National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 20, 2000

In reply refer to: A-00-109 through -119

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

In this letter, the National Transportation Safety Board recommends that the Federal Aviation Administration (FAA) take action to address the following safety issues: the adequacy of existing guidance on time of useful consciousness at altitude, the need for hypoxia awareness training, the adequacy of existing guidance on preflight procedures for aircraft with supplemental oxygen systems, the adequacy of emergency procedures and checklists for cabin altitude warnings, the difficulty of confirming the status of the oxygen bottle regulator/shutoff valve assembly on Learjet Model 35/36 airplanes, the absence of automatic emergency pressurization systems on Learjet Model 35/36 airplanes (and Part 25 aircraft), FAA oversight of Part 135 operators, and aging aircraft. The Safety Board identified these safety issues during its investigation of the October 25, 1999, crash of a Learjet Model 35 airplane near Aberdeen, South Dakota. This letter summarizes the Board's rationale for issuing these recommendations.

Background

On October 25, 1999, about 1213 central daylight time, a Learjet Model 35, N47BA, operated by Sunjet Aviation, Inc., of Sanford, Florida, crashed near Aberdeen, South Dakota. The airplane departed Orlando, Florida, for Dallas, Texas, about 0920 eastern daylight time (EDT) with 4 hours and 45 minutes of fuel on board (based on power settings for a normal flight profile). Air traffic control (ATC) lost radio contact with the airplane in the area north of Gainesville, Florida, after clearing the airplane to flight level (FL) 390. The airplane was subsequently intercepted by several U. S. Air Force and Air National Guard (ANG) aircraft as it proceeded northwestbound. The military pilots in a position to observe the accident airplane at close range stated that the forward windshields of the Learjet seemed to be frosted or covered with condensation. The military pilots could not see into the cabin. They did not observe any structural anomaly or other unusual condition. The military pilots observed the airplane depart controlled flight and spiral to the ground, impacting an open field. All occupants on board the airplane (the captain, first officer, and four passengers) were killed, and the airplane was destroyed.

Information from the accident airplane's cockpit voice recorder (CVR) indicated that the airplane lost cabin pressurization, most likely at some point during the 6 minutes and 20 seconds between the last radio transmission from N47BA at 0927:18 EDT and the flight crew's failure to respond to ATC inquiries beginning at 0933:38 EDT. Specifically, in its examination of the CVR (which recorded the last 30 minutes of the flight), the Safety Board noted the sound of the cabin altitude aural warning, which is designed to activate when the cabin altitude is above 10,000 feet,[1] and the lack of conversation between flight crewmembers. In addition, the flight crew's failure to respond to numerous radio calls from controllers and military airplanes and to control the airplane indicated that the cabin altitude climbed to levels at which consciousness could be maintained only with supplemental oxygen and that the flight crew failed to receive supplemental oxygen; the reason for this failure could not be determined. There was insufficient evidence to determine the cause of the cabin depressurization or the rate at which it occurred.[2]

The Safety Board determined that the probable cause of this accident was "incapacitation of the flight crewmembers as a result of their failure to receive supplemental oxygen following a loss of cabin pressurization, for undetermined reasons."

Discussion

Under standard conditions at sea level, atmospheric pressure is 14.7 pounds per square inch (psi) with concentrations of oxygen and nitrogen of about 21 and 78 percent, respectively. With increased altitude, the relative concentration of oxygen does not change, but the atmospheric pressure decreases disproportionately. For example, at 10,000 feet, atmospheric pressure is 10.1 psi; at 36,000 feet, it decreases to 3.3 psi. At altitudes above 10,000 feet, the reduction in the partial pressure[3] of oxygen impedes its ability to transfer across lung tissue into the bloodstream to support the

[1] All altitudes are mean sea level (msl) unless noted otherwise.

[2] The Safety Board could not determine whether the event was explosive, rapid, or gradual. Explosive decompressions typically occur in less than 1/2 second and are accompanied by loud noise and fog. Rapid decompressions typically last from 1/2 to 10 seconds, whereas gradual decompressions occur over a longer period of time.

[3] Partial pressure, which is a function of the concentration of the gas in the atmosphere, represents the amount of total pressure accounted for by a particular gas. For example, at sea level (14.7 psi), the 21-percent oxygen concentration provides a partial pressure of about 3.1 psi.

effective functioning of major organs, including the brain. These altitudes are typically referred to as "physiologically deficient altitudes."

Pressurized aircraft cabins allow physiologically safe environments to be maintained for flight crew and passengers during flight at physiologically deficient altitudes. At cruising altitudes, pressurized cabins of turbine-powered aircraft typically maintain a consistent environment equivalent to that of approximately 8,000 feet[4] by directing engine bleed air into the cabin while simultaneously regulating the flow of air out of the cabin. Decreased cabin pressurization (and, therefore, increased cabin altitude) can be caused by reductions in the flow of air into the cabin, increase in the flow of air out of the cabin, or both. A complete loss of cabin pressurization will cause the cabin altitude to increase and stabilize at the airplane flight altitude.

Cabin depressurization events are relatively infrequent in pressurized aircraft[5] and can result from leaking seals or airframe failures; systems (mechanical) failures, such as an outflow valve not cycling closed; or human failures, such as not properly configuring and managing the pressurization system. Regardless of the cause, a flight crew's timely response to a depressurization event is critical because, like the presence of smoke in the cockpit,[6] cabin depressurization can rapidly produce an environment that degrades the ability of the flight crew to effectively respond. Specifically, if an airplane is above physiologically safe flight altitudes when depressurization occurs, its occupants are at risk for exposure to conditions leading to the onset of hypoxia.

