots to perform preventive maintenance on an aircraft operating under Part 91 but not aircraft operated under Parts 121, 129, or 135. The FAA noted that, "accordingly, a pilot operating [a Learjet 60] under … Part 91 may, in accordance with the provisions of 14 CFR 43.3(g), perform daily landing gear tire pressure checks. Under the same regulation, however, a pilot of that aircraft operating under Part 135 may not perform that task." The FAA stated that any Part 135 Learjet 60 operator that may be adversely affected by the maintenance requirement may petition the FAA for relief from the regulation.

### 1.18.3 Previously Issued Safety Recommendations

#### 1.18.3.1 Learjet 60 Thrust Reverser System Recommendations Resulting From This Accident Investigation

As a result of this accident investigation, on July 17, 2009, the NTSB issued five safety recommendations to the FAA related to the Learjet 60 thrust reverser system. (A sixth recommendation addressed the Raytheon Hawker 1000 airplane, which has some thrust reverser system failure modes similar to those of the Learjet 60.[59]) The NTSB's letter to the FAA described the NTSB's concerns about safety issues involving inadvertent stowage of thrust reversers, including the potential mismatch between the cockpit reverser lever positions and the actual configuration of the thrust reversers, the lack of adequate aural or visual cues for pilots to quickly recognize inadvertent thrust reverser stowage, and the need for improved pilot training on various inadvertent thrust reverser stowage scenarios.

Safety Recommendation A-09-55 asked the FAA to do the following:

> Require Learjet to change the design of the Learjet 60 thrust reverser system in future-manufactured airplanes so that the reverse lever positions in the cockpit

[58] In its reply, the FAA addressed only the Learjet 60, noting that Learjet's question, although "framed in the context of transport-category aircraft," was specific to that airplane.

[59] Safety Recommendation A-09-60 asked that the FAA do the following: "Evaluate the design of the thrust reverser controls and indications in Raytheon Hawker 1000 business jets for potential thrust reverser failure modes that are similar to those identified in Learjet 60 airplanes and implement necessary changes."

match the positions of the thrust reverser mechanisms at the engines when the thrust reversers stow.

Safety Recommendation A-09-56 asked the FAA to do the following:

> Once design changes are developed per Safety Recommendation A-09-55, require Learjet 60 operators to retrofit existing airplanes so that the reverse lever positions in the cockpit match the positions of the thrust reverser mechanisms at the engines when the thrust reversers stow.

During technical reviews conducted for this accident investigation (after the NTSB's safety recommendations were issued), FAA representatives indicated that there is no basic certification requirement that the thrust reverser control lever position match that of the reverser mechanisms; this implies that the FAA will need to pursue a lengthy rulemaking project to amend the applicable certification regulations. However, an October 30, 2009, e-mail correspondence from NTSB staff to FAA representatives indicated that the thrust reverser design of the Learjet 60 does not appear to be in compliance with existing certification requirements, including 14 CFR 25.777 and 25.779, which relate to cockpit controls, and 14 CFR 25.1309.

The NTSB's safety recommendation letter also referenced Learjet's March 2009 TFM and stated that the NTSB is concerned that Learjet 60 airplanes do not provide sufficient cues for pilots to be able to quickly recognize inadvertent reverser stowage. Safety Recommendation A-09-57 asked the FAA to do the following:

> Require Learjet to develop and install improved aural or visual cues on future-manufactured Learjet 60 airplanes that would allow pilots to recognize an inadvertent thrust reverser stowage in a timely manner.

Safety Recommendation A-09-58 asked the FAA to do the following:

> Once improved aural or visual cues are developed per Safety Recommendation A-09-57, require Learjet 60 operators to install those cues on existing Learjet 60 airplanes.

On September 23, 2009, the FAA responded that it had assembled a team of specialists from various technical disciplines to review the recommendations and assess their underlying safety issues. The FAA stated that it intends to develop a plan to address each recommendation and will examine the adequacy of the regulatory standards associated with the recommendations. Safety Recommendations A-09-55 through -58 (and Safety Recommendation A-09-60, which applies to the Raytheon Hawker 1000 airplane) are classified "Open—Response Received."

During interviews with several Learjet 60 pilots and instructors, the NTSB learned that, although the "Inadvertent Stow of Thrust Reverser" procedure was included during initial training, the inadvertent stowage scenario was usually taught during landing and not takeoff situations. Safety Recommendation A-09-59 asked the FAA to do the following:

Require that all Learjet 60 pilots receive training, for takeoff as well as landing phases of flight, on recognizing an inadvertent thrust reverser stowage, including the possibility that the stowage can occur when the requirements for deploying thrust reversers are not fully met, such as when the air/ground sensor squat switch circuits are damaged.

On November 5, 2009, the FAA issued a SAFO that referenced the circumstances of the accident and recommended that directors of safety, directors of operations, training center program managers, and individuals responsible for training programs review their programs to ensure emphasis on recognizing inadvertent stowage of thrust reversers during takeoff and landing. Safety Recommendation A-09-59 is classified "Open—Response Received."

#### 1.18.3.2 Ongoing Assessment of Safety-Critical Systems

The safety assessment process required by 14 CFR 25.1309 and described in FAA AC 25.1309-1A, *System Design and Analysis*, is used during aircraft certification to identify and analyze safety-critical functions performed by the systems. Safety assessments are the primary means by which the certification process identifies failure conditions,[60] evaluates the potential severity of those failures, and determines their likelihood of occurrence.

In the NTSB's 2006 safety report on the aircraft certification process,[61] the NTSB noted that, once hazards[62] to safety of flight have been identified, assessed, and eliminated or controlled during certification, a program must be in place to ensure continued airworthiness and the ongoing assessment of risks to safety-critical systems.[63] The safety report stated that such a program can recognize that the certification process can change throughout the life of an airplane and can help ensure that ongoing decisions about design, operations, maintenance, and continued airworthiness consider operational data, service history, lessons learned, and new knowledge.

In the safety report, the NTSB identified a need for the FAA to formalize a process for monitoring and assessing safety-critical systems throughout the life cycle of an airplane and stated that an ongoing safety assessment process could improve the FAA's ability to evaluate derivative designs that were certificated many years before changes in the certification process occurred. The NTSB noted that the SAE International's (formerly known as the Society of Automotive Engineers) aerospace recommended practice (ARP) document, SAE ARP5150,

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[60] AC 25.1309-1A defines a failure condition as the "effects on the airplane and its occupants, both direct and consequential, caused or contributed to by one or more failures, considering relevant adverse operational or environment conditions.… [A failure is a] loss of function, or a malfunction, of a system or a part thereof."

[61] *Safety Report on the Treatment of Safety-Critical Systems in Transport Airplanes*, Safety Report NTSB/SR-06/02 (Washington, DC: NTSB, 2006).

[62] FAA Order 8040.4, *Safety Risk Management*, Appendix 1, defines "hazard" as a condition, event, or circumstance that could lead to or contribute to an unplanned or undesired event.

[63] The safety report defines a safety-critical system as a system in which a failure condition would prevent the safe flight of the airplane or would reduce the capability of the airplane or the ability of the flight crew to cope with adverse operating conditions.

*Safety Assessment of Transport Airplanes in Commercial Service,*[64] provides an industry-accepted process for the ongoing assessment of safety-critical systems[65] and describes the guidelines, methods, and tools for conducting such assessments.

As a result of its findings, the NTSB issued Safety Recommendation A-06-38, which asked the FAA to do the following:

> Adopt [SAE International's] SAE ARP5150 into 14 [CFR] Parts 21, 25, 33, and 121 to require a program for the monitoring and ongoing assessment of safety-critical systems throughout the life cycle of the airplane. Safety-critical systems will be identified as a result of A-06-36.[66] Once in place, use this program to validate that the underlying assumptions made during design and type certification about safety-critical systems are consistent with operational experience, lessons learned, and new knowledge.

In response, the FAA indicated that it intended to formalize a process for monitoring and assessing safety-critical systems. On September 12, 2007, the NTSB classified Safety Recommendation A-06-38 "Open—Acceptable Response" pending the FAA's related actions. However, due to the FAA's lack of progress in addressing this recommendation, the NTSB reiterated the recommendation and reclassified it "Open—Unacceptable Response" in its October 14, 2009, report on the accident involving a Cessna Citation 550 that crashed in Milwaukee, Wisconsin.[67]

#### 1.18.3.3 Crew Resource Management

Between 1980 and 2003, the NTSB issued numerous recommendations for the FAA to revise 14 CFR Part 135 requirements to include FAA-approved CRM training programs for Part 135 on-demand flight crews. Most recently, on December 2, 2003, the NTSB issued Safety Recommendation A-03-52, which superseded Safety Recommendation A-02-12[68] and asked the FAA to do the following:

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[64] *Safety Assessment of Transport Airplanes in Commercial Service*, SAE ARP5150 (Warrendale, Pennsylvania: Society of Automotive Engineers, 2003).

[65] SAE ARP4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*, describes industry practice for assessing the criticality of hazards to safety of flight.

[66] Safety Recommendation A-06-36 asked the FAA to do the following: "compile a list of safety-critical systems derived from the safety assessment process for each type certification project, and place in the official type certification project file the documentation for the rationale, analysis methods, failure scenarios, supporting evidence, and associated issue papers used to identify and assess safety-critical systems." In response, the FAA has indicated its plans to develop and implement a safety management system as part of each type certification project. On September 12, 2007, the NTSB classified Safety Recommendation A-06-36 "Open—Acceptable Response."

[67] National Transportation Safety Board, *Loss of Control and Crash, Marlin Air, Cessna Citation 550, N550BP, Milwaukee, Wisconsin, June 4, 2007*, Aircraft Accident Report NTSB/AAR-09/06 (Washington, DC: NTSB, 2009).

[68] On June 13, 2002, the NTSB issued Safety Recommendation A-02-12, which asked the FAA to do the following: "revise 14 [CFR] Part 135 to require on-demand charter operators that conduct operations with aircraft requiring two or more pilots to establish [an FAA]-approved crew resource management training program for their flight crews in accordance with 14 CFR Part 121, sub parts N and O."

> Require that 14 CFR Part 135 on-demand charter operators that conduct dual-pilot operations establish and implement [an FAA]-approved crew resource management training program for their flight crews in accordance with 14 CFR Part 121, subparts N and O.

Safety Recommendation A-03-52 was added to the NTSB's list of Most Wanted Transportation Safety Improvements in November 2006.

On May 1, 2009, the FAA published an NPRM titled, "Crew Resource Management Training for Crewmembers in Part 135 Operations,"[69] which responded to Safety Recommendation A-03-52 by proposing to require Part 135 certificate holders to include CRM training for pilots and flight attendants. On July 15, 2009, the NTSB provided comments in general support of the proposed rule; however, the NTSB expressed concern about some aspects of the NPRM and urged the FAA to withdraw a proposed provision to allow certificate holders to give credit for initial CRM training received from another Part 135 operator. Pending issuance of the final rule, the NTSB classified Safety Recommendation A-03-52 "Open—Acceptable Response" on December 29, 2009.

#### 1.18.3.4 Onboard Flight Recorder Systems

The NTSB has issued previous safety recommendations addressing the need to record information on all turbine-powered, nonexperimental airplanes that are not required to be equipped with an FDR and are operating under Part 135 (such as the accident airplane).The NTSB noted these issues in its January 28, 2009, report on the midair collision involving electronic news gathering helicopters in Phoenix, Arizona,[70] and expressed concern about the FAA's lack of progress. In its report, the NTSB classified some of the previous safety recommendations[71] as "Closed—Unacceptable Action/Superseded," superseding them with updated recommendations, including Safety Recommendation A-09-11, which asked the FAA to do the following:

> Require all existing turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with [an FDR] and are operating under 14 [CFR] Parts 91, 121, or 135 to be retrofitted with a crash-resistant flight recorder system. The crash-resistant flight recorder system should record cockpit audio (if a cockpit voice recorder is not installed), a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation, all to be specified in European Organization for Civil

[69] 74 FR 20263-20279, May 1, 2009.

[70] National Transportation Safety Board, *Midair Collision of Electronic News Gathering Helicopters, KTVK-TV Eurocopter AS350B2, N613TV, and U.S. Helicopters, Inc., Eurocopter AS350B2, N215TV, Phoenix, Arizona, July 27, 2007,* Aircraft Accident Report NTSB/AAR-09/02 (Washington, DC; NTSB, 2009).

[71] Among these previous recommendations was Safety Recommendation A-03-65, which asked the FAA to do the following: "require all turbine-powered, nonexperimental, nonrestricted-category aircraft that are manufactured prior to January 1, 2007, that are not equipped with [an FDR] and that are operating under … Parts 135 and 121 or that are being used full-time or part-time for commercial or corporate purposes under Part 91 to be retrofitted with a crash-protected image recording system by January 1, 2010."

Aviation Equipment document ED-155, "Minimum Operational Performance Specification for Lightweight Flight Recorder Systems," when the document is finalized and issued.

On April 17, 2009, the FAA described its participation in two proof-of-concept studies that evaluated the installation of image recorders on (1) an FAA airplane that was compliant with European Organization for Civil Aviation Equipment (EUROCAE) document ED-112 and (2) a transport-category Boeing 737 flight simulator. The findings that resulted from these studies provided valuable information about the potential uses of cockpit image recording systems on airplanes that are currently not required to carry any type of data-recording equipment. The working group incorporated this information into EUROCAE document ED-155, "Minimum Operational Performance Specification for Lightweight Flight Recorder Systems," which was published in August 2009. Safety Recommendation A-09-11 is classified "Open—Acceptable Response" pending the FAA's issuance of a TSO that includes the specifications of ED-155.

### 1.18.4 Current Airworthiness Requirements and Guidance for the Certification of Changed Aeronautical Products

The revision to 14 CFR 21.101 that became effective on June 7, 2002, states that an application for a changed aeronautical product to be added to a TC "must show that the changed product complies with the airworthiness requirements applicable to the category of the product in effect on the date of the application." The current regulation is more specific than previous revisions regarding what can be used from the original certification basis in an application for a derivative model involving a major change.

Also, on April 25, 2003, the FAA issued FAA Order 8110.48, *How to Establish the Certification Basis for Changed Aeronautical Products*, which provides the general procedures for determining the certification basis for changes to aircraft on the same TC. The handbook refers to AC 21.101-1, *Establishing the Certification Basis of Changed Aeronautical Products,* which contains additional guidance.

### 1.18.5 Tire Pressure Monitoring Systems in Aircraft Applications

Tire pressure monitoring systems (TPMS) and related systems are available for aircraft use. At least one such system may be installed on newly manufactured aircraft or as a retrofit. According to product literature, the system consists of a wireless pressure and temperature sensor built into the tire's inflation stem to facilitate the ease, accuracy, and automatic documentation of the aircraft daily tire pressure check. The system requires no batteries, power sources, or wires and obtains its operating power from an external reader or interrogator.

Another manufacturer's TPMS system takes local readings and sends data to the flight deck for display. Abnormal readings trigger visual or aural warnings in the cockpit. At the end of 2007, this TPMS was in use on nearly 2,000 commercial airliners. The second generation of this manufacturer's TPMS technology is a wireless model that transmits data via radio frequency from the wheel to the landing gear before being sent to the cockpit. The new design is lighter, smaller, more reliable, and able to be installed on smaller wheels than the previous-generation technology; further, the new design costs about 40 percent less than the earlier design. At least one model of business jet is equipped with this system.

