National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 14, 2010

In reply refer to: A-10-46 through -59

The Honorable J. Randolph Babbitt
Administrator
Federal Aviation Administration
Washington, D.C. 20591

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.[1] 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.

During the takeoff roll, less than 2 seconds after the first officer stated, “V_1,[2]” the cockpit voice recorder captured the beginning of a loud rumbling noise, and the airplane swerved briefly and crossed the runway centerline. The investigation determined that the onset of the loud rumbling noise resulted from fragments of the right outboard main landing gear (MLG) tire separating from the wheel and striking the underside of the airplane and was likely accompanied by shaking and vibration of the airframe. The three remaining MLG tires subsequently failed, and the investigation found that all four tires had been severely underinflated at the time of the accident.

In response to the anomaly, the captain, who was the pilot flying, first reduced engine power, then increased it, then decreased it again and committed to performing a high-speed rejected takeoff (RTO), which was inconsistent with her training and standard operating procedures. The accident airplane’s thrust reverser system initially performed as the captain

[1] For more information, see *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: NTSB, 2010), which is available on the National Transportation Safety Board’s website at <http://www.ntsb.gov/publictn/2010/AAR1002.pdf>.

[2] 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.

commanded; however, the circuit associated with the MLG electrical components and wiring (which includes the squat switch and wheel speed sensor systems) sustained damage (likely from tire debris) that affected the air-ground signal, disrupting the system logic requirements for maintaining thrust reverser deployment. As a result, about 7 seconds after the captain committed to the RTO (about 10 seconds after the rumbling noise began), the airplane's system status changed to "air mode," and the thrust reversers stowed. Meanwhile, as indicated by engineering and ground tests, the thrust reverser levers in the cockpit remained in the raised full-reverse-thrust position while the engines provided forward thrust at near takeoff power.

There was no warning annunciator in the cockpit to indicate any system anomaly. The investigation found that the airplane was about 2,500 feet from the end of the runway at a ground speed of about 123 knots (kts) when the uncommanded forward thrust began. Although evidence indicated that the first officer assessed the problem and reacted and that engine power subsequently began to decrease, the airplane was traveling in excess of about 100 kts when it overran the end of the runway safety area.

The National Transportation Safety Board determined 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 an 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.

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 uncommanded forward thrust 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.

Criticality of Proper Tire Inflation

Global Exec Aviation's director of maintenance estimated that the tire pressures on the accident airplane had not been checked in about 3 weeks before the accident, which was consistent with the type of damage found on the tire debris. According to FAA Technical Standard Order (TSO) TSO-C62c,[3] the maximum allowable daily air pressure loss for an

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

airplane tire under normal operating circumstances was 5 percent. According to a Goodyear qualification test report for the tire model that was installed on the accident airplane's MLG, that tire model was documented to have a daily pressure loss of about 2.2 percent.[4]

Global Exec Aviation's director of maintenance indicated that he referred to the aircraft maintenance manual (AMM) for each type of airplane operated by the company to know when to perform scheduled maintenance items. Chapter 5 of the Learjet 60 AMM 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)." 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[5] 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. (The investigation found that the accident airplane's MLG tires were about 36-percent underinflated at the time of the accident.)

An informal review of tire pressure information from a sampling of in-service transport-category airplanes found 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. Also, although nearly all of the maintenance providers interviewed during the investigation indicated that use of the AMM is required by an operator's operations specifications, a representative from one fixed-based operator (FBO) 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

[4] The tire model was the Goodyear Flight Eagle, part number 178K43-1, size 17.5 x 5.75-8. Testing for the tire was documented in Goodyear Qualification Test Report 461B-3044-TL.

[5] 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 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*.

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 NTSB notes that 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, 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 temporary revision 12-16 to the Learjet 60 AMM 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).

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[6] airplane 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 Part 91 may perform tire pressure checks but that a pilot flying a Learjet 60 under 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, 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.

[6] 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.

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 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, the 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.

Tire Pressure Monitoring Systems

Based on 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.

Tire pressure monitoring systems (TPMS), which are installed in some new airplanes and can be retrofitted on others, provide 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 can help ensure proper inflation and safe operations, particularly when the airplane is away from the operator's maintenance base for multiday trips.

Had the accident 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 enables 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.

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 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. During this accident, 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.

As a result of this investigation, the NTSB concluded in a July 17, 2009, safety recommendation letter to the FAA, 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. The NTSB issued Safety Recommendation A-09-59 that 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. (A-09-59)

In response, on November 5, 2009, the FAA issued a safety alert for operators (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."