Hypoxia, the physiological state of insufficient oxygen in the blood and body tissue,[7] can lead to incapacitation and, in extreme cases, death. Initial signs of hypoxia include increased breathing rate, headaches, lightheadedness, dizziness, feelings of warmth or tingling, sweating, irritability, and euphoria.[8] Hypoxia may ultimately cause impaired vision, judgment, or motor control; drowsiness; slurred speech;

[4] The environmental equivalent altitude is referred to as "cabin altitude."

[5] Cabin depressurization events are not limited to general aviation. For example, on November 18, 1999, a Boeing 767 depressurization event occurred during the airplane's climbout from San Diego, California. For more information, see Brief of Incident LAX00SA040.

[6] Following its investigation of the May 11, 1996, ValuJet Airlines flight 592 accident, the Safety Board issued Safety Recommendation A-97-58, which recommended that the FAA issue guidance to air carrier pilots about the need to don oxygen masks and smoke goggles at the first indication of a possible in-flight smoke or fire emergency. (On July 23, 1999, the Board classified Safety Recommendation A-97-58 "Closed—Acceptable Action" after the FAA issued a guidance bulletin.) For more information about this accident, see National Transportation Safety Board. 1997. *In-Flight Fire and Impact With Terrain, ValuJet Airlines Flight 592, DC-9-32, N904VJ, Everglades, Near Miami, Florida, May 11, 1996*. Aircraft Accident Report NTSB/AAR-97/06. Washington, DC.

[7] Hypoxia can be the result of various conditions. In this letter, hypoxia refers to hypoxic hypoxia, which is associated with increased altitudes.

[8] Susceptibility to hypoxia varies both among and within individuals. Some individuals may experience symptoms below 10,000 feet, whereas others do not. Several factors can affect an individual's tolerance; for example, physical activity and mental stress can significantly reduce tolerance of hypoxia because of increased metabolic demands. For additional information, see Advisory Circular (AC) 61-107, "Operations of Aircraft at Altitudes Above 25,000 Feet [msl] and/or Mach Numbers (Mmo) Greater Than 0.75"; and Sheffield, P. J. and Heimbach, R. D. 1996. "Respiratory Physiology." In: DeHart, R. L. ed. *Fundamentals of Aerospace Medicine (2nd ed.)*. Williams and Wilkins. Baltimore, Maryland.

memory decrements; and difficulty thinking. In addition, hypoxia can create a false sense of well being that can degrade accurate self-assessment of the condition, causing unawareness of one's symptoms and level of impairment. In most cases, the initial signs of hypoxia are subtle, and a pilot has limited time to recognize the signs, make decisions, and perform necessary tasks. The amount of time available to an individual before the ability to perform directed tasks is lost is often referred to as the time of useful consciousness (TUC), and it can vary from a few seconds to several minutes, depending on the cabin pressure altitude and how rapidly it increases.

When cabin depressurization occurs at high altitudes, the immediate proper use of supplemental oxygen is critical; if supplemental oxygen is not used, unconsciousness and even death can quickly result. In its examination of safety issues associated with this accident, the Safety Board evaluated the effectiveness of the following methods that are currently used to ensure an effective response to a cabin depressurization event: training and education, procedures and checklists, and aircraft systems.

Training and Education

On September 17, 1982, following the October 1, 1981, crash of a Learjet Model 24 near Felt, Oklahoma, and the May 6, 1982, crash of a Learjet Model 23 into the Atlantic Ocean near Savannah, Georgia,[9] the Safety Board issued Safety Recommendation A-82-127, which asked the FAA to do the following:

> Establish a minimum training curriculum to be used at pilot schools which covers special considerations involved in a pilot's initial transition into general aviation turbojet airplanes, including the aerodynamic, meteorological and physiological aspects of high-performance, high-altitude flight.

In a December 7, 1982, letter to the Safety Board, the FAA stated that it planned to convene a special flight standardization board to review the adequacy of current training and type certification requirements for general aviation multiengine turbojet airplanes and, specifically, the physiological aspects of high-performance, high-altitude flight. Further, in an August 1, 1986, letter to the Board, the FAA indicated that it would publish an AC by January 1, 1987, to address these issues. In a May 28, 1987, response, the Board stated that it viewed the issuance of the AC as an interim response and that a final action that did not include the establishment of a well-defined minimum curriculum would be unacceptable.

In a June 16, 1987, letter to the Safety Board, the FAA stated that the AC was rescheduled for publication in January 1988 and that it had initiated a project to address the revision of pilot training regulations under 14 *Code of Federal Regulations* (CFR) Parts 61 and 141. On May 8, 1989, the Board classified Safety Recommendation A-82-127 "Closed—Unacceptable Action," stating, "Since the FAA has repeatedly expressed its agreement with these recommendations, we do not

[9] Both of these accidents involved uncontrolled descents from cruise FLs. For more information, see Briefs of Accident DCA82AA001 and DCA82AA020, respectively.

understand why positive action has not been taken on these issues." On January 23, 1991, 4 years after the original proposed publication date and about 9 years after the Board issued this recommendation, the FAA issued AC 61-107, "Operations of Aircraft at Altitudes Above 25,000 Feet [msl] and/or Mach Numbers (Mmo) Greater Than 0.75."[10]

Currently, 14 CFR 61.31(g) requires pilots operating pressurized aircraft that have a service ceiling or maximum operating altitude (whichever is lower) above 25,000 feet to receive ground training in areas relevant to high-altitude flight, including respiration; effects, symptoms, and causes of hypoxia and other high-altitude sicknesses; duration of consciousness without supplemental oxygen; physical phenomena and incidents of decompression; and any other physiological aspects of high-altitude flight.[11] This section also requires pilots to demonstrate proper emergency procedures in response to a simulated rapid decompression. In addition, for flight crews operating under 14 CFR Parts 121 and 135, training covering the physiological aspects of high-altitude flight is provided as part of required general emergency training on a recurrent basis.