During the accident investigation, both Learjet and Global Exec Aviation personnel stated that they were reviewing TPMS. Learjet personnel reported that one initial concern is the possibility that, because the Learjet 60's MLG wheel well is so confined, an external tire valve stem system may strike components in the wheel well.

### 1.18.6 Tire Load Certification Requirements

The Goodyear Flight Eagle tire used on the Learjet 60 was originally approved on April 3, 1982, by the FAA Chicago Aircraft Certification Office based on Goodyear QTR 461B-3044-TL, dated January 27, 1982. Goodyear personnel noted that some airframe manufacturers, including Boeing and Airbus, specify additional design requirements (beyond the requirements in 14 CFR 25.733 and TSO-C62e) for the tires installed on their airplanes.

An airplane tire's rated load is the maximum load that the tire is allowed to carry at a rated inflation pressure; according to the QTR, the Goodyear Flight Eagle tire has a load rating of 6,050 pounds. For airplanes with MLG axles fitted with dual wheel and tire assemblies (including the Learjet 60), 14 CFR 25.733 requires that the maximum service load for each tire (the actual load carried by each tire with the airplane at its maximum weight), when multiplied by a factor of 1.07, may not be greater than the rated load of the tire. Thus, according to the regulation, the maximum service load allowed for each Goodyear Flight Eagle tire used in a dual-wheel installation is 5,654 pounds.[72] The airplane's load is distributed primarily among the four MLG tires; the load supported by the nosewheel tire is relatively small.

All FAA tire certification requirements and performance verification tests are based on static loading and dynamometer[73] tests. For these tests, a properly inflated tire is mounted perpendicular to a dynamometer during load, speed, endurance, and deceleration testing.[74] TSO-C62c also included an overload takeoff cycle testing requirement, which specified that the tire must be able to withstand a takeoff cycle while overloaded to at least 1.5 times the load required in the takeoff cycle tests and retain at least 90 percent of its initial test air pressure after 24 hours. The QTR for the Goodyear Flight Eagle tire indicated that, during the overload takeoff test, a single tire inflated at 220 psi withstood a 34-second test with an initial load of 9,075 pounds (1.5 times the load rating for a single wheel/tire assembly) that reduced to 8,700 pounds as the speed increased to 210 mph. The tire also exhibited no sidewall wrinkles after two 7-mile taxi tests at 40 mph with a 20-percent overload.

[72] A service load of 5,654 pounds, multiplied by a factor of 1.07, equals the rated load of 6,050 pounds.

[73] A dynamometer is a tire test system in which the tire is pressed against a large, motor-driven steel wheel under various controlled conditions. The dynamometer test, a tool for applying loads and speeds for specific time periods, includes extreme criteria and does not replicate other variables to which in-service tires are subjected.

[74] The FAA requirements include other non-dynamic tests, such as allowable rates of air leakage.

#### 1.18.6.1 Learjet 60 Tire Selection

At the time of the Goodyear Flight Eagle tire's testing and approval, the tire had been developed for the Learjet 55. When the Learjet 60 was subsequently developed, the airplane required use of the tire's load and speed capabilities at the limits of the tire's certification criteria; that is, at the airplane's maximum weight, the MLG tires are loaded at the maximum service load permissible based on the tire's rated load

A review of static tire load calculations indicated that, with the Learjet 60's dual-axle installation, four properly inflated MLG tires would each support 100 percent of their share of the airplane's load (about 1/4 of the airplane's maximum gross weight). The calculations showed that complete pressure loss on one tire can increase the load of the adjacent, properly inflated tire on the axle to more than 120 percent. Further, changes in airplane angle also affect the load on the remaining tires.

#### 1.18.6.2 Effect of Tire Camber Angle on Tire Sidewall Loads

The investigation collected data and photographs from a Learjet 25D (which has MLG dimensions similar to the Learjet 60) that sustained damage during an RTO incident on August 19, 2009. In that incident, both of the left MLG tires were destroyed, and the right MLG tires were flat. With the left side of the incident airplane resting on the wheel rims and the right side resting on flat tires, the airplane's roll angle was measured at 1.8° to 1.9°. Learjet ground testing data showed that, if the MLG struts remained extended, an airplane with one side resting on inflated tires and the other side resting on the outboard wheel rim would have a roll angle of 2.61°.

Tire loads are spread throughout cords in the footprint and sidewalls. When an airplane has one wing lower than the opposite wing while on the ground, each tire on that airplane has a resulting camber angle,[75] making one sidewall taller than the other. Goodyear load testing data conducted for the investigation showed that, as tire camber increases, the load on one sidewall increases, which is consistent with a Learjet ground test finding that a tire's footprint and lateral loading changes with respect to camber angle. For the investigation, Goodyear personnel also performed load testing with various cambers on tires at reduced pressures; the data showed that, with camber, as tire pressure decreases, the load on one sidewall increases (and the load in the center of the tread decreases).

[75] Camber is the angle between the vertical axis of the wheel and the vertical axis of the weight being applied to the tire when viewed from the front or rear.

### 1.18.7 Takeoff Accident and Incident Data

#### 1.18.7.1 High-Speed Rejected Takeoffs

In 1990, the NTSB issued a special investigation report (SIR), *Runway Overruns Following High Speed Rejected Takeoffs*,[76] that examined high-speed RTOs involving commercial jet airplanes. The SIR reviewed three studies, which included data from the NTSB, the National Aeronautics and Space Administration, and Boeing, related to the causes and outcomes of RTOs. The SIR found that tire failures led to more high-speed RTOs than engine-related anomalies.

The Boeing study reviewed in the SIR analyzed data on RTO-related incidents and accidents from 1959 to 1988 and found that that many of the RTOs were initiated after $V_1$ and that more than half of the RTOs were unwarranted. The study found that the airplanes should have been able to continue the takeoff without incident. Since the time that the SIR was published, Boeing updated its review to include a total of 94 RTO-related accidents or incidents from 1959 to 1999.[77] The updated review found that just as many events were attributed to tire or wheel failures and malfunctions as propulsion anomalies (21 percent each) and that more than half of the RTOs were performed after $V_1$.

#### 1.18.7.2 Airplane Types Involved in Tire-Related Events

A review of NTSB data for accidents and incidents involving tire problems during takeoff identified 37 events involving corporate jets since 1982. These accidents and incidents involved 10 business jet models, including four Learjet models (25B, 35, 35A, and 36), two Beechjet/Hawker Siddeley models, and one model each for the Dassault Falcon, Raytheon Hawker, Israeli Aircraft Industries (Model 1124), and Rockwell Sabreliner airplanes. Each of the events included long taxi distances, RTOs, hot day conditions, suspected low tire pressures, or a combination of these issues.

#### 1.18.7.3 Pilot Accounts of Real and Simulated Tire Failure Events

During the accident investigation, an FAA flight test manager (who had been part of the certification process for the Learjet product line) recalled having once been involved in a high-speed RTO in a Learjet 55. He stated that, at the time, he was in the first officer's seat, and a Learjet company pilot was in the captain's seat. They were performing a takeoff at gross weight in Orlando, Florida, and all four MLG tires came apart after the airplane was beyond $V_1$. He stated that both he and the other pilot heard the tires coming apart and that he saw through the window that tire fragments were passing forward of the cockpit; he indicated that the takeoff was

[76] National Transportation Safety Board, *Runway Overruns Following High Speed Rejected Takeoffs*. Special Investigation Report SIR-90-02 (Washington, DC: NTSB, 1990).

[77] This information was obtained from Boeing's website <http://www.boeing.com/commercial/aeromagazine/aero_11/takeoff_reasons.html> (accessed February 15, 2010).

rejected due to concern that the tire fragments could be ingested by an engine. The thrust reversers were available, and he recalled that it took about 9,300 feet to stop the airplane on the 12,000-foot runway.

In addition, a pilot for the FAA's Learjet 60 aircraft evaluation group stated that he attempted to recreate the accident's inadvertent stowage scenario in a simulator. He stated that his first two attempted RTOs resulted in the simulated airplane going off the end of the runway but that his third RTO attempt was successful. Another person, who had 8 years of experience working with various Learjet-model simulators, stated that he had never performed the procedure for uncommanded thrust reverser stowage. The FAA flight test manager stated that he had trained extensively in simulators and believed that they are usually realistic but that he did not think that they could accurately portray a tire failure event.

# 2. Analysis

## 2.1 General

The captain and the first officer were certificated and qualified in accordance with Federal regulations and the operator's requirements for the Part 135 on-demand flight. Neither pilot had any previous aviation accidents, incidents, or enforcement actions.

FAA records showed that the captain received a total of four notices of disapproval. Although such disapprovals can be an indication of pilot competency problems, they must be assessed in the context of the pilot's career as a whole. In the case of the accident captain, three of these disapproval notices were issued about 11 years before the accident (when the captain had only about 200 to 250 total flight hours), and only one disapproval (for which the captain successfully retested the same day) occurred during her Part 135 flying career. 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 accident airplane was properly certificated and equipped in accordance with the regulations that applied to it as a changed aeronautical product.

The presence of organic debris within the engine's gas path is consistent with the engines running at the time of ground impact. There was no evidence of any preimpact anomalies or distress that would have prevented the engines from producing power. In addition, there was no evidence of any flight control anomalies.

The relatively new set of tires on the accident airplane showed no evidence of failures in design, manufacturing flaws, or exterior damage, such as punctures or other damage from striking foreign objects. Therefore, the NTSB concludes that the following were not factors in this accident: tire design, tire manufacture, or damage to the exterior of any tire.

The flight crew failed to perform airplane weight and balance calculations in accordance with the operator's procedures. Although postaccident estimates indicated that the airplane's maximum gross takeoff weight may have been exceeded by up to 300 pounds, there is no evidence that weight and balance issues contributed to the accident.

The following analysis describes the accident sequence, including the captain's initiation of an RTO after $V_1$ and the uncommanded forward thrust emergency that followed; airplane tire failures and maintenance; Learjet 60 design deficiencies and certification issues; flight crew performance; passenger survivability; and certification and testing considerations for aircraft tires.

## 2.2 Accident Sequence

As reported by witnesses, the beginning of the accident airplane's takeoff roll appeared normal. According to the studies discussed in sections 1.16.1 and 1.16.2, the airplane accelerated from about 12 kts at 2354:51 to about 131 kts at 2355:10.5, when the first officer stated, "$V_1$." During this timeframe, the airplane's acceleration and engine operation were consistent with the airplane's expected performance during a normal takeoff.

Less than 2 seconds later, however, when the airplane was more than 2,500 feet down the runway (with about 6,100 feet remaining), the CVR captured the beginning of a loud rumbling noise. The airplane's location on the runway at the onset of the noise correlated with the location where the first pieces of right outboard MLG tire were found. Thus, the onset of the loud rumbling noise likely resulted from pieces of the right outboard tire separating from the wheel and striking the underside of the airplane and was likely accompanied by shaking and vibration of the airframe. From this point forward, the accident sequence can be divided into two distinct segments. The first segment involves the captain's initiation of the high-speed RTO, which was a high-risk event. The second segment of the accident sequence involves the uncommanded forward thrust emergency related to the uncommanded stowage of the airplane's thrust reversers.

### 2.2.1 Captain's Initiation of Rejected Takeoff After $V_1$

The captain and the first officer were trained that rejecting a takeoff is acceptable for any anomaly occurring before the airplane reaches 80 kts and that, for speeds between 80 kts and $V_1$, the takeoff could be rejected for major anomalies, such as catastrophic failure, engine fire, engine failure, thrust reverser deployment, or loss of directional control. Their training and standard operating procedures indicated 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.

During the captain's pretakeoff briefing, she incorrectly stated that the takeoff could be rejected for major anomalies occurring between $V_1$ and $V_2$. None of the captain's training provided by FSI and Global Exec Aviation referenced any RTO criteria beyond $V_1$, and no evidence indicated that the captain was unfamiliar with the concept of $V_1$ as it related to go/no-go decision-making. An instructor who provided the captain with recurrent ground and simulator training, which included $V_1$ cuts and RTOs, described her as meticulous with good organizational skills. As noted previously, $V_1$ for the accident flight conditions was about 136 KIAS. Given that $V_2$ (which is a takeoff safety speed that would provide a minimum climb gradient after a loss of engine power [about 153 KIAS]) occurs after $V_r$ (which is the airplane's rotation speed [about 145 KIAS]), it is unlikely that the captain would have considered $V_2$ to be part of the RTO criteria.

A pretakeoff briefing is fairly standard in that the RTO criteria rarely change from one takeoff to the next. Thus, one explanation for the captain's incorrect briefing may be the use of automaticity in processing information, which is when a person uses low levels of attention to recite routine or habitual information. Such an error was consistent with a number of other information processing errors that the captain made during the taxi (including reading back wind information incorrectly) that showed a lack of focus. Therefore, the NTSB concludes that there was no indication that the captain's understanding of the rejected takeoff criteria was deficient; thus, the captain likely misspoke when she incorrectly stated the criteria in her pretakeoff briefing.

During the takeoff, when the first tire failed and the rumbling noise began, the first officer stated, "go," then "go, go, go." The airplane's ground speed at the time was about 137 kts, and, as shown by runway gouging and tire skid marks, the airplane veered to the right and across the runway centerline. Only debris from the right outboard tire was found at the runway location that coincided with the timing of this event; thus, the runway marks were likely created by the right outboard wheel rim contacting the runway surface and the skidding of the still-intact right inboard tire. (The airplane was initially left of the runway centerline before it veered.) Hydraulic fluid, consistent with that found in at least one severed brake hose, was present on some tire fragments.

In the next second (2 seconds after the onset of the rumbling sound), the captain asked, "go?" At this point in the takeoff roll, the airplane neared its peak ground speed of about 144 kts (extrapolated data show that it may have reached about 150 kts within the next second) and began shedding fragments of a landing light and other pieces (which likely separated after having been impacted by fragments of the right outboard tire). The timing of the captain's question to the first officer coincided with the captain reducing engine power for about 1 second, then increasing it for about 1 second before decreasing it again, about which time the first officer stated, "no? ar-right … what the [expletive] was that?" The entire RTO procedure, up to this point, spanned about 5 seconds since the onset of the rumbling noise from tire fragments, first from the right outboard tire and then from the right inboard tire.

Although there is no indication that either the captain or the first officer knew what type of problem occurred, each reacted to it differently. The first officer's statements to "go" suggest that, despite being unaware of the type of failure that occurred, he relied on his training and recognized that, once the airplane's speed passes $V_1$, the appropriate response is to continue the takeoff for nearly all anomalies except when airplane controllability is in serious doubt. Both the captain and the first officer were trained that continuing the takeoff under such circumstances offers several safety advantages over an RTO, such as more time to analyze the situation, the ability to reduce the airplane's gross weight and to use landing flaps, the ability to prepare for vibration and directional control problems on landing, and the availability of more runway on which to stop the airplane.

The NTSB acknowledges that the first officer, as the pilot not flying, would not have received the same airplane controllability cues that the captain received, particularly when the airplane veered to the right after the first tire failure. Thus, the NTSB considered the possibility that the captain rejected the takeoff because of a perceived loss of airplane control. However, runway markings show that, after the airplane veered, it was realigned with the runway heading, indicating that the captain was able to regain and maintain directional control. Further, although the captain initially reduced engine power, she did not make an RTO callout, and her subsequent increase in engine power, concurrent with her question "go?," indicates that she briefly considered continuing the takeoff before finally committing to the RTO. Therefore, the NTSB concludes that the captain's uncertainty as to whether to continue the takeoff suggests that her initial action to reject it did not result from a perception that the airplane was uncontrollable and could not fly.