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. In its July 17, 2009, safety recommendation letter to the FAA, the NTSB also issued safety recommendations addressing the need for changes to the Learjet 60's thrust reverser system (and that of the Raytheon Hawker 1000, which has a similar system). Specifically, the NTSB asked that the FAA 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 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)
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> 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)
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> 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)
>
> 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)

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. 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.[7] 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 2001 accident, the solutions it implemented (and that the FAA approved) did not adequately address the design deficiencies. On November 20, 2003, Learjet issued an airplane flight manual (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. However, the NTSB notes that this AFM revision inappropriately relied on a flight crew procedure to mitigate a serious hazard (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.

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

Although Learjet subsequently introduced a design change to supplement the procedure, the modification also failed to adequately address the problem. 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.[8]

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[9] 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 Advisory Circular (AC) 25.1309-1A, *System Design and Analysis*. 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 International's (formerly known as the Society of Automotive Engineers) aerospace recommended practice (ARP) document, SAE ARP4761,[10] 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 analysis 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 analysis 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),[11] which the FAA has described as the most effective way to improve safety and accomplish

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[8] 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.

[9] 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.

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

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

oversight.[12] Although the NTSB endorses SMS implementation as a means to improve safety,[13] 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.

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 the previous safety recommendation (Safety Recommendation A-10-51), require that designated engineering representatives 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).

Safety of Changed Aeronautical Products

The certification procedure 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 type certificate (TC) apply. 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.

[12] 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."

[13] The NTSB has issued previous recommendations related to SMS. Safety Recommendation A-07-09, which asked that the FAA "[require that all …Part 121 operators establish [SMS] programs," is classified "Open—Acceptable Response"; Safety Recommendation A-09-89, which asked that the FAA "[r]equire helicopter emergency medical services operators to implement [an SMS] program that includes sound risk management practices," is classified "Open—Await Response"; and Safety Recommendation A-09-99, which asked that public operators of helicopter emergency medical services "[i]nstall flight data recording devices and establish a structured flight data monitoring program that incorporates routine reviews of all available sources of information to identify deviations from established norms and procedures and other potential safety issues," is classified "Open—Await Response."

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 of the certification basis for derivative model aircraft, the procedures still allow for inconsistencies and varied 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 was required to comply with as a modification under the original version of 14 CFR 25.1309 (a regulation which relates to failures of equipment, systems, and installations), rather than the extensively revised version of the regulation, including amendment 25-41 (applicable to the Learjet 45), which had been in effect since 1977.

In 1981, during a certification review of a different Learjet derivative model,[14] 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 the reverser doors while the

[14] 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). None of the design characteristics for the Learjet 25 under that FAA review were related to the systems examined in this investigation.

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.

Lack of Flight Crew Training for Tire-Related Events

AC 120-62, *Takeoff Safety Training Aid*, section 2, "Pilot Guide to Takeoff Safety," 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, 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.

As indicated in the NTSB's 1990 special investigation report (SIR), *Runway Overruns Following High Speed Rejected Takeoffs*,[15] and an updated review by Boeing that includes data up to 1999, accidents and incidents related to RTOs initiated because of wheel or tire

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

malfunctions are as common as those related to RTOs performed in response to engine failures. The accidents and incidents 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 instructor from FlightSafety International, the training curriculum provided to the accident 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 spend training 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, and that this 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. 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. Therefore, 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 the previous safety recommendation (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.

Lack of Minimum Operating Experience Requirements for Part 135 Pilots

A pilot-in-command (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, she asked the more experienced first officer if takeoff should continue (saying "go?"),[16] and she wavered on engine power input; both actions 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 included 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 as second-in-command) 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.[17] 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 14 CFR 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 14 CFR Part 135 operations in aircraft that require a type rating gain a minimum level of initial operating experience, similar to that

[16] Four-tenths second after the beginning of the loud rumbling sound, the first officer stated, "go," then, "go go go," indicating that he believed that the takeoff should be continued (which was consistent with training and operating procedures). In response, the captain asked, "go?" but ultimately committed rejecting the takeoff.

[17] 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.

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 14 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.

Tire Certification and Testing Considerations

In this accident, after the failure of the first MLG tire (the right outboard tire), 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. During this investigation, a review of tires in service found that most airplanes sampled 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 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.

Therefore, the National Transportation Safety Board recommends that 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)

Further, the following previously issued recommendations to the Federal Aviation Administration are reclassified as follows:

> 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)
>
> 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."

Further, the following previously issued recommendation to the Federal Aviation Administration is reclassified as follows:

> 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)
>
> Safety Recommendation A-09-59 (previously classified "Open—Response Received") is classified "Open—Acceptable Alternate Response."

In response to the recommendations in this letter, please refer to Safety Recommendations A-10-46 through -59 and Safety Recommendations A-09-55 through -60 in your reply. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

Chairman HERSMAN, Vice Chairman HART, and Member SUMWALT concurred in these recommendations.

[Original Signed]

By: Deborah A.P. Hersman
Chairman