The Safety Board identified two safety issues during its investigation of this accident regarding physiological training and education: (1) the adequacy of existing guidance on TUC at altitude and (2) the need for hypoxia awareness training.

Guidance on Time of Useful Consciousness at Altitude

Differing information on high-altitude physiology is available in several FAA and industry publications. For example, AC 61-107 indicates that the TUC at about 25,000 feet is 3 to 5 minutes, whereas AC 25-20, "Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight, Including High Altitude Operation,"[12] indicates that the TUC at about 25,000 feet is 3 to 10 minutes. (The Medical Facts for Pilots informational bulletin [FAA-P-8740-41][13] and the Aeronautical Information Manual [AIM], chapter 8, contain similar information.)[14] A widely recognized text on aerospace medicine lists the effective performance time at 30,000 feet without supplemental oxygen as 1 to 2 minutes.[15]

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[10] AC 61-107 was issued to inform pilots who are transitioning to airplanes that can operate at high altitudes and airspeeds of the need to understand the physiological and aerodynamic considerations associated with these airplanes. The AC addresses the high-altitude training requirements of 14 CFR Part 61.

[11] Those training requirements are not applicable to pilots who have acted as pilot-in-command (PIC) of a pressurized aircraft or completed a proficiency check for a certificate or rating in a pressurized aircraft (or flight simulator/training device representative of a pressurized aircraft) before April 15, 1991. In addition, pilots of pressurized aircraft who have completed a PIC check in the military or a proficiency check under 14 CFR Parts 121, 125, and 135 are exempt.

[12] AC 25-20, which was issued on September 10, 1996, contains a discussion of TUC and guidance on methods of compliance with 14 CFR Part 25.

[13] This bulletin was published by the FAA's Aeromedical Education Division in 1999 and was distributed to pilots.

[14] In addition, the Safety Board notes that a major operator's September 2, 1994, A300 Operating Manual has an EXCESS CAB ALT expanded checklist that contains the following warning regarding decompression and TUC: "The time of useful consciousness following an explosive decompression will vary from approximately 1-2 minutes at 25,000 feet to 15-23 seconds at 40,000 feet."

[15] Sheffield and Heimbach. 1996. p. 96.

The studies upon which those times were based were conducted using comfortably seated participants who were expecting a decompression and who were asked to perform simple repetitive tasks (such as counting backward from 1,000) until they could no longer accomplish them.[16] Therefore, these studies do not accurately replicate the complex and changing environment of an aircraft that is losing cabin pressure, and the tasks performed do not accurately simulate the types of tasks involved in accurately identifying and responding to an emergency situation.

Regarding complex task performance at altitude, several other studies suggest that impairment occurs much sooner. For example, an altitude chamber study published in 1990 indicated that a delay of as little as 8 seconds in supplying oxygen to subjects that had been rapidly decompressed to a pressure altitude of 29,850 feet resulted in a significant drop in oxygen saturation;[17] even a moderate drop in oxygen saturation has been shown to significantly impair cognitive functioning and increase the amount of time required to complete complex tasks.[18] Further, the ability to learn new tasks measurably decreases at altitudes as low as 8,000 feet,[19] and, at 15,000 feet, significant impairment is noted in the performance of even simple cognitive tasks.[20] Simulator studies have shown that at 15,000 feet, the ability to manually maintain a given airspeed, heading, or vertical velocity is reduced by 20 to 30 percent.[21] At about 33,000 feet, the ambient pressure is no longer sufficient to force oxygen across the lung tissue into the bloodstream; therefore, after a few seconds of exposure above that altitude, maintenance of a normal oxygen level in the blood is impossible.

Performance decrements may persist for several minutes even after oxygen is administered.[22] For example, in a National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) report, such an impairment was documented by a pilot, who noted the following:

> It probably took no more than 10 [seconds] to don oxygen masks and get airflow, however I felt very confused for the first 2 to 3 minutes (or at least it seemed that long). One part of my brain would tell me to be sure and get the checklist done and another

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[16] Hoffler, G. W.; Turner, H. S.; Wick, R. L., Jr.; and Billings, C. E. 1974. "Behavior of Naïve Subjects During Rapid Decompression From 8,000 to 30,000 Feet." *Aerospace Medicine* 45(2): 117-122.

[17] Marotte, H.; Toure, C.; Clere, J. M.; and Vieillefond, H. 1990. "Rapid Decompression of a Transport Aircraft Cabin: Protection Against Hypoxia." *Aviation, Space, and Environmental Medicine* 61: 21-27.

[18] Noble, J.; Jones, J. G.; and Davis, E. J. 1993. "Cognitive Function During Moderate Hypoxaemia." *Anesthesia and Intensive Care* 21(2): 180-184.

[19] Kelman, G. R. and Crow, T. J. 1969. "Impairment of Mental Performance at a Simulated Altitude of 8,000 Feet." *Aerospace Medicine* 40(9): 981-982.

[20] Harding, R. M. (revised by Gradwell, D. P.). 1999. "Hypoxia and Hyperventilation." In: Ernsting, J.; Nicholson, A. N.; and Rainford, D. J. eds. *Aviation Medicine (3rd ed.)*. Butterworth Heinemann. Oxford, England. p. 53.

[21] Harding, R. M. (revised by Gradwell, D. P.). 1999. pp. 43-58.

[22] O'Connor, W. F. and Pendergrass, G. F. 1966. "Task Interruption and Performance Decrement Following Rapid Decompression." *Aerospace Medicine* 37(6): 615-617; Harding, R.M. (revised by Gradwell, D. P.). 1999. pp. 48-49.