During about 4 seconds after the captain made the second engine power reduction, the airplane's engine $N_1$ decreased to about 7,300 rpm, the captain made the comment "full out" (likely referring to full deployment of the thrust reversers), and wheel brakes were applied (as indicated by CVR sound evidence). Extrapolated ground speed information estimated that the airplane decelerated to about 128 kts. Debris evidence showed that, at this point, all of the MLG tires had failed (within about 9 seconds of the first tire's failure).

The captain's action to reject the takeoff after the airplane had passed $V_1$ placed the flight crew and passengers in a high-risk situation; accident and incident data show that high-speed RTOs can result in runway overruns. During pilot training, $V_1$ is generally considered to be the speed at which the pilot must be committed to transition the airplane to flight; to reinforce this concept, pilot training programs and standard operating procedures (including those provided to the captain) emphasize that the pilot flying should remove his/her hand from the throttles at the time that the $V_1$ callout is made. The purpose of such training and reinforcement is to ensure that the pilot responds immediately and correctly to any anomalies because the situation allows no time for assessment after the problem occurs, and any delays or mistakes increase the chance of an overrun (or the speed at which an overrun occurs). The NTSB concludes that, in the absence of evidence that the airplane was uncontrollable, the captain's execution of a rejected takeoff for an unknown anomaly after the airplane's speed had passed $V_1$ was inconsistent with her training and standard operating procedures.

### 2.2.2 Uncommanded Forward Thrust Emergency

As supported by the airplane performance study discussed in section 1.16.2, after the captain had committed to performing the high-speed RTO, the accident airplane's thrust reverser system initially performed as commanded. On the basis of the captain's comment "full out," which coincided with a noticeable deceleration of the airplane, the study found that the thrust reversers had fully deployed, and the system provided reverse engine thrust. However, about 7 seconds after the captain committed (about 10 seconds after the rumbling noise began), the CAM captured the nosewheel steering disconnect warning tone. Because nosewheel steering is typically engaged while the airplane is on the ground, the timing of this tone provides an indication of when the system status changed to "air mode." For this to occur, the circuit associated with the MLG electrical components and wiring, which include the wheel speed sensor and squat switch, must have sustained damage that affected the air-ground signal. Debris found on the runway and other physical evidence show that the MLG area where system components were mounted sustained damage from the shedding tire fragments.[78]

As a result, because the system logic requirements for maintaining thrust reverser deployment were no longer being met, the thrust reversers stowed. Meanwhile, as indicated by engineering and ground tests, the thrust reverser levers in the cockpit remained in the raised

[78] The right landing light was mounted immediately above the squat switch, and the wiring was routed together. Glass from the light was found on the runway near the fragments from the right outboard and inboard tires.

full-reverse-thrust position, the TR DEPLOY annunciators extinguished, and the TR UNLOCK annunciators momentarily illuminated (while the reverser doors were in transit toward stow); then, the TR ARM annunciators flashed briefly before all TR annunciators extinguished completely. During this sequence, the EECs shifted logic and signaled the FADEC components to change to the forward thrust power schedule. Because the flight crew had commanded full reverse thrust, the EECs (because of the shifted logic) interpreted the TLA and RDVT positions and signaled the FADEC components to provide forward thrust at near takeoff power.

As a result, the flight crew was faced with an emergency in which the wheel braking system was compromised due to tire and hydraulic system damage, and the airplane was accelerating with high engine power toward obstacles beyond the end of the runway. There was no warning annunciator in the cockpit to indicate any system anomaly; thus, initially, the captain was expecting to have continued reverse thrust as commanded with the reverse thrust levers. Under these abnormal circumstances, reducing the airplane's uncommanded forward thrust would require moving the thrust reverser levers to the stowed position. However, moving the reverser levers to the stowed position (when maximum reverse thrust was needed and commanded) during an RTO was likely counterintuitive to the captain. (The NTSB's safety recommendations to address this problem are discussed in sections 1.18.3.1 and 2.3.2.)

As depicted in the airplane performance map overlay in section 1.16.2, the airplane was about 2,500 feet from the end of the runway at a ground speed of about 123 kts when the uncommanded forward thrust began, and the airplane accelerated for several seconds until the first officer assessed the problem and reacted. By the time that the first officer stated, "shut 'em off," the engines' $N_1$ had increased to about 9,165 rpm. Although the sound spectrum evidence indicates that engine power subsequently began to decrease, the ground speed information, ground witness marks, obstacle collision evidence, and the condition and location of the main wreckage indicated that the airplane was traveling in excess of about 100 kts when it overran the end of the RSA.

As mentioned previously, most of an airplane's stopping power is provided by the wheel braking system, and the flight crew applied the wheel brakes within 1 second of the captain's "full out" comment. However, there are no data that can be used to reliably estimate the braking performance for an airplane that has a compromised hydraulic system and no intact MLG tires. Thus, it is 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. Although the captain lost seconds when delaying her commitment to the RTO, had the airplane developed reverse thrust as the captain commanded or transitioned to idle thrust with the uncommanded stowage of the thrust reversers, the airplane's ground speed for the overrun would have been slower. Therefore, the NTSB concludes that the accident airplane's uncommanded forward thrust, which accelerated the airplane at a time when the flight crew commanded full reverse thrust to decelerate the airplane, increased the severity of the accident because the uncommanded forward thrust substantially increased the airplane's runway excursion speed.

## 2.3 Airplane Issues

Although the captain's action to initiate a high-speed RTO and her delays in performing the procedure placed the flight at risk for a runway overrun, issues related to the airplane played a role in both setting up the chain of events that led to the accident and exacerbating the final outcome. Of particular concern are the operator's tire maintenance practices, Learjet's design of the airplane's thrust reverser system, the inadequacy of both Learjet's and the FAA's review of the Learjet 60 after the 2001 accident, and the safety of the FAA's certification process for changed aeronautical products. All of these issues combined to create a situation that was unacceptably intolerant to the captain's deviation from a standard operating procedure.

### 2.3.1 Tire Failures

Damage observed on fragments from all four MLG tires, such as abrasion marks on the inner liner and heat damage to the rubber and nylon materials, was consistent with overdeflection of the tires. Two tire operating conditions can result in such sidewall overdeflection: overloading and underinflation. Under either condition, excessive flexing of the sidewall generates high internal temperatures and weakening of the sidewall plies, leading directly to failure.

The location of the sidewall damage on each of the accident airplane's tires was helpful in determining which condition resulted in or contributed to the tire failures. Static test data show that, if proper inflation of all four MLG tires is assumed, to achieve the amount of overdeflection evident from the damage, each tire would need to be overloaded with about 12,200 pounds (about twice as much weight as the accident airplane could have imposed on each tire). Such overloading of four properly inflated tires is implausible (it would require an airplane gross weight in excess of 48,800 pounds), and other evidence strongly supports that the tires were not properly inflated.

As indicated by Global Exec Aviation's director of maintenance, the airplane's tire pressures had not likely been checked in the 3 weeks before the accident. The QTR for the Goodyear Flight Eagle tire indicated a 2.2-percent average daily pressure loss (the TSO for the tire allows a loss of up to 5 percent per day). With the assumption that the accident airplane's tires were properly inflated at the beginning of the 3-week period and that the daily loss rate was about 2 percent, the tires were likely operating while about 36-percent underinflated on the day of the accident.[79] The Learjet AMM indicates that tires should be replaced after operating at 15-percent underinflation. (This replacement specification is due to the overdeflection and damage that the tire sidewalls sustain from operation at such an underinflated pressure.)

As indicated in section 1.16.3.2, testing performed to determine what level of underinflation would produce the type of damage observed on the accident airplane's tires found that the damage was consistent with tires operating while about 36-percent underinflated. Thus, the underinflation value derived from the loss-rate calculation (based on the tire service history)

[79] The calculation applies the loss rate to each day's (decreasing) initial inflation value for the tire.

corresponds with the value that testing showed would be needed to produce damage such as that found on all four of the accident airplane's tires. Therefore, the NTSB concludes that all four MLG tires on the airplane were operating while severely underinflated during the takeoff roll, which resulted in the tire failures.

#### 2.3.1.1 Operator's Tire Maintenance Practices

Global Exec Aviation's director of maintenance indicated that he did not know how often the Learjet 60's tire pressures should be checked but that he referred to the respective AMM for each type of airplane operated by the company to know when to perform scheduled maintenance items. Chapter 12 of the Learjet AMM suggested daily tire pressure checks, which is consistent with the AMMs for other airplanes (Cessna CE-650 and Dassault Falcon 50) operated by Global Exec Aviation. Learjet maintenance and product support publications, FAA AC 20-97B, and several Goodyear publications also specified daily or regular tire pressure checks.

Although the daily tire pressure check interval referenced in the AMM was not specified as a requirement, the director of maintenance is responsible for ensuring proper airplane tire maintenance, including adequate tire pressures. Allowing the airplane to operate for weeks without a tire pressure check is inconsistent with all available guidance. Further, the NTSB's informal survey to collect information about in-service tires found that most of the tires sampled were inflated to within 10 percent of their rated pressure (typically within AMM limits), which suggests that most, but not all, operators are ensuring adequate tire inflation.

Given the average expected daily pressure loss for the accident airplane's tires, any operations involving the accident airplane within the 2 weeks preceding the accident would have been conducted while the tires were likely at inflation pressures below the replacement criteria listed in the AMM. As indicated in the AMM, such underinflation of MLG tires cannot be determined by a visual inspection; thus, the flight crewmembers (who typically do not perform tire pressure checks) would have been unable to detect the underinflated condition of the tires. Therefore, the NTSB concludes that the accident airplane's insufficient tire air pressure was due to Global Exec Aviation's inadequate maintenance.

#### 2.3.1.2 Maintenance Manual References to Tire Pressure Check Intervals

As referenced, most of the tires reviewed in the NTSB's informal survey were adequately inflated; however, some were not. Although nearly all of the maintenance providers interviewed indicated that use of the AMM is required by an operator's operations specifications, one FBO operator interviewed noted that some AMMs do not call for mandatory tire pressure checks and that he believed that weekly pressure checks were generally good practice. Contrary to what this FBO operator believed, a weekly check would not be sufficient for some tires (such as those installed on the Learjet 60). Therefore, the NTSB concludes that some operators are not sufficiently aware of the appropriate tire pressure check intervals for the airplanes in their fleets and are operating their airplanes with tires inflated below the AMM replacement specifications. Therefore, the NTSB recommends that the FAA provide pilots and maintenance personnel with information that (1) transport-category aircraft tires can lose up to 5-percent pressure per day,

(2) it may take only a few days for such tires to reach an underinflation level below what the AMM specifies for tire replacement, and (3) the underinflation level that would require tire replacement is not visually detectable. The NTSB further recommends that the FAA require that all 14 CFR Part 121, 135, and 91 subpart K operators perform tire pressure checks at a frequency that will ensure that the tires remain inflated to within AMM-specified inflation pressures.

Although the Learjet 60 AMM contained information about tire pressure checks, the information was not prominent in the manual. The only reference to tire pressure checks that appeared in the section of the Learjet 60 AMM dedicated to inspection intervals (chapter 5) was under a 300-hour interval phase inspection and indicated that the user should refer to chapter 12 for the information. Chapter 12 is a section of the AMM dedicated to descriptions of how to perform maintenance tasks but not when they should be performed. Further, the daily tire pressure check intervals listed in chapter 12 of the Learjet 60 AMM appeared under the heading "Practices and Tips," indicating that the information was discretionary rather than mandatory.

Although Learjet issued AMM TR 12-16 on March 18, 2009, to better define when and how to check tire pressures (and to state that such checks "must" be performed), this clarifying information remains in chapter 12. Other airplane manufacturers also list tire pressure check interval information in chapter 12 of their respective AMMs; however, this format is not consistent among all manufacturers' FAA-approved manuals. The NTSB concludes that AMM formats that refer to tire pressure checks as guidance information rather than required maintenance intervals and the lack of standardization of AMM formats with respect to the location of tire pressure check interval information do not provide sufficient emphasis on the criticality of checking and maintaining tire pressure. Therefore, the NTSB recommends that the FAA require that AMMs specify, in a readily identifiable and standardized location, required maintenance intervals for tire pressure checks (as applicable to each aircraft).

Other inconsistencies related to tire pressure checks were found in the FAA's February 26, 2009, response to Learjet regarding the Learjet 60. In the letter, the FAA stated that checking the tires on a Learjet 60 is preventive maintenance, which pilots would not be permitted to do as part of a preflight check. However, the FAA further explained that a pilot flying a Learjet 60 under 14 CFR Part 91 may perform tire pressure checks but that a pilot flying a Learjet 60 under 14 CFR Part 135 may not.

The NTSB notes that, according to the FAA's interpretation, a pilot working for a Part 135 on-demand operator would be allowed to check tire pressures on a Learjet 60 for Part 91 ferry or maintenance flights but that the same pilot would be prohibited from performing the same checks on the same airplane for a Part 135 flight for revenue passengers or cargo. Because of the nature of Part 135 on-demand operations (and as evidenced by this accident flight crew's trip pairings), it is not unusual for a flight crew to remain with an airplane away from the operator's base for several days while flying both revenue and positioning flights.

The NTSB acknowledges that the different rules that apply to Part 135 flights generally represent a higher level of safety than those contained in Part 91. In this case, however, the NTSB is concerned that the FAA's interpretation may have an unintended negative effect on safety because the interpretation arbitrarily prohibits personnel from performing a safety task. Although the interpretation pertains only to the Learjet 60 (in direct response to questions from

Bombardier Learjet) and allows operators to petition for exemption, pilots and operators of other transport-category airplanes may be unsure if the interpretation applies to their operations.

Therefore, NTSB concludes that the FAA's legal interpretation that checking tire pressures on a Learjet 60 is preventive maintenance has an unintended negative effect on the safety of Part 135 operations because, according to the provisions of 14 CFR 43.3, a Learjet 60 pilot who is allowed to perform preventive maintenance, such as tire pressure checks, on the airplane for a flight operated under Part 91 is prohibited from performing the checks on the same airplane for a Part 135 flight. Therefore, the NTSB recommends that the FAA allow pilots to perform tire pressure checks on aircraft, regardless of whether the aircraft is operating under 14 CFR Part 91, Part 91 subpart K, or Part 135.

#### 2.3.1.3 Lack of Tire Pressure Information for Flight Crews

Tires require proper inflation to perform as designed. TPMS, which is installed in some new airplanes and can be retrofitted on others, provides flight crews with tire pressure information at the tire inflation valve (or, with some systems, visual or aural alerts in the cockpit to indicate abnormal conditions). Because the allowable daily pressure loss for aircraft tires can result in tire pressures that are below acceptable operational values within only a few days, providing tire pressure information to a flight crew helps ensure proper inflation and safe operations, particularly when the airplane is away from the operator's maintenance base for multiday trips.

As previously mentioned, the accident pilots (who were not tasked with checking the tire pressures) had no means by which to detect the accident airplane's underinflated tires. Had the pilots been aware of the airplane's tire condition, they could have had the airplane's tires serviced by a maintenance facility. (The NTSB notes that the airplane was in a facility for other maintenance before the airplane was repositioned for the accident flight.) Therefore, the NTSB concludes that TPMS, which enable flight crews to easily verify tire pressures, provides safety benefits because the pressure-loss rate of aircraft tires can result in tire pressures below acceptable operational values within only a few days, and such underinflation cannot be visually detected by flight crews. Therefore, the NTSB recommends that the FAA require TPMS for all transport-category airplanes.