> part would say 'just fly the airplane.' It almost seemed like there was conflict going on inside my brain.[23]

The Safety Board's review of 129 ASRS reports (from March 1988 through December 1998) involving cabin pressure incidents indicated that many pilots did not use oxygen masks while they were troubleshooting cabin pressure problems as the cabin altitude climbed.[24] For example, the Board investigated an incident in which several flight crewmembers of a Boeing 727 who did not immediately don oxygen masks lost consciousness after silencing the cabin altitude aural warning while troubleshooting a cabin pressure problem.[25] A similar incident occurred in the United Kingdom involving a Boeing 737.[26] Several ASRS reports also indicate that some pilots at extremely high altitudes (more than 40,000 feet) were not wearing oxygen masks at the time of the loss of pressurization events,[27] even though *Federal Aviation Regulations* require at least one pilot to wear an oxygen mask when the airplane is operating above 35,000 feet for Part 135 operations and 41,000 feet for Part 121 operations.

The Safety Board concludes that existing guidance and information on TUC is inconsistent and misleading because it does not accurately reflect the TUC for pilots trying to perform complex tasks in an emergency environment. It fails to convey to flight crews the urgency of donning oxygen masks immediately after a loss of pressurization at relatively high altitudes. Therefore, the Safety Board believes that the FAA should (1) revise existing guidance and information about high-altitude operations to accurately reflect the TUC and rate of performance degradation following decompression and to highlight the effect of hypoxia on an individual's ability to perform complex tasks in a changing environment and (2) incorporate this revised information into both the required general emergency training conducted under 14 CFR Parts 121 and 135 and training and flight manuals provided to all pilots operating pressurized aircraft.

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[23] See National Aeronautics and Space Administration Aviation Safety Reporting System Report Accession Number 85640 (1988).

[24] The Safety Board recognizes that there may be several factors associated with the flight crews' not donning oxygen masks, including issues related to mask comfort. The FAA's Civil Aeromedical Institute has conducted research on mask comfort issues in its work on inflatable quick-don masks. See, for example, Motavalli, S.; Rhode, N.; and Garner, R. P. 1996. *Survey of Commercial Pilots Addressing Comfort and Fit Issues of Aircrew Oxygen Masks.* 34th Annual SAFE Symposium Proceedings.

[25] For more information, see Brief of Incident CHI96IA157.

[26] When the Boeing 737 lost pressurization during a descent from FL 350 to FL 280, the captain and flight attendant lost consciousness. The Air Accidents Investigation Branch (AAIB) report stated that "it is…possible that neither [the captain nor the flight attendant] fully appreciated the nature of hypoxia. The term 'time of useful consciousness' may lead crew members to assume that a longer time is available for performance of tasks than is actually the case." For more information about this accident, see Air Accidents Investigation Branch Bulletin No: 6/99 Ref: EW/C98/8/6.

[27] See, for example, National Aeronautics and Space Administration Aviation Safety Reporting System Report Accession Number 385476 (1997).

Hypoxia Awareness Training

U.S. military services, other Federal agencies, and flight departments of some corporations require pilots operating pressurized aircraft in a high-altitude flight environment to undergo periodic high-altitude physiological ground training, including training in a hypobaric or altitude chamber.[28] However, there are no regulations requiring altitude chamber training for civilian pilots.

Training profiles for altitude chambers typically include a simulated rapid decompression in which participants experience the sounds and misting phenomenon associated with a rapid decrease in atmospheric pressure and exposure to pressure altitude of 25,000 feet without oxygen. The intent of this training is to allow pilots to experience the effects of hypoxia under controlled conditions and, because the initial symptoms of hypoxia vary among individuals, to help pilots recognize their individual symptoms.

The AIM, section 8-1-2, states the following:

> The effects of hypoxia are usually quite difficult to recognize, especially when they occur gradually. Since symptoms of hypoxia do not vary in an individual, the ability to recognize hypoxia can be greatly improved by experiencing and witnessing the effects of hypoxia during an altitude chamber 'flight.'

In addition, the Medical Facts for Pilots informational bulletin states that individuals react differently to the effects of hypoxia and that "only [altitude chamber training] can safely 'break the code' for [each pilot]." Further, an FAA technical report[29] that reviewed civilian and military training in high-altitude flight physiology concluded that evidence supported the addition of altitude chamber flights to mandated training for civilian pilots.

However, the Safety Board questions the usefulness of altitude chamber training[30] for civilian pilots.[31] For example, the possibility exists that such training may contribute to pilot complacency (and

[28] Before leaving the U.S. ANG in 1993, the captain of the accident airplane would have been required to undergo high-altitude physiological training, including altitude chamber training, every 3 years. No evidence suggests that the first officer of the accident airplane had received altitude chamber training.

[29] Turner, J. W., and Huntley, M. S., Jr. 1991. *Civilian Training in High-Altitude Flight Physiology*. DOT/FAA/AM-91/13.

[30] The Safety Board notes that there are several alternatives to altitude chamber training, including enhanced physiological training, enhanced procedures training using oxygen equipment in the airplane and in simulations, and mixed gas inhalation.

[31] In a draft report on an accident involving a Beechcraft Super King Air 200, the Australian Transport Safety Bureau stated, "The pilot and passengers had all undertaken regular hypobaric hypoxia training. Despite this training, they did not identify the onset of the symptoms of hypoxia until one person became unconscious. The training had not provided an effective defence by equipping the flight crew to recognise the onset of symptoms of hypoxia." For more information, see the draft Australian Transport Safety Bureau Air Safety Occurrence Report No. 199902928. In addition, the AAIB report regarding the Boeing 737 depressurization event stated, "In view of the commander's experience…it would appear that even those crew members who have had the benefit of decompression training in

thereby cause delayed response to decompression events in the aircraft) because the onset of symptoms at the altitudes experienced in chambers does not accurately reflect the acute onset of symptoms experienced during decompression events at higher flight altitudes.[32] In addition, the oxygen masks and regulators used in the training chamber may vary from those available to civilian pilots in daily operations.[33] Further, hypoxic symptoms in an individual may be affected by factors such as sleep, nutrition, and exercise, which could reduce the effectiveness of this training in promoting awareness of symptoms. Finally, there can be medical risks associated with altitude chamber training, such as damage to the sinuses or middle ear[34] and altitude decompression sickness.[35]

Because of these concerns, the Safety Board concludes that a formal study is necessary to evaluate whether hypoxia awareness training, including altitude chamber training, should be required for civilian pilots. Therefore, the Safety Board believes that the FAA should convene a multidisciplinary panel of aeromedical and operational specialists to study and submit a report on whether mandatory hypoxia awareness training, such as altitude chamber training, for civilian pilots would benefit safety. The report should consider alternatives to altitude chamber training, clearly identify which pilots and/or flight operations would benefit most from such training, and determine the scope and periodicity of this training. If warranted, the FAA should establish training requirements based on the findings of this panel.

Procedures and Checklists

Preflight Procedures for Aircraft with Supplemental Oxygen Systems

Routine preflight procedures for aircraft with supplemental oxygen systems generally include an inspection of oxygen equipment to ensure that it is operational and will function properly if needed in flight.[36] The expanded preflight checklists for many aircraft list items to be inspected during the preflight check of the oxygen equipment.

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hypobaric chambers in the past may not be immune from failing to recognise the importance of immediate action to protect respiration." For more information about this accident, see Air Accidents Investigation Branch Bulletin No: 6/99 Ref: EW/C98/8/6.

[32] The complacency factor could be addressed via enhanced ground training with improved guidance regarding TUC, as previously discussed.

[33] For example, the position of the regulators (mask mounted versus aircraft mounted) and the location of the masks may be different.

[34] See, for example, Davenport, N. A. 1997. "Predictors of Barotrauma Events in a Navy Altitude Chamber." *Aviation, Space, and Environmental Medicine.* 68(1): 61-65.

[35] See, for example, Rudge, F. W. "The Role of Ground Level Oxygen in the Treatment of Altitude Chamber Decompression Sickness." *Aviation, Space, and Environmental Medicine.* 63(12): 1102-1105.

[36] Preflight examination of the oxygen system is required for 14 CFR Part 121 operations. Specifically, 14 CFR 121.333 states, "Before the takeoff of a flight, each flight crewmember shall personally preflight his oxygen equipment to insure that the oxygen mask is functioning, fitted properly, and connected to appropriate supply terminals, and that the oxygen supply and pressure are adequate for use."

However, the Safety Board reviewed ASRS reports that documented instances in which flight crews donned oxygen masks, but system components were inoperative. For example, in one report, a pilot indicated that “once we were wearing the oxygen masks, communications between the crew were very difficult. We also found after departure that the captain’s mask mike was inoperative so he was unable to communicate with ATC.”[37] In another report, a pilot stated that “[t]he captain requested that I fly the aircraft briefly while he tried to adjust his oxygen mask which had ‘come apart’ and was unusable. After...fixing the mask, he again took control of the aircraft”; he recommended that the “preflight check of [the] oxygen mask includes putting it on. It can be a pain restowing (on this airplane) but it could be your life.”[38]

In the event of a loss of cabin pressure, there may be insufficient time to troubleshoot an oxygen mask problem in flight and ensure that the pilot receives supplemental oxygen in a timely manner. The Safety Board is concerned that some flight crews are not performing thorough functional preflight checks of the oxygen system and concludes that additional emphasis must be placed on the importance of these checks. Therefore, the Safety Board believes that the FAA should require that operators of all pressurized cabin aircraft provide guidance to pilots on the importance of a thorough functional preflight of the oxygen system, including, but not limited to, verification of supply pressure, regulator operation, oxygen flow, mask fit, and communications using mask microphones.

Checklists for Cabin Altitude Warnings

Pressurized aircraft certificated under 14 CFR Parts 23 and 25 are required to present cabin altitude and differential pressure to flight crews; typically, a combined analog cabin altimeter and differential pressure gauge present this information. In addition to the requirement to present this information, 14 CFR 23.841 and 25.841 require pressurized aircraft to have a warning advising flight crew when cabin altitude has exceeded 10,000 feet.[39]

On November 4, 1999, the FAA began conducting a Special Certification Review (SCR) of the Learjet Model 35/36 oxygen and pressurization systems as a result of this accident. In its review, the FAA found that the Learjet Model 35/36 Aircraft Flight Manual (AFM) does not contain an emergency procedure requiring the flight crew to don oxygen masks immediately after the cabin altitude aural warning is activated. Because the AFM contains an Abnormal Procedures checklist allowing the flight crew to troubleshoot the pressurization system before donning oxygen masks, the FAA noted that the flight crew may delay donning oxygen masks and become incapacitated.

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[37] National Aeronautics and Space Administration Aviation Safety Reporting System Report Accession Number 328650 (1996).

[38] National Aeronautics and Space Administration Aviation Safety Reporting System Report Accession Number 183274 (1991).

[39] The cabin altitude warning can be aural or visual. For example, on the Boeing MD-11, a visual CABIN ALTITUDE alert is displayed with an aural warning. On the Learjet Model 35 (the model of the accident airplane), a horn sounds when the cabin altitude exceeds 10,000 feet. On the Embraer EMB-145, a voice message states “cabin” when the altitude limits are exceeded.