### 2.3.2 Thrust Reverser System Deficiencies

The thrust reversers on the Learjet 60, as with those on other airplanes, are intended to assist with ground braking. The Learjet 60 was the first Learjet model to be equipped with a fully electronic thrust reverser control, and no other Learjet model has a similar system. To protect against thrust reverser deployment in flight, the thrust reverser logic criteria are such that, in the event of any system failures or anomalies, the thrust reversers will stow. This safety feature ensures that a system anomaly cannot result in a thrust reverser deployment in flight, which could affect the airplane's controllability. Although the protection against in-flight deployment provided by the stowage feature is necessary, the circumstances of this accident (and the other events discussed in section 1.16.4.2) highlight a system vulnerability in which the damage from a single tire can result in an erroneous air/ground mode signal, inadvertently activating the protection logic and leading to the acceleration of the airplane in response to a pilot's control commands for deceleration.

As previously discussed, the accident airplane's thrust reverser system initially performed as commanded until debris damage resulted in the loss of the "ground mode" signal and the logic changed to "air mode." As demonstrated by ground testing performed in a Learjet 60 equipped to duplicate the accident airplane's scenario (in which the logic requirements for maintaining thrust reverser deployment were not longer being met), the sequence that followed was that the thrust reverser doors stowed while the cockpit thrust reverser levers remained lifted in the reverse thrust position (as had been selected by the captain) and the engines instead produced forward thrust at near takeoff power. The only cockpit indication available to the captain and the first officer about the nature of the emergency was the absence of thrust reverser annunciators.

In a July 17, 2009, safety recommendation letter to the FAA, the NTSB concluded that, during an RTO, which requires quick and concentrated pilot actions, a pilot may have difficulties recognizing the significance of the absence of reverse thrust indicator lights. As described in section 1.18.3.1, the NTSB issued Safety Recommendation A-09-59 that asked the FAA to require that Learjet 60 pilots receive training on recognizing inadvertent thrust reverser stowage. On November 5, 2009, the FAA issued a SAFO that referenced the circumstances of the accident and recommended that directors of safety, directors of operations, training center program managers, and individuals responsible for training programs review their programs to ensure emphasis on recognizing inadvertent stowage of thrust reversers during takeoff and landing. The NTSB notes that, if the FAA can demonstrate that the issuance of the SAFO has achieved the same effect as a requirement that all Learjet 60 operators and training centers include the recommended training, the NTSB will consider the FAA's action to be an acceptable alternative. To complete the action recommended, the FAA needs to supply information documenting that all Learjet 60 operators and training centers have incorporated the recommended training. Pending receipt of that information, the NTSB classifies Safety Recommendation A-09-59, "Open—Acceptable Alternate Response."

Because the NTSB views this pilot training as an interim measure to help mitigate the hazards associated with the identified thrust reverser design deficiencies until these deficiencies are corrected, the NTSB also issued several safety recommendations (A-09-55 through -58 and -60, referenced in section 1.18.3.1) addressing the need for changes to the Learjet 60's (and the Raytheon Hawker 1000's) thrust reverser system design. The recommended design changes include modifications to ensure that the thrust reverser lever positions in the cockpit match the positions of the thrust reverser mechanisms at the engines and to provide improved aural or visual cues to allow pilots to recognize an inadvertent thrust reverser stowage in a timely manner.

The NTSB is pleased that the FAA has assembled a team of technical specialists to develop a plan for addressing each recommendation (as indicated in the FAA's September 23, 2009, response). Although FAA representatives assisting with this accident investigation have indicated that there is no basic certification requirement that the thrust reverser control lever position match that of the reverser mechanisms, the NTSB notes that the thrust reverser design of the Learjet 60 does not appear to be in compliance with existing certification requirements, including 14 CFR 25.777, 25.779, and 25.1309. Also, 14 CFR 25.933, which relates to thrust reverser systems, requires a means to prevent the engine from producing more than idle forward thrust in the event of a thrust reverser system malfunction. Because of these existing regulations, the NTSB believes that the FAA should be able to take the recommended actions without any lengthy rulemaking project to revise the certification standards. Pending the FAA's completion of the recommended actions, the NTSB classifies Safety Recommendations A-09-55 through -58 and -60, "Open—Acceptable Response."

Although the NTSB is pleased that the FAA has initiated responsive action to address these safety recommendations, the NTSB is concerned that many of these issues were not more thoroughly addressed by Learjet and the FAA after the January 14, 2001, landing accident in Troy, Alabama, in which a Learjet 60 accelerated off the end of the runway after an uncommanded stowage of the thrust reversers. Although the 2001 accident occurred during landing, it also involved an uncommanded forward thrust event after squat switch system damage.

After the 2001 accident, the FAA did not require any modifications to the airplane's design. Although Learjet initiated a safety review of the circumstances of the accident, the solutions it implemented (and that the FAA approved) did not adequately address the design deficiencies. For example, Learjet's AFM revision in 2003 (to include the "Inadvertent Stow of Thrust Reverser After a Crew-Commanded Deployment" procedure as an emergency procedure) inappropriately relied on a flight crew procedure to mitigate a hazard as serious as uncommanded forward thrust. Use of a procedure, instead of a design change, is not an adequate corrective action for such an emergency, especially when the airplane's design makes performing the procedure counterintuitive. Although Learjet subsequently introduced a design change to supplement the procedure, the modification also failed to adequately address the problem.

According to SB 60-78-7, which specified the modification, the design change was intended "to reduce the possibility of inadvertent stowing during thrust reverser operation." The modification incorporated the airplane's existing wheel speed sensors into the thrust reverser logic, but the redundant signal was designed to provide input only after the airplane's squat switches signaled air mode for at least 2 minutes, beginning within 50 seconds of the ground-to-air transition. Although this restriction is consistent with the system's original fail-safe concept to protect against thrust reverser deployment in flight, the restriction prevents the wheel speed sensor redundancy during RTO scenarios because the airplane never enters air mode before thrust reverser deployment. Thus, the design change did not reduce the possibility of uncommanded stowage of the thrust reversers during an RTO.

An effective safety assessment process should result in the creation of system-level design requirements to ensure safe operation during abnormal or emergency conditions (such as an RTO), including situations in which there are disagreements between commanded and actual system states (as exhibited by the thrust reverser system in this accident). Guidance for demonstrating compliance with the safety requirements contained in 14 CFR 25.1309 is described in AC 25.1309-1A. This guidance directs the use of a structured process for performing safety assessments on systems that have high levels of complexity, integration, and safety-critical functionality (such as the Learjet 60 thrust reverser system). SAE ARP4761,[80] which is intended to be used with the regulatory guidance contained in AC 25.1309-1A, also describes industry best practices for performing safety assessments for the certification of civil aircraft.

The NTSB is concerned that neither Learjet's safety analyses for the modification nor the FAA's review resulted in adequate design protection against uncommanded stowage of the thrust reversers—and, more importantly, the associated uncommanded forward thrust—during RTO scenarios. The NTSB finds these shortcomings particularly alarming because the type of analyses used by Learjet and reviewed by the FAA represents a safety risk management technique that the FAA has promoted as one of the four pillars of an effective safety management system (SMS),[81] which the FAA has described as the most effective way to improve safety and accomplish oversight.[82] Although the NTSB endorses SMS implementation as a means to improve safety,[83] it is critical that the FAA use this accident as an opportunity to examine why the processes that are essential to an effective SMS, hazard identification, and risk analysis and assessment were not effective in preventing this accident despite the presence of precursor in-service data.

Therefore, the NTSB concludes that Learjet's system safety analysis for and the FAA's review of the Learjet 60's thrust reverser system modification and revised crew procedure were inadequate because they failed to effectively address an unsafe condition for all phases of flight, specifically, uncommanded forward thrust during an RTO. Therefore, the NTSB recommends that the FAA identify the deficiencies in Learjet's system safety analyses, both for the original Learjet 60 design and for the modifications after the 2001 accident, that failed to properly address the thrust reverser system design flaws related to this accident, and require Learjet to perform a system safety assessment in accordance with 14 CFR 25.1309 for all other systems that also rely on air-ground signal integrity and ensure that hazards resulting from a loss of signal integrity are appropriately mitigated to fully comply with this regulation. The NTSB further recommends that the FAA revise available safety assessment guidance (such as AC 25.1309-1A) for manufacturers to adequately address the deficiencies identified in Safety Recommendation A-10-51, require that DERs and their FAA mentors are trained on this methodology, and modify FAA design oversight procedures to ensure that manufacturers are performing system safety analyses for all new or modified designs that effectively identify and properly mitigate hazards for all phases of flight, including foreseeable events during those phases (such as an RTO).

[80] *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*, SAE ARP4761 (Warrendale, Pennsylvania: Society of Automotive Engineers, 1996).

[81] AC 120-92, *Introduction to Safety Management Systems for Air Operators*.

[82] As noted in a statement by Nicholas A. Sabatini, FAA Associate Administrator for Aviation Safety, before the House Committee on Transportation and Infrastructure, Subcommittee on Aviation, on September 20, 2006: "SMS formalizes risk management, which is imperative as we move from a forensic, or after-the-fact accident investigation approach, to a diagnostic and more prognostic, or predictive, approach. With the accident rate as low as it is, we must get in front of information, analyze trends, and anticipate problems if we are to continue to improve on an already remarkable record of achievement. Operating under [an SMS] will allow airlines, manufacturers, and the FAA to do this better than before."

[83] Reference NTSB Safety Recommendations A-07-10, A-09-89, and A-09-99.

In the NTSB's 2006 safety report on the aircraft certification process, the NTSB noted that a program must be in place to ensure continued airworthiness and the ongoing assessment of risks to safety-critical systems. The safety report stated that such a program can recognize that the certification process can change throughout the life of an airplane and can help ensure that ongoing decisions about design, operations, maintenance, and continued airworthiness consider operational data, service history, lessons learned, and new knowledge. The NTSB noted that SAE ARP5150 provides a process that is accepted by industry for the ongoing assessment of safety-critical systems.

As a result of its findings, the NTSB issued Safety Recommendation A-06-38, which asked the FAA to do the following:

> Adopt [SAE International's] ARP5150 into 14 [CFR] Parts 21, 25, 33, and 121 to require a program for the monitoring and ongoing assessment of safety-critical systems throughout the life cycle of the airplane. Safety-critical systems will be identified as a result of A-06-36.[84] Once in place, use this program to validate that the underlying assumptions made during design and type certification about safety-critical systems are consistent with operational experience, lessons learned, and new knowledge.

Because of the FAA's lack of progress in response to the recommendation, on October 14, 2009, the NTSB reiterated Safety Recommendation A-06-38 and reclassified it "Open—Unacceptable Response."

The circumstances of this accident demonstrate the importance of an FAA program to monitor and conduct ongoing assessments of safety-critical systems throughout the life cycle of an airplane to detect indications of a problem and correct the problem before an accident results. Therefore, the NTSB concludes that, had the FAA adopted the procedures described in SAE International's SAE ARP5150, *Safety Assessment of Transport Airplanes in Commercial Service,* to require a program for the monitoring and ongoing assessment of safety-critical systems, the FAA may have recognized, based on problems reported after previous incidents and an accident, that the Learjet 60's thrust reverser system design was deficient and thus may have required appropriate modifications before this accident occurred.

### 2.3.3 Safety of Changed Aeronautical Products

The certification basis for changed aeronautical products allows an aircraft manufacturer to use the results of some of the analyses and testing from the original type certification to demonstrate compliance for derivative models, and some regulations that were in effect on the date of the original TC apply (with exceptions specified in the TCDS). The Learjet 60 was certificated in 1993 but was added to Learjet TC A10CE, which was originally issued for the Learjet 24 in 1966. From a certification basis, the Learjet 24 and the Learjet 60 are the same type of airplane; however, they share few similarities or structural components.

[84] Safety Recommendation A-06-36 is discussed in section 1.18.3.2.

Since the certification of the Learjet 60, the FAA has made improvements in the certification process for changed aeronautical products. The current version of 14 CFR 21.101 (which was issued in 2000) is more specific than the version of the regulation that applied to the Learjet 60 with regard to the circumstances under which current airworthiness regulations must be used and when earlier amendments of a regulation are acceptable. Also, FAA Order 8110.48, issued in 2003, provides the general procedures for determining the certification basis for changes to aircraft on the same TC and specifies that the FAA may require a manufacturer to apply for a new TC for extensive changes. Although these more specific requirements and improved guidelines have removed some of the subjectivity to the certification basis for derivative model aircraft, the procedures still allow for inconsistencies and interpretation.

For example, the FAA has approved airplane designs for some manufacturers that are sold as new products over production lives that span decades but are on one TC, whereas the airplane designs from another manufacturer (or certain designs from the same manufacturer, such as the Learjet 45) may have each been certificated on a new TC. As a result, airplane models that may appear comparable based on criteria such as date of release and/or payload and range specifications may actually be certificated to different safety standards. For example, although the Learjet 45 and the Learjet 60 were both introduced in the 1990s, the Learjet 45 was subject to the most updated, more stringent certification regulations at the time, whereas many of the certification requirements that applied to the Learjet 60 were based on older, less stringent requirements. (Manufacturers may electively exceed the certification requirements, and many, including Learjet, have done so.) The Learjet 60's compliance with 14 CFR 25.1309, which relates to failures of equipment, systems, and installations, was required to be based on a modification to the original version of the regulation, even though an extensively revised version of the regulation, including amendment 25-41 (applicable to the Learjet 45), had been in effect since 1977.

In 1981, during a certification review of a different Learjet derivative model, the FAA noted that the revised requirements of 14 CFR 25.1309 provided a higher level of safety than previous versions of the regulation and that "it is necessary that flight critical systems meet these more stringent requirements to ensure safety." A comparison of the protection for equipment in the wheel wells of the Learjet 60 with that in the Learjet 45 illustrates the safety impact that the revised regulations can have on aircraft designs. Although both airplanes were subject to the same criteria specified in 14 CFR 25.729 for protecting equipment from the damage that could be caused by fragments from a disintegrating tire, the Learjet 45 was also subject to the revised version of 14 CFR 25.1309. As a result, the Learjet 45 has protective shielding and other design improvements that protect hydraulic system components, wiring, and other equipment installed in the wheel well, whereas some of the same system components in the Learjet 60 are considerably more exposed.

Another improved safety feature on the Learjet 45 relates to the thrust reverser system. In the event that an abnormal condition results in the stowage of reverser doors while the cockpit levers are raised, the Learjet 45's thrust reverser control electronically triggers the cockpit thrust reverser levers to move to the stowed position and the engine thrust to idle power. The NTSB notes that either of these Learjet 45 design features (the added wheel well protection or the improved electronic thrust reverser control) would likely prevent the Learjet 45 from producing uncommanded forward thrust after a chain of events stemming from a tire failure, which occurred in this accident.

The NTSB concludes that the FAA's 1993 certification of the Learjet 60 as a changed aeronautical product, which allowed the airplane's equipment, systems, and installations to conform to some regulations applicable to the original 1966 certification, did not ensure the highest level of safety and allowed for deficiencies that would not likely have been present if the current regulations had applied. Therefore, the NTSB recommends that the FAA revise FAA Order 8110.48 to require that the most current airworthiness regulations related to equipment, systems, and installations (14 CFR 25.1309) are applied to all derivative design aircraft certificated as changed aeronautical products. The NTSB further recommends that the FAA review the designs of existing derivative design aircraft that were certificated as changed aeronautical products against the requirements of the current revision of 14 CFR 25.1309 and require modification of the equipment, systems, and installations to fully comply with this regulation.

## 2.4 Flight Crew Performance

Section 2 of AC 120-62 acknowledges that tire failures may be difficult to identify from the flight deck and stresses that flight crews must be cautious not to inappropriately conclude that another problem exists. The accident airplane's swerve, the onset of continuous noise from tire fragments striking the fuselage, and the related airframe vibration could have startled the captain. Further, the hydraulic fluid found on some tire fragments indicates that hydraulic integrity was compromised early in the sequence. As a result, the hydraulic pressure annunciators in the cockpit would have illuminated, providing the captain with additional cues about problems that she might not have fully comprehended.

However, all of these cues occurred after the airplane had passed $V_1$, and there was no strong evidence that the airplane was uncontrollable. The captain's action to reject the takeoff and her lack of a callout, contrary to her training, may have been the result of the "startle factor," which is often lacking in training scenarios. In most $V_1$ training scenarios, pilots are in a simulator, are aware that they will be receiving an anomaly (usually an engine failure) on takeoff, and are prepared to respond. In the real world, the situation is more dynamic, the consequences are greater, and the pilot is not aware that a failure will occur or what type of failure it is. This "startle factor" can increase the stress level of the pilot, resulting in an incorrect decision being made. The following analysis examines factors that may have influenced the captain's actions.

### 2.4.1 Lack of Training for Tire-Related Events

As indicated in the NTSB's 1990 SIR related to runway overruns associated with high-speed RTOs[85] and an updated review by Boeing that includes data up to 1999, accidents and incidents related to RTOs initiated because of wheel or tire malfunctions are as common as those related to RTOs performed in response to engine failures. The accidents and incidents

[85] NTSB SIR-90-02.

show that, like the accident captain, many other pilots have misinterpreted tire anomalies and responded by initiating an unnecessary RTO after $V_1$.

According to an FSI instructor, the training curriculum provided to the captain and the first officer did not include any scenarios in which a tire failure occurred. Training materials provided to flight crews about RTOs focus primarily on engine failures at or around $V_1$. There was no indication that wheel and tire failure scenarios are readily trained or that training scenarios are conducted to assess a flight crew's reactions to failures or malfunctions occurring after $V_1$.

The NTSB realizes that there are limits to the time operators can allocate to training to prepare pilots to respond to all possible emergency and abnormal situations. However, the data from past accidents show that numerous flight crews were not prepared to respond appropriately, as trained, to tire anomalies, which resulted in runway overrun accidents that might have been avoided had the takeoff been continued. Although AC 120-62 is a useful training aid in that it provides thorough guidance related to takeoff safety and cautions pilots about misinterpreting tire events, as a textual training tool, its effectiveness is limited in preparing flight crews for the startling cues, including loud noises and airframe shaking and vibration, associated with tire failures when they occur. However, flight simulators are often used effectively to train flight crews to recognize and respond properly to startling cues associated with various abnormal and emergency flight situations.

The NTSB concludes that the accident pilots would have been better prepared to recognize the tire failure and to continue the takeoff if they had received realistic training in a flight simulator on the recognition of and proper response to tire failures occurring during takeoff. The NTSB recommends that the FAA define and codify minimum simulator model fidelity requirements for tire failure scenarios. These requirements should include tire failure scenarios during takeoff that present the need for rapid evaluation and execution of procedures and provide realistic sound and motion cueing. The NTSB further recommends that, once the simulator model fidelity requirements requested in Safety Recommendation A-10-55 are implemented, the FAA require that simulator training for pilots who conduct turbojet operations include opportunities to practice responding to events other than engine failures occurring both near $V_1$ and after $V_1$, including, but not limited to, tire failures.

### 2.4.2 Captain's Experience in the Learjet 60 and as Pilot-in-Command

A PIC who is not yet confident in commanding a new type of airplane may not respond quickly enough or appropriately in an abnormal situation. The captain in this accident demonstrated some uncertainty about her response to the anomalies during takeoff. Although the RTO criteria and procedures for the Learjet 60 do not fundamentally differ from those of the other airplane types flown by the captain, both her question to the more experienced first officer ("go?") and her wavering back and forth on engine power input indicate a lack of confidence in commanding the airplane.

The captain was trained and qualified to fly both the Learjet 60 and the Cessna CE-650 in Part 135 on-demand operations. The captain received a type rating for the Learjet 60 about 11 months before the accident and logged about 35 hours in the airplane, about 8 of which were accumulated while acting as PIC. While accruing time in the Learjet 60, she also became type rated in the Cessna CE-650 (about 9 months before the accident) and flew about 118 hours in that airplane for Global Exec Aviation. Before the captain was assigned to the trip pairing on the accident airplane (which includes the day before the accident), the captain had not flown as PIC in the Learjet 60 for about 1 month. She had performed most of her flying duties (as PIC or SIC) in the Cessna CE-650, with fewer hours in the Learjet 60, and had not accrued much PIC experience in either airplane.

The NTSB is concerned that when a pilot switches between two types of airplanes before the pilot has accrued much experience on either airplane, the pilot may lose proficiency in the newly acquired knowledge and skills. Unlike Part 135 on-demand operations, Part 121 commercial operations require that a PIC who has completed initial or upgrade training on one airplane must gain a minimum level of pilot operating experience under the supervision of a check pilot and demonstrate that he or she is qualified to perform PIC duties in that type of airplane. Also, according to 14 CFR 121.434(g), a pilot must gain 100 hours of experience in an airplane type within 120 days of obtaining the type rating or proficiency check before that pilot can act as PIC in that type of airplane without limitations.[86] According to 14 CFR 121.434(h)(3), if the pilot performs flying duties for the air carrier in a different type of airplane before completing 100 hours of flight time on the new airplane, the pilot must also complete approved refresher training before he or she may serve as PIC on the newly qualified airplane. Part 135 on-demand operations have no such minimum operating flight time requirements.

Minimum levels of operating experience help ensure that, when a pilot transitions to a new type of airplane, the pilot obtains the experience needed in that airplane to gain knowledge of the airplane's particular systems and handling characteristics and to develop skills in flying it. The consolidation of knowledge and skills through operating experience helps the pilot build confidence in flying the new airplane, which is particularly important for the PIC. The NTSB notes that the cockpit environments and the duties of the dual-pilot flight crews of Part 135 on-demand operations are similar to those of Part 121 operations and often use comparably sophisticated aircraft. The NTSB concludes that, because Part 135 does not require that pilots in on-demand turbojet operations have a minimum level of experience in airplane type, the pilots may lack adequate knowledge and skills in that airplane. Therefore, the NTSB recommends that the FAA require that pilots who fly in Part 135 operations in aircraft that require a type rating gain a minimum level of initial operating experience, similar to that specified in 14 CFR 121.434, taking into consideration the unique characteristics of Part 135 operations. The NTSB further recommends that the FAA require that pilots who fly in Part 135 operations in an aircraft that requires a type rating gain a minimum level of flight time in that aircraft type, similar to that described in 14 CFR 121.434, taking into consideration the unique characteristics of Part 135 operations, to obtain consolidation of knowledge and skills.

[86] For PICs who have not yet accumulated 100 hours in the airplane type, Part 121 specifies certain limitations, such as increased landing weather minimums, that must be applied to those specified in the air carrier's operations specifications.

### 2.4.3 Crew Resource Management

CRM includes skills and techniques for effective crew coordination, resource allocation, and error management. When used effectively, CRM augments technical training and enhances crew performance in the cockpit. One aspect of CRM includes the effective use of briefings, which allow flight crews to think ahead and be prepared for abnormal or emergency situations that may arise.

AC 120-62 notes that the pretakeoff briefing "should not be a meaningless repetition of known facts, but rather a tool for improving team performance that addresses the specific factors appropriate to that takeoff." After the captain provided the incorrect RTO criteria in her briefing, the first officer initially replied, "correct" but then questioned her briefing by stating the correct criteria. The captain agreed with the first officer, but it is unclear from the exchange whether the captain recognized that she had previously misspoken.

From the beginning, when the flight crew received the taxi clearance, there were instances in which the captain and the first officer had disparate thoughts about the clearance yet did not make effective use of available resources to verify the information. In one instance, the captain indicated that she believed that they were instructed to hold short of the active runway (of which she misspoke and stated was runway 22 instead of 23), but the first officer indicated, "I think he said … that we could cross it." In this instance, the first officer was correct, and the captain went along with what the first officer stated. During a subsequent discussion (in which the captain and the first officer had different ideas about which direction to taxi), the captain again went along with what the first officer thought to be accurate; however, in this case, the first officer was incorrect, which resulted in the captain making a wrong turn onto the taxiway. In either case, because the crewmembers were not in agreement about the controller's instructions, they should have verified the correct clearance with the controller.

In addition, there were several instances during the taxi in which the captain or the first officer read back incorrect information, and the mistake went uncorrected by the other crewmember. Just before initiating the takeoff roll, the captain asked the first officer to request a wind check. However, the captain repeated the winds back to the first officer incorrectly, and the first officer agreed; thus, neither the captain nor the first officer was effectively listening to each other or the controller. The captain's next statement that the winds were "pretty much straight down" the runway was also incorrect, and the first officer did not correct that error. Although none of the incorrect information during the taxi related directly to the circumstances of the accident, the exchanges are of concern in that, collectively, they provide evidence that neither crewmember was particularly focused.

The CRM skills exhibited by the flight crew were inconsistent with the skills needed for effective communication and the coordination of a professional flight crew. During the taxi, 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 anomaly. The captain's lack of accuracy in her pretakeoff briefing and the first officer's indirect questioning of it were missed opportunities for the crew to make use of the briefing for its intended purpose as a CRM tool for improving team performance. The NTSB concludes that the captain's indecision in responding to the anomaly and her failure to follow standard operating procedures was the result of a combination of poor CRM skills, limited experience as a pilot-in-command in the Learjet 60, and, during the accident sequence in particular, her less than confident and assertive leadership in the cockpit.

The NTSB has had longstanding concerns about the consequences of ineffective CRM among Part 135 on-demand flight crews; such issues are included on the NTSB's Most Wanted List. On December 2, 2003, the NTSB issued Safety Recommendation A-03-52, which superseded Safety Recommendation A-02-12 and asked the FAA to do the following:

> Require that 14 CFR Part 135 on-demand charter operators that conduct dual-pilot operations establish and implement [an FAA]-approved crew resource management training program for their flight crews in accordance with 14 CFR Part 121, subparts N and O.

On May 1, 2009, the FAA published an NPRM titled, "Crew Resource Management Training for Crewmembers in Part 135 Operations,"[87] which responded to Safety Recommendation A-03-52 in that it proposed to require Part 135 certificate holders to include CRM training for pilots and flight attendants. On July 15, 2009, the NTSB provided comments in general support of the proposed rule; however, the NTSB expressed concern about some aspects of the NPRM and urged the FAA to withdraw a proposed provision to allow certificate holders to give credit for initial CRM training received from another Part 135 operator. Pending issuance of the final rule, the NTSB classified Safety Recommendation A-03-52 "Open—Acceptable Response" on December 29, 2009..

The NTSB is encouraged by the FAA's progress and looks forward to the timely issuance of the final rule. In addition, the NTSB plans to hold a public forum in 2010 to address high standards for both flight crews and air traffic controllers. The planned forum has resulted from the NTSB's investigation of a number of accidents and incidents in recent years involving air transportation professionals who have deviated from expected levels of performance.

### 2.4.4 Medication Use and Rest Opportunities

Diphenhydramine, a medication that can result in drowsiness and performance deficits,[88] was detected in specimens from both the captain and the first officer. Diphenhydramine is commonly used to treat allergy symptoms or as a sleep aid. However, the relevance of the reported diphenhydramine levels is difficult to determine because it is not known when the pilots last took the medication, why they took it, or in what dose.[89] In addition, the reliability of the

[87] 74 FR 20263-20279.

[88] Diphenhydramine has been shown to have a measurable effect on performance of complex cognitive and motor tasks during at least the first 4 hours after the use of a maximum over-the-counter dose. See R.C. Baselt, *Drug Effects on Psychomotor Performance* (Foster City, California: Biomedical Publications, 2001).

[89] Medical analysis suggests that the drug levels detected in each pilot's blood samples could be consistent with the ingestion of either the maximum over-the-counter dose about 6 to 12 hours before the accident or a lower dose more recently (Baselt, 2001). Other research suggests a significant mental impairment and increased reaction time (compared with those who took a placebo) within 2 hours of taking 50 mg of diphenhydramine, after which time no significant differences were found. Subjective reporting of drowsiness effects was significantly different for up to 6

detected drug levels can be affected by the anatomical source and condition of the specimens tested, neither of which were reported.

Based on cellular telephone records, the captain's telephone activity on the day of the accident left the potential for three 1-hour uninterrupted periods to take a nap. Cellular telephone activity for the first officer afforded one 1-hour and one 2-hour time periods for rest.[90] However, each pilot's actual sleep, supplemental sleep (naps), and awake times in the 72 hours before the accident could not be determined.

Although both the captain and the first officer made errors before and during the takeoff, these errors are consistent with the training, experience, and CRM deficiencies that are discussed in sections 2.4.1 through 2.4.3 and are addressed by separate safety recommendations. Further, both flight crewmembers were off duty for about 30 hours before reporting for work on the night of the accident, which provided enough time for adequate rest. The NTSB concludes that, although flight crew impairment related to diphenhydramine use or fatigue is possible, there is insufficient evidence to determine to what extent, if any, diphenhydramine use or fatigue may have affected the captain's and the first officer's performance.

## 2.5 Occupant Survivability

In this accident, two factors were critical for occupant survival: protection from traumatic injury and the ability to quickly escape the fire. During the accident sequence, the captain and first officer sustained immobilizing blunt force injuries and died of smoke inhalation, and two of the passengers sustained fatal blunt force injuries. The fastened seatbelt buckles recovered from the cockpit suggest that the captain and first officer were likely restrained; however, the available wreckage showed evidence of cockpit crush intrusion and deformation, which may have contributed to their impact injuries.

The reported cause of death for two of the passengers indicated that they succumbed to their traumatic injuries and not the postcrash fire. Although none of the cabin seatbelt buckles were found buckled, not all of the cabin buckles were located. In addition, seatbelt webbing and seat structures in the cabin were destroyed by fire. Therefore, the restraint usage for the passenger fatalities could not be determined. Both survivors, however, reported that they were wearing their seatbelts, and neither sustained any immobilizing impact injuries.

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hours after administration of the drug. The observed concentrations of diphenhydramine at the "off set" of impairment ranged from 0.0582 to 0.0744 μg/mL and for drowsiness from 0.0304 to 0.0415 μg/mL. See F. Gengo, C. Gabos, and J. K. Miller, "The Pharmacodynamics of Diphenhydramine-Induced Drowsiness and Changes in Mental Performance." *Clinical Pharmacology & Therapeutics*, vol. 45, 15-2, January 1989.