On June 8, 2000, the FAA issued Notice of Proposed Rulemaking (NPRM) "Airworthiness Directives; Learjet Model 35, 35A, 36, and 36A Series Airplanes," which was published in 65 *Federal Register* (FR) 36391. The NPRM proposed to require revising the AFM to add emergency procedures instructing the flight crew to don oxygen masks[40] when the cabin altitude warning horn is activated.[41] In a July 26, 2000 letter to the FAA, the Safety Board commented on the NPRM, stating the following:

> The Safety Board supports the proposed AD [airworthiness directive] and agrees that the flight crew's oxygen masks should be donned immediately on activation of the cabin altitude warning horn. However, the Board notes that the proposed AFM changes instruct the flight crew to perform an emergency descent upon activation of the cabin altitude warning horn, regardless of the existing flight conditions. It is possible for the cabin altitude warning horn to activate during flight conditions that would not require an emergency descent and landing. To further improve the AFM guidance for flight crews, the Board encourages the FAA to identify all flight conditions in which an emergency descent is not required subsequent to donning oxygen masks and clearly present the appropriate instructions in the final rule.

The Safety Board reviewed checklists for several other pressurized aircraft and determined that some do not consistently provide explicit guidance to flight crews regarding the donning of oxygen masks and other steps to be taken when the cabin altitude warning begins. For example, the Cessna 560 Emergency/Abnormal Procedures checklist references the cabin altitude warning onset by inserting an illustration of the CABIN ALT 10000 FT [feet] annunciator in the Rapid Decompression checklist and lists donning of oxygen masks as the first step on the checklist. However, guidance to flight crews of other airplanes appears in Rapid Depressurization/Emergency Descent or Loss of Pressurization checklists and does not reference the cabin altitude warning. In addition, other checklists do not explicitly instruct flight crews to don oxygen masks.[42]

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[40] On August 30, 2000, the FAA issued an NPRM (65 FR 52677) proposing to require revising the AFM for Lockheed Model 188A and 188C series airplanes to add procedures for donning the flight crew oxygen masks when the cabin altitude warning horn is activated. As with the Learjet Model 35/36, the FAA found that the Lockheed 188A and 188C series AFM did not contain emergency procedures directing flight crews to don oxygen masks upon the onset of the cabin altitude warning. A final rule was issued on November 6, 2000.

[41] The SCR team recommended that "The Transport Airplane Directorate should request [that] all ACOs [aircraft certification offices] review the AFM's of all transport category pressurized airplanes certificated for flight above 25,000 feet and ensure there is an emergency procedure (or equivalent) when the cabin altitude warning is activated. The team recommends that the first crew action after a cabin altitude warning should be to don the oxygen mask. Mandate any necessary revisions through the AD process." In a November 16, 2000, memorandum provided to the Safety Board, the FAA indicated that it had already issued NPRMs regarding Learjet and Lockheed airplanes (as previously discussed) and that it was working with other airplane manufacturers to address the recommendation. An equivalent recommendation was made to the Small Airplane Directorate to address all normal- and commuter-category pressurized airplanes certificated for flight above 25,000 feet.

[42] The preface of a major operator's Boeing 767 quick reference handbook states that the procedures outlined in the checklists assume that "oxygen masks and goggles are donned and communications established when their use is required. This includes but is not limited to: loss of cabin pressure."

According to FAA Order 8400.10, "Air Transportation Operations Inspectors Handbook," paragraph 2177, a flight crew's donning of oxygen masks is considered to be an immediate action item after the cabin altitude warning sounds because an imminent threat of incapacitation and continued safe flight exists. However, in paragraph 2207c, the order states that immediate action items "may be stated as policies rather than checklist items when appropriate." The FAA offers the example of flight crews donning oxygen masks in the event of a loss of cabin pressure, adding, "In this example the loss of cabin pressure checklist would contain subsequent items based on the assumption that the flightcrew is on oxygen and has established interphone contact." The Safety Board does not agree with the FAA's guidance; immediate action items, including the flight crew's donning of oxygen masks, should be presented in the checklist to facilitate training and ensure that all appropriate actions have been completed during checklist review. Therefore, the Safety Board believes that the FAA should remove the reference to the donning of oxygen masks in the event of loss of pressurization as an example of an immediate action item that may be stated as a policy rather than as a checklist item as an acceptable use in FAA Order 8400.10, "Air Transportation Operations Inspectors Handbook," paragraph 2207c, and review the appropriateness of its position that immediate action items may be stated as policies rather than checklist items.

The cabin altitude warning signals the presence of a potentially dangerous environmental condition that can rapidly lead to flight crew impairment if not responded to appropriately. As previously discussed, in some cases TUC may be only seconds, during which time the flight crew may become incapacitated if troubleshooting is attempted before the donning of oxygen masks. The Safety Board concludes that, because of the lack of clear and explicit guidance to flight crews regarding the donning of oxygen masks immediately after the onset of the cabin altitude warning, flight crews may attempt to diagnose and troubleshoot the problem before donning masks and, therefore, risk becoming incapacitated. Therefore, the Safety Board believes that the FAA should require that all pressurized aircraft certificated to operate above 25,000 feet have a clear and explicit emergency procedure associated with the onset of the cabin altitude warning that contains instructions for flight crews to don oxygen masks as a first and immediate action item, followed by instructions appropriate to diagnose, manage, and resolve the condition indicated by the warning. The Board notes that there may be a delay involved in amending the emergency procedures. Therefore, the Safety Board believes that the FAA should issue guidance within 6 months directly to pilots operating pressurized aircraft regarding the need to don oxygen masks immediately following activation of the cabin altitude warning.