[90] If the captain and first officer were not able to nap during the day, their time awake at the time of the accident would have been at least 12.75 hours and 14 hours, respectively. The NTSB's 1994 study of flight crew-related major aviation accidents indicated that fatigue related to lengthy periods of wakefulness can contribute to accidents. Specifically, the study found that captains who had been awake for more than about 12 hours made significantly more errors than those who had been awake for less than 12 hours; such errors included procedural and tactical errors. The NTSB notes that careful adherence to standard operating procedures and CRM can help flight crews mitigate the degrading effects of fatigue. See National Transportation Safety Board, *A Review of Flightcrew-Involved, Major Accidents of U.S. Air Carriers, 1978 through 1990,* Safety Study NTSB/SS-94/01 (Washington, DC: NTSB, 1994).

Global Exec Aviation's operations manual states that the PIC is responsible for ensuring that all passengers receive an oral briefing containing required safety information. One passenger stated the captain's briefing was not the "usual" safety briefing, and the other passenger did not recall receiving a briefing. It is likely that the passenger's perception was based on 14 CFR Part 121 airline briefings, which are typically delivered by flight attendants or video systems and use standardized phraseology. However, neither the regulations nor Global Exec Aviation policy requires particular verbatim briefing language; thus, some variation in execution might be expected based on a pilot's individual style and preferences of delivery. The CVR did not capture the content of the captain's briefing; however, one passenger recalled that the captain mentioned the seatbelts, fire extinguisher, and exits. Such topics are among those required by 14 CFR 135.117.

Although one passenger stated that he did not think that the safety briefing sounded very professional, evidence suggests that his actions after the crash were influenced by the captain's briefing. This passenger had opened the aft escape hatch exit, and he stated that he remembered being told about it by a crewmember. The location of the aft escape hatch exit, because it was on the right side of the airplane in the lavatory area, was partially obscured by the lavatory partition and was not conspicuously visible from the cabin. Thus, it is unlikely that the passenger would have known about the escape hatch location had he not learned about it during the briefing. This knowledge was critical for survival because of the rapid onset of the postcrash fire and the crush-damage impingement on the other exit (the passenger boarding door), which would have made it unusable for egress. In addition, although one passenger did not recall receiving a briefing and did not know that there was an exit behind him, he benefited from the other passenger's knowledge of the briefing because the other passenger located and opened the exit, enabling them both to escape. Therefore, the NTSB concludes that the captain's passenger safety briefing contributed to the survival of two passengers.

## 2.6 Other Safety Issues

### 2.6.1 Tire Certification and Testing Considerations

In this accident, after the first MLG tire failed, the remaining three tires failed in sequence from right to left. The investigation found that the accident airplane's tires were subjected to internal heating damage from operating while severely underinflated, which made each tire particularly susceptible to failure. However, the investigation also examined the possibility that the effects of adjacent tire loading after the loss of one tire can overload and potentially contribute to the failure of properly inflated tires. The investigation found that, after the loss of one tire, the other tires could become subject to loads not specifically accounted for in the tire's certification.

All tire testing criteria are based on the performance of a new, optimally inflated tire. This investigation's review of a sampling of tires in service found that most airplanes were operated with tire inflations within 10 percent of their rated pressure. However, although such inflation values are acceptable per the AMMs, FAA tire testing criteria do not necessarily account for tire pressure and wear that are at acceptable, but less than optimal, conditions. Tires operated at acceptable but lower-than-rated pressure will experience more sidewall flexing and heating than tires in the test condition. Aircraft tire manufacturers have provided historical evidence to show that heating, such as that which accumulates in the tire sidewalls during long taxi operations, can result in potentially harmful reductions in tire capability.

The FAA's lack of testing criteria for tire operations with less-than-optimal inflation and wear is not consistent with the conservative criteria that the FAA applies to other components that require testing with more realistic operating scenarios. For example, 14 CFR 25.109 and 25.735, which are the regulations pertaining to braking performance, specify that braking performance must be demonstrated with the brakes at the maximum wear limit. That rational approach to braking performance was implemented after a series of airplane accidents.

According to 14 CFR 25.733, for airplanes with dual-wheel and tire assemblies, the service load carried by each MLG tire, when multiplied by 1.07, may not be greater than the rated load of the tire. Although requirements specify this minimum margin between service load and rated load, the NTSB's investigation found that this margin may easily be exceeded in the normal operating environment, particularly for airplanes (such as the Learjet 60) that operate with tires at the rated load. In a static situation, the Learjet 60's load is distributed primarily among the four MLG tires. However, on this dual-axle installation, the loss of one tire can increase the load on the remaining properly inflated tire on that axle to a factor of about 1.2.

The FAA's basic static load certification criteria also do not take into consideration the additional dynamic loads, such as camber changes that could unevenly load the remaining tire's sidewalls. None of the tire testing criteria considers the dynamic forces imposed on the MLG tires after the loss of one tire. These forces include compression of the adjacent tire when one tire in an axle pair fails; sudden, unequal sidewall loading that is not uniform when camber is created; and the side loading and other dynamics imposed up to the point of tire slippage when friction is lost in a swerve that could follow the loss of the first tire. Other conditions are also not represented, such as even greater camber attributed to uneven pressure in MLG struts.

The NTSB concludes that the tire design and testing requirements of 14 CFR 25.733 may not adequately ensure tire integrity because they do not reflect the actual static and dynamic loads that may be imposed on tires both during normal operating conditions and after the loss of one tire, especially if the tires are operated at their load rating, and the requirements may not adequately account for tires that are operated at less-than-optimal conditions. Therefore, the NTSB recommends that the FAA require that tire testing criteria reflect the actual static and dynamic loads that may be imposed on tires both during normal operating conditions and after the loss of one tire and consider less-than-optimal allowable tire conditions, including, but not limited to, the full range of allowable operating pressures and acceptable tread wear.

### 2.6.2 Flight Recorders

The accident airplane was not required by FAA regulation to have an FDR installed. In the NTSB's January 28, 2009, report on the midair collision involving electronic news gathering helicopters in Phoenix, Arizona,[91] the NTSB issued Safety Recommendation A-09-11, which asked the FAA to do the following:

> Require all existing turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with [an FDR] and are operating under 14 [CFR] Parts 91, 121, or 135 to be retrofitted with a crash-resistant flight recorder system. The crash-resistant flight recorder system should record cockpit audio (if a cockpit voice recorder is not installed), a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation, all to be specified in [EUROCAE] document ED-155, "Minimum Operational Performance Specification for Lightweight Flight Recorder Systems," when the document is finalized and issued.

Although the FAA is making progress in this area and Safety Recommendation A-09-11 is classified "Open—Acceptable Response," the NTSB notes that, had the FAA implemented previous NTSB recommendations (including A-03-65, now superseded by A-09-11), the accident airplane would have been subject to the requirements for a cockpit image recording system by January 1, 2010. The NTSB concludes that a cockpit image recorder would have helped determine the precise speeds at which the accident airplane traveled and the flight crew's responses to the anomaly, including flight and engine control inputs.

[91] NTSB/AAR-09/02.

# 3. Conclusions

## 3.1 Findings

1. The captain and the first officer were certificated and qualified in accordance with Federal regulations and the operator's requirements for the 14 *Code of Federal Regulations* Part 135 on-demand flight. Neither pilot had any previous aviation accidents, incidents, or enforcement actions.

2. The accident airplane was certificated and equipped in accordance with the regulations that applied to it as a changed aeronautical product.

3. There was no evidence of any preimpact anomalies or distress that would have prevented the engines from producing power.

4. There was no evidence of any flight control anomalies.

5. The following were not factors in this accident: tire design, tire manufacture, or damage to the exterior of any tire.

6. Although postaccident estimates indicated that the airplane's maximum gross weight may have been exceeded by up to 300 pounds, there is no evidence that weight and balance issues contributed to the accident.

7. There was no indication that the captain's understanding of the rejected takeoff criteria was deficient; thus, the captain likely misspoke when she incorrectly stated the criteria in her pretakeoff briefing.

8. The captain's uncertainty as to whether to continue the takeoff suggests that her initial action to reject it did not result from a perception that the airplane was uncontrollable and could not fly.

9. In the absence of evidence that the airplane was uncontrollable, the captain's execution of a rejected takeoff for an unknown anomaly after the airplane's speed had passed $V_1$ was inconsistent with her training and standard operating procedures.

10. The accident airplane's uncommanded forward thrust, which accelerated the airplane at a time when the flight crew commanded full reverse thrust to decelerate the airplane, increased the severity of the accident because the uncommanded forward thrust substantially increased the airplane's runway excursion speed.

11. All four main landing gear tires on the airplane were operating while severely underinflated during the takeoff roll, which resulted in the tire failures.

12. The accident airplane's insufficient tire air pressure was due to Global Exec Aviation's inadequate maintenance.

13. Some operators are not sufficiently aware of the appropriate tire pressure check intervals for the airplanes in their fleets and are operating their airplanes with tires inflated below the aircraft maintenance manual replacement specifications.

14. Aircraft maintenance manual (AMM) formats that refer to tire pressure checks as guidance information rather than required maintenance intervals and the lack of standardization of AMM formats with respect to the location of tire pressure check interval information do not provide sufficient emphasis on the criticality of checking and maintaining tire pressure.

15. The Federal Aviation Administration's legal interpretation that checking tire pressures on a Learjet 60 is preventive maintenance has an unintended negative effect on the safety of 14 *Code of Federal Regulations* (CFR) Part 135 operations because, according to the provisions of 14 CFR 43.3, a Learjet 60 pilot who is allowed to perform preventive maintenance, such as tire pressure checks, on the airplane for a flight operated under 14 CFR Part 91 is prohibited from performing the checks on the same airplane for a Part 135 flight.

16. Tire pressure monitoring systems, which enable flight crews to easily verify tire pressures, provide safety benefits because the pressure-loss rate of aircraft tires can result in tire pressures below acceptable operational values within only a few days, and such underinflation cannot be visually detected by flight crews.

17. Learjet's system safety analysis for and the Federal Aviation Administration's review of the Learjet 60's thrust reverser system modification and revised crew procedure were inadequate because they failed to effectively address an unsafe condition for all phases of flight, specifically, uncommanded forward thrust during a rejected takeoff.

18. Had the Federal Aviation Administration adopted the procedures described in SAE International's SAE ARP5150, *Safety Assessment of Transport Airplanes in Commercial Service,* to require a program for the monitoring and ongoing assessment of safety-critical systems, the FAA may have recognized, based on problems reported after previous incidents and an accident, that the Learjet 60's thrust reverser system design was deficient and thus may have required appropriate modifications before this accident occurred.

19. The Federal Aviation Administration's 1993 certification of the Learjet 60 as a changed aeronautical product, which allowed the airplane's equipment, systems, and installations to conform to some regulations applicable to the original 1966 certification, did not ensure the highest level of safety and allowed for deficiencies that would not likely have been present if the current regulations had applied.

20. The accident pilots would have been better prepared to recognize the tire failure and to continue the takeoff if they had received realistic training in a flight simulator on the recognition of and proper response to tire failures occurring during takeoff.

21. Because 14 *Code of Federal Regulations* Part 135 does not require that pilots in on-demand turbojet operations have a minimum level of experience in airplane type, the pilots may lack adequate knowledge and skills in that airplane.

22. The captain's indecision in responding to the anomaly and her failure to follow standard operating procedures was the result of a combination of poor crew resource management skills, limited experience as a pilot-in-command in the Learjet 60, and, during the accident sequence in particular, her less than confident and assertive leadership in the cockpit.

23. Although flight crew impairment related to diphenhydramine use or fatigue is possible, there is insufficient evidence to determine to what extent, if any, diphenhydramine use or fatigue may have affected the captain's and the first officer's performance.

24. The captain's passenger safety briefing contributed to the survival of two passengers.

25. The tire design and testing requirements of 14 *Code of Federal Regulations* 25.733 may not adequately ensure tire integrity because they do not reflect the actual static and dynamic loads that may be imposed on tires both during normal operating conditions and after the loss of one tire, especially if the tires are operated at their load rating, and the requirements may not adequately account for tires that are operated at less-than-optimal conditions.

26. A cockpit image recorder would have helped determine the precise speeds at which the accident airplane traveled and the flight crew's responses to the anomaly, including flight and engine control inputs.

## 3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the operator's inadequate maintenance of the airplane's tires, which resulted in multiple tire failures during takeoff roll due to severe underinflation, and the captain's execution of a rejected takeoff after $V_1$, which was inconsistent with her training and standard operating procedures.

Contributing to the accident were (1) 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; (2) 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; (3) inadequate industry training standards for flight crews in tire failure scenarios; and (4) the flight crew's poor crew resource management.

# 4. Recommendations

## 4.1 New Recommendations

The National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Provide pilots and maintenance personnel with information that (1) transport-category aircraft tires can lose up to 5-percent pressure per day, (2) it may take only a few days for such tires to reach an underinflation level below what the aircraft maintenance manual specifies for tire replacement, and (3) the underinflation level that would require tire replacement is not visually detectable. (A-10-46)

> Require that all 14 *Code of Federal Regulations* Part 121, 135, and 91 subpart K operators perform tire pressure checks at a frequency that will ensure that the tires remain inflated to within aircraft maintenance manual-specified inflation pressures. (A-10-47)

> Require that aircraft maintenance manuals specify, in a readily identifiable and standardized location, required maintenance intervals for tire pressure checks (as applicable to each aircraft). (A-10-48)

> Allow pilots to perform tire pressure checks on aircraft, regardless of whether the aircraft is operating under 14 *Code of Federal Regulations* Part 91, Part 91 subpart K, or Part 135. (A-10-49)

> Require tire pressure monitoring systems for all transport-category airplanes. (A-10-50)

> Identify the deficiencies in Learjet's system safety analyses, both for the original Learjet 60 design and for the modifications after the 2001 accident, that failed to properly address the thrust reverser system design flaws related to this accident, and require Learjet to perform a system safety assessment in accordance with 14 *Code of Federal Regulations 25.1309* for all other systems that also rely on air-ground signal integrity and ensure that hazards resulting from a loss of signal integrity are appropriately mitigated to fully comply with this regulation. (A-10-51)

> Revise available safety assessment guidance (such as Advisory Circular 25.1309-1A) for manufacturers to adequately address the deficiencies identified in Safety Recommendation A-10-51, require that designated engineering representatives and their Federal Aviation Administration (FAA)

mentors are trained on this methodology, and modify FAA design oversight procedures to ensure that manufacturers are performing system safety analyses for all new or modified designs that effectively identify and properly mitigate hazards for all phases of flight, including foreseeable events during those phases (such as a rejected takeoff). (A-10-52)

Revise Federal Aviation Administration Order 8110.48 to require that the most current airworthiness regulations related to equipment, systems, and installations (14 *Code of Federal Regulations* 25.1309) are applied to all derivative design aircraft certificated as changed aeronautical products. (A-10-53)

Review the designs of existing derivative design aircraft that were certificated as changed aeronautical products against the requirements of the current revision of 14 *Code of Federal Regulations* 25.1309 and require modification of the equipment, systems, and installations to fully comply with this regulation. (A-10-54)

Define and codify minimum simulator model fidelity requirements for tire failure scenarios. These requirements should include tire failure scenarios during takeoff that present the need for rapid evaluation and execution of procedures and provide realistic sound and motion cueing. (A-10-55)

Once the simulator model fidelity requirements requested in Safety Recommendation A-10-55 are implemented, require that simulator training for pilots who conduct turbojet operations include opportunities to practice responding to events other than engine failures occurring both near $V_1$ and after $V_1$, including, but not limited to, tire failures. (A-10-56)

Require that pilots who fly in 14 *Code of Federal Regulations* (CFR) Part 135 operations in aircraft that require a type rating gain a minimum level of initial operating experience, similar to that specified in 14 CFR 121.434, taking into consideration the unique characteristics of Part 135 operations. (A-10-57)

Require that pilots who fly in 14 *Code of Federal Regulations* (CFR) Part 135 operations in an aircraft that requires a type rating gain a minimum level of flight time in that aircraft type, similar to that described in 14 CFR 121.434, taking into consideration the unique characteristics of Part 135 operations, to obtain consolidation of knowledge and skills. (A-10-58)

Require that tire testing criteria reflect the actual static and dynamic loads that may be imposed on tires both during normal operating conditions and after the loss of one tire and consider less-than-optimal allowable tire conditions, including, but not limited to, the full range of allowable operating pressures and acceptable tread wear. (A-10-59)

## 4.2 Previously Issued Recommendations Resulting From This Accident Investigation and Classified in This Report

As a result of this investigation, the NTSB issued the following safety recommendations to the Federal Aviation Administration on July 17, 2009:

> Require Learjet to change the design of the Learjet 60 thrust reverser system in future-manufactured airplanes so that the reverse lever positions in the cockpit match the positions of the thrust reverser mechanisms at the engines when the thrust reversers stow. (A-09-55)
>
> Once design changes are developed per Safety Recommendation A-09-55, require Learjet 60 operators to retrofit existing airplanes so that the reverse lever positions in the cockpit match the positions of the thrust reverser mechanisms at the engines when the thrust reversers stow. (A-09-56)
>
> Require Learjet to develop and install improved aural or visual cues on future-manufactured Learjet 60 airplanes that would allow pilots to recognize an inadvertent thrust reverser stowage in a timely manner. (A-09-57)
>
> Once improved aural or visual cues are developed per Safety Recommendation A-09-57, require Learjet 60 operators to install those cues on existing Learjet 60 airplanes. (A-09-58)
>
> Require that all Learjet 60 pilots receive training, for takeoff as well as landing phases of flight, on recognizing an inadvertent thrust reverser stowage, including the possibility that the stowage can occur when the requirements for deploying thrust reversers are not fully met, such as when the air/ground sensor squat switch circuits are damaged. (A-09-59)
>
> Evaluate the design of the thrust reverser controls and indications in Raytheon Hawker 1000 business jets for potential thrust reverser failure modes that are similar to those identified in Learjet 60 airplanes and implement necessary changes. (A-09-60)

Safety Recommendations A-09-55 through -58 and -60 (previously classified “Open—Response Received”) are classified “Open—Acceptable Response” in this report. Safety Recommendation A-09-59 (previously classified “Open—Response Received”) is classified “Open—Acceptable Alternate Response” in this report. These classifications are discussed in section 2.3.2 of this report.

## BY THE NATIONAL TRANSPORTATION SAFETY BOARD

**DEBORAH A.P. HERSMAN**
Chairman

**ROBERT L. SUMWALT**
Member

**CHRISTOPHER A. HART**
Vice Chairman

**Adopted: April 6, 2010**

# 5. Appendixes

# Appendix A

## Investigation and Hearing

### Investigation

The National Transportation Safety Board (NTSB) was notified of this accident early on the morning of September 20, 2008. Staff from the NTSB arrived on scene on September 20, remaining there until September 25, to conduct the field portion of the investigation. Board Member Deborah A.P. Hersman accompanied the team.[92]

Parties to the investigation were the Federal Aviation Administration, Learjet, Global Exec Aviation, Columbia Metropolitan Airport, and The Goodyear Tire & Rubber Company. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the Transportation Safety Board of Canada (TSB) participated in the investigation as the representative of the State of Design and Manufacture (Powerplants). Pratt & Whitney Canada participated in the investigation as a technical advisor to the TSB.

### Public Hearing

No public hearing was held for this accident.

[92] Board Member Hersman is now Chairman of the NTSB.

# Appendix B

## Cockpit Voice Recorder Transcript

Following is the transcript of a Universal 1603-02-12 solid-state cockpit voice recorder, serial number 1629, installed on an Inter Travel & Services LearJet 60 (N999LJ), which crashed while attempting to abort a takeoff at Columbia Airport in Columbia, South Carolina.

### LEGEND

| | |
|---|---|
| **CAM** | Cockpit area microphone voice or sound source |
| **HOT** | Flight crew audio panel voice or sound source |
| **RDO** | Radio transmissions from N999LJ |
| **GND** | Radio transmission from the Columbia Airport ground controller |
| **-1** | Voice identified as the captain |
| **-2** | Voice identified as the first officer |
| -? | Voice unidentified |
| * | Unintelligible word |
| # | Expletive |
| @ | Non-pertinent word |
| **( )** | Questionable insertion |
| **[ ]** | Editorial insertion |

Note 1: Times are expressed in eastern daylight time (EDT).

Note 2: Generally, only radio transmissions to and from the accident aircraft were transcribed.

Note 3: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.

Note 4: A nonpertinent word, where noted, refers to a word not directly related to the operation, control or condition of the aircraft.

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:23:40.1<br>**[start of recording]** | | | |
| 23:36:31.9<br>**[start of transcript]** | | | |
| 23:36:31.9<br>**CAM** | [sound consistent with cabin door closing]. | | |
| 23:36:50.3<br>**CAM-1** | I briefed 'em all. | | |
| 23:36:51.8<br>**CAM-2** | did you tell them about the temperature? | | |
| 23:36:54.0<br>**CAM-1** | ah no I didn't. | | |
| 23:36:54.8<br>**CAM-?** | let let let us know * *. | | |
| 23:37:00.4<br>**CAM-?** | [unintelligible vocalizations]. | | |
| 23:37:13.3<br>**HOT-1** | hey we're startin' engines. | | |
| 23:37:17.0<br>**HOT-1** | okay I'll call you when we get in. | | |
| 23:37:20.0<br>**HOT-1** | I'm gonna wake you up. | | |
| 23:37:27.1<br>**HOT-1** | yeah I talked to @ I think we may just check into the Airtel for a little while. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:37:32.1<br>**HOT-1** | alright? | | |
| 23:37:35.6<br>**HOT-1** | okay. thanks talk to you in a bit. | | |
| 23:37:40.6<br>**HOT-1** | okay perfect appreciate it. okay should only be a little over five hours so. | | |
| 23:37:48.5<br>**HOT-1** | I appreciate that. talk to you later. bye. | | |
| 23:38:10.4<br>**CAM-1** | * *? | | |
| 23:38:11.4<br>**CAM-2** | yeah * *. | | |
| 23:38:18.4<br>**CAM-?** | [unintelligible vocalizations]. | | |
| 23:38:45.7<br>**CAM-2** | so I think. (that's the wrong). | | |
| 23:38:53.0<br>**CAM-1** | there's beer in there there's beer the bottom drawer and then there's a bunch in there (that we're) putting on ice. | | |
| 23:39:07.5<br>**HOT-2** | 'kay. | | |
| 23:39:10.6<br>**HOT-2** | alright and do you have the ah checklist? | | |
| 23:39:15.0<br>**CAM-1** | do you want do you want me to get something? | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:39:17.5 **CAM-1** | it's no it's no problem its easier to do it now, are you sure? okay. | | |
| 23:39:24.3 **CAM-1** | I wonder if they should, want those lights on? | | |
| 23:39:26.8 **HOT-2** | no they didn't they- I asked 'em they said no but I don't know why they're on. | | |
| 23:39:30.6 **HOT-2** | unless they turn on on the ground. | | |
| 23:39:32.5 **CAM-1** | * * (armed) * in an emergency * *? | | |
| 23:39:33.8 **HOT-2** | yeah. | | |
| 23:39:35.5 **HOT-2** | I don't know the answer to that. | | |
| 23:39:39.9 **HOT-2** | ahm do you have the checklist over there? | | |
| 23:39:42.9 **CAM-1** | * * * (no) * * *. *(I think) yeah there ya go. | | |
| 23:39:49.8 **HOT-2** | okay. | | |
| 23:39:55.7 **HOT-2** | let's go ah before start right? pilot side window? | | |
| 23:39:58.7 **HOT-1** | is ahhh doesn't open. | | |
| 23:40:01.1 **HOT-1** | I'm sorry? | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:40:01.5<br>**CAM-?** | one more question do you have water? | | |
| 23:40:02.9<br>**HOT-1** | water yeah. | | |
| 23:40:03.7<br>**HOT-2** | shou- should be one in each armrest already in your cup holders. | | |
| 23:40:04.1<br>**HOT-1** | there should be some water bottles- | | |
| 23:40:07.9<br>**HOT-1** | oh okay just leave it for me there that's fine thank you. | | |
| 23:40:12.6<br>**HOT-1** | yeah there's some there and then if you need more- if you open this there's some in the back. and then anything else just let me know we'll get it for you when we get up. | | |
| 23:40:18.8<br>**CAM-?** | (no problem). | | |
| 23:40:19.6<br>**HOT-1** | sure. | | |
| 23:40:21.1<br>**HOT-1** | alright. | | |
| 23:40:21.4<br>**HOT-2** | pilot side window? | | |
| 23:40:22.3<br>**HOT-1** | ahh doesn't open. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:40:23.8 **HOT-2** | parking ah yeah this one doesn't right? parking ah brake chocks? | | |
| 23:40:25.7 **HOT-1** | *. | | |
| 23:40:27.3 **HOT-1** | our brakes are pulled right? parking brake's set. | | |
| 23:40:30.0 **HOT-2** | * ah beacon nav light? | | |
| 23:40:32.0 **HOT-1** | beacon nav lights we've got the nav light on throw the beacon on now. | | |
| 23:40:35.5 **HOT-2** | * * * * logo on now I'm gonna turn on this * * anything * cockpit set up. | | |
| 23:40:39.6 **CAM** | [sound similar to seatbelt chime]. | | |
| 23:40:43.7 **HOT-1** | cockpit set up a it's good for now. | | |
| 23:40:46.1 **HOT-2** | air conditioning they said they're warm but I'll get it back on after start. | | |
| 23:40:49.8 **HOT-1** | okay. | | |
| 23:40:49.9 **HOT-2** | aux heat is off EFIS avionics masters? | | |
| 23:40:52.7 **HOT-1** | are comin' off. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:40:53.7 **HOT-2** | off right. | | |
| 23:40:57.2 **HOT-2** | okay we're up to starting the engines. | | |
| 23:40:59.7 **HOT-1** | alright. | | |
| 23:41:00.8 **HOT-2** | ah beacon's on. | | |
| 23:41:02.5 **HOT-1** | okay I'm gonna start the left one first. | | |
| 23:41:04.3 **HOT-2** | 'kay. | | |
| 23:41:04.6 **HOT-1** | it's clear on the left. | | |
| 23:41:06.2 **CAM** | [sound of decreasing background noise]. | | |
| 23:41:07.3 **HOT-1** | ahh. | | |
| 23:41:11.8 **CAM** | [sound of increasing background noise]. | | |
| 23:41:14.3 **HOT-1** | (comin') up two lights. | | |
| 23:41:28.4 **HOT-2** | we're ah pretty heavy so I'm gonna re-bug for flaps eight if you don't object. | | |
| 23:41:33.8 **HOT-1** | no that's fine. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:41:34.1 **HOT-2** | we got plenty of runway. | | |
| 23:41:35.1 **HOT-1** | yeah. | | |
| 23:41:53.4 **HOT-1** | 'kay that looks good generator's comin' on and ready on the right? | | |
| 23:41:59.2 **HOT-2** | clear right. | | |
| 23:42:00.1 **HOT-1** | 'kay. | | |
| 23:42:00.4 **CAM** | [sound of decreasing background noise]. | | |
| 23:42:04.7 **HOT-1** | two lights. | | |
| 23:42:18.8 **CAM** | [sound of increasing background noise]. | | |
| 23:42:19.9 **CAM** | [unintelligible vocalizations]. | | |
| 23:42:35.3 **HOT-1** | that side is a little hotter. lights are out. | | |
| 23:42:42.1 **HOT-1** | two five five and two back on. kill the APU. | | |
| 23:42:53.0 **HOT-2** | okay you ready? | | |
| 23:42:54.2 **HOT-1** | ready. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:42:54.8 **HOT-2** | master caution inhibited. | | |
| 23:42:56.1 **HOT-1** | alright. | | |
| 23:42:57.1 **HOT-2** | GPU is off. | | |
| 23:42:59.6 **HOT-2** | EFIS avionics masters. | | |
| 23:43:01.1 **HOT-1** | are back on. | | |
| 23:43:02.5 **HOT-2** | engine instruments. | | |
| 23:43:03.4 **HOT-1** | engine instruments are two five five and two look good. | | |
| 23:43:06.6 **HOT-2** | generators E-P-M. | | |
| 23:43:08.1 **HOT-1** | ah as expected twenty eight. | | |
| 23:43:10.9 **HOT-2** | windshield ah heat anti-ice ah you can pass on it if you want now. | | |
| 23:43:13.2 **HOT-1** | ah yeah I'm gonna skip those I'm not. | | |
| 23:43:16.1 **HOT-2** | spoilers (systems) auto spoilers. | | |
| 23:43:17.6 **HOT-1** | ah I'm gonna skip that * too. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:43:18.7 **HOT-2** | flight controls. | | |
| 23:43:19.4 **HOT-1** | flight controls are. | | |
| 23:43:22.9 **HOT-1** | excuse me I'm sorry. | | |
| 23:43:24.2 **HOT-2** | that's alright. | | |
| 23:43:24.5 **HOT-1** | (alright) good. | | |
| 23:43:25.3 **HOT-2** | let's stop a second at flight instruments and I'm gonna re-s bug us for ahm- | | |
| 23:43:28.3 **HOT-1** | for eight? | | |
| 23:43:29.4 **HOT-2** | yeah ah. | | |
| 23:43:29.5 **HOT-1** | 'kay yeah I agree with that. | | |
| 23:43:34.5 **HOT-2** | okay flaps eight now. | | |
| 23:43:38.5 **HOT-2** | thirty six forty five fifty three. | | |
| 23:43:48.2 **HOT-2** | fifty three. | | |
| 23:43:51.1 **HOT-2** | flaps up speed changes to one seventy three if you wanna set it I don't know if you do that or not but? | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:43:55.3 **HOT-1** | I usually do the two fifty for the climb. | | |
| 23:43:57.0 **HOT-2** | okay that'll work. | | |
| 23:43:59.2 **HOT-1** | long as you tell me when to put 'em up. | | |
| 23:44:01.0 **HOT-2** | 'kay. | | |
| 23:44:03.0 **HOT-1** | 'kay. | | |
| 23:44:03.9 **HOT-2** | ahm flight instruments? | | |
| 23:44:05.5 **HOT-1** | flight instruments I've got zero on the airspeed one thirty six forty five fifty three two fifty on the speed-bug and I'm in go-around and heading ah three zero two one on the altimeter's giving me two hundred feet zero on the VSI and I'm heading three three five one times two times three times four and five. | | |
| 23:44:26.0 **HOT-2** | 'kay. ah standby horizon? | | |
| 23:44:29.6 **HOT-1** | is up and erect. | | |
| 23:44:30.8 **HOT-2** | anti-skid? | | |
| 23:44:31.7 **HOT-1** | anti-skid is on and the lights out. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:44:33.2 **HOT-2** | TCAS? | | |
| 23:44:34.0 **HOT-1** | TCAS let's see put it up on mine. | | |
| 23:44:37.7 **HOT-1** | traffic I think I was up wasn't I? ah I just turned it off. | | |
| 23:44:37.9 **HOT-2** | I think you were you were already up yeah. | | |
| 23:44:42.1 **HOT-1** | traffic and display we're good. | | |
| 23:44:44.9 **HOT-2** | hydraulic pressure gear and brake air? | | |
| 23:44:46.3 **HOT-1** | ah three green. | | |
| 23:44:47.5 **HOT-2** | emergency pressurization? | | |
| 23:44:49.1 **HOT-2** | tested earlier. | | |
| 23:44:49.4 **HOT-1** | ah that is tested. | | |
| 23:44:50.7 **HOT-2** | 'kay I'm gonna get the AC on for a little bit ah fuel indicator fuel panel? | | |
| 23:44:55.4 **HOT-1** | is balanced as expected and plenty for the flight. | | |
| 23:44:57.9 **HOT-2** | and flaps are goin' to eight? | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:44:59.8 HOT-1 | I agree. | | |
| 23:45:01.6 HOT-1 | indicating eight. | | |
| 23:45:02.9 HOT-2 | 'kay. | | |
| 23:45:04.5 HOT-2 | trims? | | |
| 23:45:05.8 HOT-1 | trims are one two and three and primary and the light's out. | | |
| 23:45:12.2 HOT-2 | door? | | |
| 23:45:12.8 HOT-1 | door's closed lights are out. | | |
| 23:45:14.3 HOT-2 | seatbelt no smoking? | | |
| 23:45:15.5 HOT-1 | is ah on. | | |
| 23:45:17.2 HOT-2 | parking brake? | | |
| 23:45:17.8 HOT-1 | parking brake is released. | | |
| 23:45:19.3 HOT-2 | okay let me see here. | | |
| 23:45:20.8 HOT-1 | * don't know what time the tower close(es) ah it's still open. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:45:26.0 **HOT-2** | and ah nineteen. | | |
| 23:45:27.0 **HOT-1** | thinkin' I wanna go out this way still or can I go straight out here? | | |
| 23:45:29.4 **HOT-2** | I think we can go straight nineteen five and twenty one nine. | | |
| 23:45:33.7 **HOT-2** | ah * which way do you use? | | |
| 23:45:35.7 **HOT-1** | I w- I use two. | | |
| 23:45:37.2 **HOT-2** | okay. | | |
| 23:45:37.8 **HOT-1** | yeah then I * put the departure frequency over here so I can see it. and. | | |
| 23:45:38.5 **HOT-2** | *. | | |
| 23:45:41.7 **HOT-2** | see I do it just the opposite or we do it yeah. | | |
| 23:45:43.2 **HOT-1** | * [sound of laugh] I don't care what you do just tell me. | | |
| 23:45:45.4 **HOT-2** | I don't either. * let me just get the ah what did you do with the flight plan? | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:45:49.4 **HOT-1** | it's on the board there's a clipboard on your side there. | | |
| 23:45:50.9 **HOT-2** | 'kay. | | |
| 23:45:52.3 **HOT-2** | let me just double check the frequency for that. | | |
| 23:45:56.0 **HOT-2** | thirty three four. | | |
| 23:45:57.5 **HOT-1** | and was that squawk right? | | |
| 23:45:58.1 **HOT-2** | yes it's ah huh thirty three four and ten oh three so no. | | |
| 23:45:59.3 **HOT-1** | I'm sorry okay. | | |
| 23:46:02.5 **HOT-2** | oh oops thirty three four we'll leave it there and ten zero three. one zero zero three. | | |
| 23:46:12.8 **HOT-1** | * *. | | |
| 23:46:12.8 **HOT-2** | okay initial altitude is ah four thousand expect forty in ten. | | |
| 23:46:16.5 **HOT-1** | okay perfect. | | |
| 23:46:17.3 **HOT-2** | okay well that's good. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:46:19.1<br>**HOT-2** | so here we go you ready? | | |
| 23:46:20.9<br>**HOT-1** | I'm ready. | | |
| 23:46:21.9<br>**HOT-2** | what's the name of this joint? | | |
| 23:46:23.3<br>**HOT-1** | oh # I f- Columbia. | | |
| 23:46:24.8<br>**HOT-2** | Columbia. | | |
| 23:46:25.6<br>**HOT-1** | * I keep forgetting where we are on the way in. | | |
| | | 23:46:29.9<br>**RDO-2** | Columbia ground Lear triple nine Lima Juliet Columbia aviation with the ATIS taxi. |
| | | 23:46:38.1<br>**GND** | calling ground say it again please? |
| | | 23:46:41.2<br>**RDO-2** | it's Lear ah triple nine Lima Juliet Columbia aviation Victor taxi. |
| | | 23:46:45.1<br>**GND** | Lear triple nine Lima Juliet Columbia ground ah roger taxi to runway two niner via taxiway Uniform actually the wind zero seven zero at seven gust one six altimeter three zero two one you wanna go out to runway one one? |
| 23:47:01.1<br>**HOT-2** | whaddya want? | | |