Aircraft Systems

Learjet Model 35/36 Oxygen Bottle Regulator/Shutoff Valve

In the Learjet Model 35/36 airplane, the oxygen bottle regulator/shutoff valve is located in the nose cone of the airplane[43] and is therefore inaccessible to flight crewmembers during flight. Oxygen

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[43] The oxygen bottle is installed in the nose cone of the Learjet Model 35/36 airplane, serial numbers 35-002 through 35-491 and 36-002 through 36-050.

bottle supply pressure is indicated on a gauge in the cockpit; however, this gauge does not provide information about the position of the oxygen bottle regulator/shutoff valve, which controls the availability of oxygen to the flight crew.[44] Therefore, the flight crew's only indication in the cockpit that the oxygen bottle regulator/shutoff valve is in the OFF position is the failure of the oxygen mask to deliver oxygen.[45] The Safety Board notes that it is critical that the valve position indicators are clearly visible and easily understandable during preflight inspections.

Postaccident evaluation of the accident airplane's oxygen bottle regulator/shutoff valve indicated that it was in the ON position, which would have allowed the oxygen lines downstream of the bottle to be pressurized; therefore, the valve's position was not a factor in this accident. However, during its investigation, the Safety Board discovered that flight crews may have difficulty visually verifying the position of this valve during a preflight inspection because of its installation in the airplane.

The ON/OFF markings on the regulator cap indicate the position of the valve when aligned with a fixed index mark at the base of the valve. The cap is also marked with arrows (next to the ON/OFF markings) that indicate the direction of rotation required to operate the valve. However, because of the installation of the valve in the airplane, the fixed index marks at the base of the valve are not visible from a normal viewing position; a pilot visually checking the valve status would see an ← OFF marking on the regulator cap when the valve is in or near the ON position.

Learjet Model 35 instructors stated that the difficulty of visually confirming valve status is stressed to pilots who are transitioning into the airplane. Several Learjet Model 35 pilots described methods that they used to verify the status of this valve, including physically turning the valve to confirm its position or associating an ← OFF indication visible from the access panel with an ON position. The Safety Board concludes that the current design of the oxygen bottle regulator/shutoff valve may present a hazard in the operation of the oxygen system on the Learjet Model 35/36 airplane because its location and orientation creates the potential for misinterpretation and may lead to the oxygen supply being unavailable to flight crewmembers and passengers during flight. Because some pilots are accustomed to associating an OFF indication with an ON position, simply relabeling the valve assembly may create further confusion. Therefore, the Safety Board believes that the FAA should issue an AD requiring Learjet, Inc., to instruct operators of the Learjet Model 35/36 (and other affected models) to modify the oxygen bottle regulator/shutoff valve assembly so that flight crews can clearly and accurately verify the position of the valve during preflight visual inspections.

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[44] The oxygen pressure gauge indicates bottle pressure regardless of the position of the oxygen bottle regulator/shutoff valve but does not indicate the pressure from the oxygen supply to the flight crew masks when the valve is closed.

[45] Some flight crew masks are fitted with an in-line pressure gauge that turns from red to green when the hose from the mask-mounted regulator to the oxygen supply line is pressurized. However, under some circumstances, it may be possible for the gauge to turn green when the oxygen bottle regulator/shutoff valve is in the OFF position. For example, this may occur if residual system pressure exists in the lines leading from the supply.

Automatic Emergency Pressurization

The investigation revealed that the accident airplane's flow control valve was closed during the accident flight, thereby preventing the normal pressurization of the cabin. Although the accident airplane was equipped with an emergency pressurization system, the system was not automated and required the pilot to activate the system, whereas later models of the Learjet Model 35/36 have automatic emergency pressurization systems. These automatic emergency pressurization systems use aneroid (pressure) switches that activate when they sense increasing cabin altitudes, such as those that would result after closure of the flow control valve at altitudes above 8,000 feet. The systems then automatically initiate the flow of an alternate bleed air source to the cabin for emergency pressurization.

Although the Safety Board recognizes that the retrofit of earlier model Learjet airplanes with the automatic emergency pressurization systems installed on newer airplanes may be economically impractical because of the extensive changes that would be necessary, it would not likely be economically prohibitive to require the automation of the existing emergency pressurization systems on board. Therefore, the Safety Board believes that the FAA should evaluate the feasibility of requiring design changes to automate the existing emergency pressurization systems on Learjet Model 35/36 airplanes (and other affected models) that do not have an automatic emergency pressurization system. If the automation of their existing systems is determined to be feasible, the FAA should require such design changes. The Safety Board further believes that the FAA should evaluate all Part 25 aircraft that do not have automatic emergency pressurization systems to determine if automation of their existing systems is feasible and, if warranted, require changes to affected models as soon as possible.

FAA Oversight of Part 135 Operators

A sequence of maintenance actions from July 22 through October 23, 1999, for the accident airplane indicates that there were several pressurization-related discrepancies during this period. Maintenance records indicate that Sunjet Aviation personnel attempted to correct the discrepancies by cleaning the pressurization system outflow valve and performing system ground checks. Work on a staggered engine throttle condition, which resulted in the replacement of the left modulation valve on October 23, 1999, was also related to concerns about the pressurization system (as shown by Sunjet Aviation's reference to pressurization on the removed modulation valve's part tag). However, Sunjet Aviation was not able to provide records of pilot-reported discrepancies that led to these maintenance actions.

The investigation did not identify any evidence that the preceding discrepancies were related to the cause of this accident. However, if Sunjet Aviation had maintained pilot discrepancy reports (as required by its General Operations Manual), the Safety Board may have learned additional details about the frequency and nature of the airplane's prior pressurization-related problems and possibly been able to determine whether they were related to a common problem. Further, available records from Sunjet Aviation did not verify whether the discrepancies were corrected before flight.