| INTRA-COCKPIT COMMUNICATION TIME and SOURCE | CONTENT | AIR-GROUND COMMUNICATION TIME and SOURCE | CONTENT |
|---|---|---|---|
| 23:47:01.5 **HOT-1** | gust to two one? | | |
| | | 23:47:02.5 **RDO-2** | yeah we better do that. |
| | | 23:47:04.4 **GND** | roger taxi to runway one one via Uniform cross the approach end of two three to taxiway November to taxiway Alpha and ah taxi runway one one via Alpha. |
| | | 23:47:16.7 **RDO-2** | okay Uniform November Alpha ah to one one ah triple nine Lima Juliet. |
| 23:47:21.1 **HOT-1** | and hold short of two two I think it was. | | |
| 23:47:24.0 **HOT-2** | I think he said * we could cross it Uniform November Alpha to one one. | | |
| 23:47:24.9 **HOT-1** | oh did he? | | |
| 23:47:29.5 **HOT-1** | and we're going right outta here, correct? | | |
| 23:47:31.4 **HOT-2** | ah well I think we have to go left outta here don't we? | | |
| 23:47:35.6 **HOT-1** | oh if we're going back over the end of that runway yeah, yeah. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:47:36.8 **HOT-2** | we're go- we're gonna go back to the runway we landed on. | | |
| 23:47:40.3 **HOT-2** | so. alright where'd it go here it is. | | |
| 23:47:51.0 **HOT-2** | alright. let's go ah. | | |
| 23:47:52.0 **HOT-1** | *. | | |
| 23:47:54.7 **HOT-1** | ready? | | |
| 23:47:55.2 **HOT-2** | ah huh. | | |
| 23:47:59.7 **HOT-2** | so we go straight out here into Uniform and make a left. | | |
| 23:48:28.8 **HOT-2** | my head's down here. | | |
| 23:48:30.3 **HOT-1** | okay. doin' left on Uniform here. | | |
| 23:48:33.8 **HOT-2** | yeah. | | |
| 23:48:37.8 **HOT-2** | this is Uniform. | | |
| 23:48:49.2 **HOT-2** | Uniform November Alpha. | | |
| 23:48:51.4 **CAM** | [sound similar to thrust reverse lever actuation]. | | |

| INTRA-COCKPIT COMMUNICATION TIME and SOURCE | INTRA-COCKPIT COMMUNICATION CONTENT | AIR-GROUND COMMUNICATION TIME and SOURCE | AIR-GROUND COMMUNICATION CONTENT |
|---|---|---|---|
| 23:48:51.4 **HOT-1** | (two unlocks) two deploys. | | |
| | | 23:49:19.1 **GND** | Learjet ah I think did you ah oh I think you're on Uniform there you need to go the other way on Uniform ah and cross the approach end of two three actually ah yeah you'll need to you'll need to make a ah hundred and eighty degree turn looks like you're on Uniform goin' out towards two nine. |
| | | 23:49:36.5 **RDO-2** | yeah we are on Uniform so one eighty on Uniform and back Uniform November Alpha right? |
| | | 23:49:42.1 **GND** | and I'll tell ya what just hold your position there I'm gonna see if I can back-taxi on ah runway two nine to one one actually we can ah you ready to ready to go? |
| 23:49:46.6 **HOT-2** | stop here. | | |
| | | 23:49:51.6 **RDO-2** | ah that's affirmative. |
| | | 23:49:52.7 **GND** | alright you can back taxi the whole way down runway one one and once you get ah to the west ah end of runway one one then make a hundred and eighty degree turn ah turn right heading one five zero and runway one one you're cleared for takeoff. |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| | | 23:50:07.2 **RDO-2** | okay we'll back taxi ah the full length one one then cleared for takeoff ah one five zero d- degree heading on departure ah nine Lima Juliet. |
| 23:50:15.3 **HOT-2** | #. | | |
| 23:50:24.8 **HOT-1** | alright light me up please. | | |
| 23:50:27.3 **HOT-2** | we are as much as we can with this thing. | | |
| 23:50:35.9 **HOT-2** | okay right turn all the way down one eighty and back cleared for takeoff at the other end you have brakes and steering I see. | | |
| 23:50:45.4 **HOT-1** | yup (I'm gonna). | | |
| 23:50:46.0 **HOT-2** | reversers you did. | | |
| 23:50:47.2 **HOT-1** | stay off the lights right here yeah reversers are done. | | |
| 23:50:50.9 **HOT-2** | 'kay. | | |
| 23:51:02.9 **HOT** | [unidentified mechanical noise]. | | |
| 23:51:04.8 **HOT-2** | 'kay one one eighty six hundred feet long. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:51:18.8 **HOT-2** | okay so brake steering reversers you did just a crew briefing. | | |
| 23:51:22.3 **HOT-1** | okay ah we've got plenty of runway so we'll abort for anything below eighty knots after V-one and before V-two engine failure fire malfunction loss of directional control all the big things after V-two we'll go ahead and take it into the air treat it as an in-flight emergency I think this is probably a pretty good option to come back to unless we have like a complete a hydraulic failure or something and ah then we'll look for a longer runway nearby probably Charleston ahm after takeoff it was heading one five zero up to four thousand. | | |
| 23:51:53.8 **HOT-2** | correct. | | |
| 23:51:54.0 **HOT-1** | correct? any questions comments concerns? | | |
| 23:51:56.6 **HOT-2** | ah just it's ah wha- reference the ah between eighty and ah V-one you're only ah aborting for the fire failure loss of directional control? | | |
| 23:52:06.0 **HOT-1** | yes. | | |
| 23:52:06.6 **HOT-2** | 'kay ah alrighty we're ah. | | |
| 23:52:09.8 **HOT-1** | or an inadvertent thrust- ah T-R deployment. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:52:12.4 **HOT-2** | 'kay. | | |
| 23:52:14.6 **HOT-2** | that will reverse in the rev- that will ah cause the loss of directional control I guess. | | |
| 23:52:18.5 **HOT-1** | exactly hah they go together. | | |
| 23:52:25.8 **HOT-1** | which I think kinda like what you're talking about * any red light that can be so many things ya know? | | |
| 23:52:31.4 **HOT-2** | well eh if the runway is long I abort but if it's short I kinda do different briefing depending on the what the length of the runway is but we're pretty heavy so it's probably not a bad idea. | | |
| 23:52:41.3 **HOT-1** | yeah. | | |
| 23:52:47.0 **HOT-2** | you know what I mean? | | |
| 23:52:47.8 **HOT-1** | yeah. | | |
| 23:53:40.4 **HOT-2** | * here we are. | | |
| 23:53:57.8 **HOT-1** | do your brakes squeak like this? | | |
| 23:53:59.6 **HOT-2** | it's not the brakes it's the, the air being released so yes most- they all do. | | |

| INTRA-COCKPIT COMMUNICATION TIME and SOURCE | INTRA-COCKPIT COMMUNICATION CONTENT | AIR-GROUND COMMUNICATION TIME and SOURCE | AIR-GROUND COMMUNICATION CONTENT |
|---|---|---|---|
| 23:54:07.5 **HOT-2** | I'm gonna reach over here and do this for ya. | | |
| 23:54:09.5 **HOT-1** | thanks I appreciate it. | | |
| 23:54:13.5 **HOT-2** | okay we're cleared for takeoff cabin air is on transponder on anti-collision rec lights on and on ignitions pitot heats auto-spoilers on on armed ah anti-ice not required warning panels are normal for the conditions APR on the roll cleared for takeoff. | | |
| 23:54:26.7 **HOT-1** | okay would you get me a wind check again real quick? | | |
| | | 23:54:29.0 **RDO-2** | nine Lima Juliet wind check? |
| 23:54:29.2 **HOT-1** | do you remember what it was? | | |
| 23:54:32.4 **CAM-1** | guys all set? | | |
| | | 23:54:32.8 **GND** | wind zero seven zero at eight gust one four. |
| | | 23:54:35.2 **RDO-2** | thank you sir. |
| 23:54:36.5 **HOT-1** | zero one zero at eight? | | |
| 23:54:37.7 **HOT-2** | ah huh. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:54:38.4 **HOT-1** | 'kay. so pretty much straight down. | | |
| 23:54:47.9 **HOT-2** | 'kay ah takeoff detent. | | |
| 23:54:49.5 **CAM** | [sound of increasing background noise]. | | |
| 23:54:50.8 **HOT-2** | power's set. | | |
| 23:54:53.7 **HOT-2** | two good engines airspeed's alive both sides APR is armed. | | |
| 23:55:00.1 **HOT-2** | eighty knots. crosscheck. | | |
| 23:55:02.1 **HOT-1** | check. | | |
| 23:55:10.5 **HOT-2** | V-one. | | |
| 23:55:12.0 **CAM** | [beginning of loud broadband rumbling]. | | |
| 23:55:12.4 **HOT-2** | go. | | |
| 23:55:12.8 **HOT-1** | *? | | |
| 23:55:13.0 **HOT-2** | go go go. | | |
| 23:55:13.7 **HOT-2** | [sound similar to metallic click]. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:55:14.0 **HOT-1** | go? | | |
| 23:55:14.6 **HOT-2** | no? ar- alright. get ah what the # was that? | | |
| 23:55:15.1 **HOT-2** | [sound similar to metallic click]. | | |
| 23:55:17.0 **HOT-1** | I don't know. we're not goin' though. | | |
| 23:55:18.4 **CAM** | [sound similar to metallic click]. | | |
| 23:55:19.5 **HOT-1** | full out. | | |
| 23:55:20.3 **CAM** | [high frequency sound consistent with brake pedal application]. | | |
| 23:55:21.6 **HOT** | [sound similar to nose-wheel steering disconnect warning tone]. | | |
| 23:55:27.7 **HOT-1** | #. | | |
| 23:55:28.7 **HOT-2** | shut 'em off. | | |
| 23:55:29.5 **CAM-?** | what is goin' on here? | | |
| 23:55:30.8 **CAM** | [unintelligible vocalizations]. | | |
| 23:55:32.4 **HOT-2** | they're shut off they're shut off. | | |

| INTRA-COCKPIT COMMUNICATION | | AIR-GROUND COMMUNICATION | |
|---|---|---|---|
| TIME and SOURCE | CONTENT | TIME and SOURCE | CONTENT |
| 23:55:35.5<br>**HOT-1** | #. | | |
| | | 23:55:36.0<br>**RDO-2** | roll the equipment we're goin' off the end. |
| 23:55:38.5<br>**HOT-1** | how many? | | |
| 23:55:39.5<br>**[end of transcript]** | | | |
| 23:55:41.1<br>**[end of recording]** | | | |