In addition to Sunjet Aviation's failure to maintain records of pilot discrepancy reports, the investigation revealed that maintenance work performed on the pressurization system was not signed off by mechanics or inspectors and that Sunjet Aviation then operated the accident airplane on revenue trips with deferred maintenance on the pressurization system (without authorization under an FAA-approved Minimum Equipment List). The Safety Board notes that Sunjet Aviation's failure to maintain pilot discrepancy records and its unauthorized operation of flights with deferred maintenance items reflect shortcomings in the company's procedures for identifying, tracking, and resolving repetitive maintenance items and adverse trends.

The Safety Board notes that these shortcomings in the company's maintenance operations were not discovered before the accident by FAA surveillance. In addition, the FAA performed only one airworthiness inspection on the Sunjet Aviation certificate during 1999 (resulting in no findings). However, after the accident, the FAA developed an enforcement package, an excerpt of which was provided to the Board, identifying numerous maintenance items that the FAA indicated were improperly deferred. (According to the FAA, as a result of Sunjet Aviation's surrender of its operating certificate, no enforcement action against Sunjet Aviation was pursued.[46]) The ineffectiveness of the FAA's surveillance of Sunjet Aviation raises concerns about the effectiveness of FAA surveillance of other 14 CFR Part 135 commercial operators. Therefore, to ensure that its surveillance of such operators is adequate, the Safety Board believes that the FAA should increase the frequency of unannounced inspections of Part 135 operators to verify the accuracy and adequacy of pilot discrepancy and maintenance logbook record-keeping procedures and entries.

Aging Transport Aircraft Systems and Structures

There was no evidence that aging systems or structures played a role in causing the depressurization that led to this accident. However, in light of the fact that the accident airplane was 23 years old at the time of the accident, it is possible that its aging structure and/or systems could have been a factor. The Safety Board is aware the FAA has several ongoing programs to address aging systems and structures in transport-category aircraft. However, it is not clear whether transport-category airplanes that may not be operated under Part 121, such as the Learjet Model 35, are included in the scope of these programs. Because issues relating to aging systems and structures are likely to affect all transport-category airplanes, the Safety Board believes that the FAA should ensure that all transport-category airplanes, regardless of whether they are operated under 14 CFR Parts 91, 121, 125, or 135, are included in its review of aging transport aircraft systems and structures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

(1) Revise existing guidance and information about high-altitude operations to accurately reflect the time of useful consciousness and rate of performance degradation following decompression and to highlight the effect of hypoxia on an individual's ability to perform

[46] Sunjet Aviation surrendered its operating certificate to the FAA on July 17, 2000.

complex tasks in a changing environment and (2) incorporate this revised information into both the required general emergency training conducted under 14 *Code of Federal Regulations* Parts 121 and 135 and training and flight manuals provided to all pilots operating pressurized aircraft. (A-00-109)

Convene a multidisciplinary panel of aeromedical and operational specialists to study and submit a report on whether mandatory hypoxia awareness training, such as altitude chamber training, for civilian pilots would benefit safety. The report should consider alternatives to altitude chamber training, clearly identify which pilots and/or flight operations would benefit most from such training, and determine the scope and periodicity of this training. If warranted, establish training requirements based on the findings of this panel. (A-00-110)

Require that operators of all pressurized cabin aircraft provide guidance to pilots on the importance of a thorough functional preflight of the oxygen system, including, but not limited to, verification of supply pressure, regulator operation, oxygen flow, mask fit, and communications using mask microphones. (A-00-111)

Remove the reference to the donning of oxygen masks in the event of loss of pressurization as an example of an immediate action item that may be stated as a policy rather than as a checklist item as an acceptable use in Federal Aviation Administration Order 8400.10, "Air Transportation Operations Inspectors Handbook," paragraph 2207c, and review the appropriateness of its position that immediate action items may be stated as policies rather than checklist items. (A-00-112)

Require that all pressurized aircraft certificated to operate above 25,000 feet have a clear and explicit emergency procedure associated with the onset of the cabin altitude warning that contains instructions for flight crews to don oxygen masks as a first and immediate action item, followed by instructions appropriate to diagnose, manage, and resolve the condition indicated by the warning. (A-00-113)

Issue guidance within 6 months directly to pilots operating pressurized aircraft regarding the need to don oxygen masks immediately following activation of the cabin altitude warning. (A-00-114)

Issue an airworthiness directive requiring Learjet, Inc., to instruct operators of the Learjet Model 35/36 (and other affected models) to modify the oxygen bottle regulator/shutoff valve assembly so that flight crews can clearly and accurately verify the position of the valve during preflight visual inspections. (A-00-115)

Evaluate the feasibility of requiring design changes to automate the existing emergency pressurization systems on Learjet Model 35/36 airplanes (and other affected models) that do not have an automatic emergency pressurization system. If the automation of their existing systems is determined to be feasible, require such design changes. (A-00-116)

Evaluate all Part 25 aircraft that do not have automatic emergency pressurization systems to determine if automation of their existing systems is feasible and, if warranted, require changes to affected models as soon as possible. (A-00-117)

Increase the frequency of unannounced inspections of Part 135 operators to verify the accuracy and adequacy of pilot discrepancy and maintenance logbook record-keeping procedures and entries. (A-00-118)

Ensure that all transport-category airplanes, regardless of whether they are operated under 14 *Code of Federal Regulations* Parts 91, 121, 125, or 135, are included in its review of aging transport aircraft systems and structures. (A-00-119)

Chairman HALL and Members HAMMERSCHMIDT, BLACK, GOGLIA, and CARMODY concurred in these recommendations.

Original signed

By: Jim Hall
Acting Chairman