Losing the Cabin

Insights on civil aircraft depressurization.

BY MARK LACAGNINA

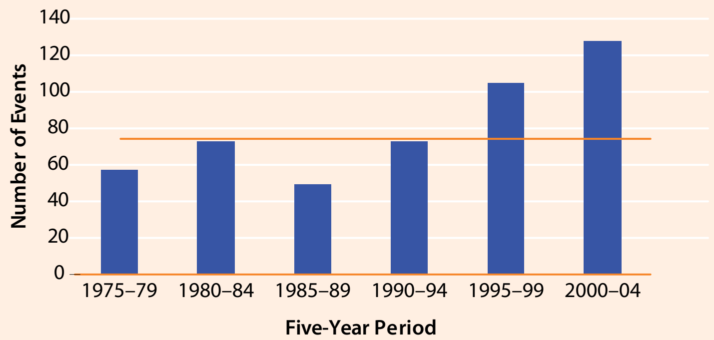
A cabin depressurization likely will be survived if it is recognized early and the appropriate emergency procedures are conducted expeditiously, according to a recent report by the Australian Transport Safety Bureau (ATSB).

Citing a paucity of studies of accidents and incidents involving cabin depressurization in civil aircraft, ATSB delved into more than 30 years of data to throw more light on how often such events occur, why they occur and what happens when they occur.[1]

Sifting through 8,302 accidents, 95 serious incidents (near accidents) and 151,941 incidents that occurred in Australia from Jan. 1, 1975, through March 31, 2006, researchers identified 517 as "pressurization failure events." Figure 1 shows the events grouped in five-year periods. "The apparent increase in depressurization [events] from 1985–1989 to a peak in 2000–2004 may be due to several factors, such as changes in reporting and recording of events, differences in aircraft fleet composition with each epoch, differences in hours flown per five-year period, etc.," the report said. "In the absence of more information, it is not possible to attribute any specific significance to this apparent trend."

Table 1 shows that two-thirds of the events occurred in airline operations. "The vast

Pressurization Failure Events by Five-Year Periods



Source: Australian Transport Safety Bureau

Figure 1

majority of depressurization events occurred in large passenger-carrying commercial transport aircraft category," the report said. "This is not surprising, given that these aircraft fly the most frequently and have the highest pressure differential."

Almost three-quarters of the pressurization failure events were precipitated by mechanical problems.

A pressurization system typically flows compressed air from turbine engine compressor sections, piston engine turbochargers or engine-driven superchargers through air-conditioning packs or heat exchangers into a sealed "pressure vessel" that can include the flight deck, passenger cabin and baggage and cargo compartments. A perfect seal is not possible — control cables, electrical wiring and other components must be routed through the pressure vessel; cutouts must be made for doors, emergency exits, windows and appendages such as radio antennas — so, the system must accommodate some leakage.

The flight crew has controls to regulate the flow of compressed air through inflow valves and outflow valves. Modern pressurization system controllers can operate automatically with information provided by air data computers and cabin sensors. Instruments enable the flight crew to monitor cabin altitude, the rate of change of cabin altitude and *differential*, the difference between cabin air pressure and outside air pressure. When air pressure inside and outside the cabin is equal, the differential is zero. When the cabin is being maintained at sea level pressure, 14.7 psi, at a pressure altitude of 24,000 ft, 5.7 psi, the differential is 9.0 psi (14.7 minus 5.7). Each system has a maximum differential — 4.7 psi for the Beech King Air 90 and 10.7 psi for the Concorde, for example. European and U.S. certification regulations say that cabin altitude cannot exceed 8,000 ft when a transport category airplane is being flown at its maximum operating altitude.[2] Transport category airplanes have warning lights that illuminate when cabin altitude nears or exceeds 10,000 ft, and some also have aural warnings.

Pressurization Failure Events by Operation

Operation	Number	Percentage
Airlines	344	66.5%
Charter	78	15.1%
Other aerial work	34	6.6%
Military	19	3.7%
Commuter	16	3.1%
Private	10	1.9%
Business	8	1.5%
Flight training	3	0.6%
Unknown	5	1.0%
Total	**517**	**100.0%**

Source: Australian Transport Safety Bureau

Table 1

Altitude data were available for 55 of the 517 events. The average altitude at which the 55 events occurred was 25,800 ft; the average cabin altitude reached after the depressurizations was 10,978 ft. The report said that cabin altitude exceeded 14,000 ft in six events. The highest cabin altitude reached was 22,000 ft, when cabin pressure in a Fairchild SA227C was "dumped" for unspecified reasons at 22,000 ft during a charter flight.

Data on the rate of cabin altitude change were available for 39 events. The average rate was 1,712 fpm. In eight events, the rate was 2,000 fpm. Sixteen events exceeded a rate of 2,000 fpm. The highest rate was 6,500 fpm.

Mechanical Problems

Table 2 (page 36) shows the causes of the pressurization failure events. The report said that studies of military aviation in Australia, Canada and the United States also have found that nearly 75 percent of depressurizations were caused by mechanical problems.

More than half — 228 — of the mechanical problems found in the ATSB study originated with pressurization system controllers. "System failure" was cited in 42 events, and outflow valve problems played a role in 28 events. "Maintaining a constant cabin altitude is a balance between the entry of pressurized air and the outflow of

Almost three-quarters of the pressurization failure events were precipitated by mechanical problems.

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this air," the report said. "If the outflow valves are not operating properly, cabin altitude will not be maintained at the desired level."

Mechanical problems also included air leaking through doors and windows. "The leaks were due to several reasons, including faulty door and window seals, cracked windows or improperly closed doors," the report said. "In general, these events resulted in inability to maintain the desired cabin altitude, even though the cabin pressurization system was otherwise working normally. The rate of cabin pressure change in those cases was generally slow, readily identified by the crew, and an uneventful descent was generally carried out."

Structural failure caused two events, neither of which involved injury to occupants. "In one event, the structural failure was a loss of a fuselage panel, leading to an explosive decompression," the report said. "The other event occurred in a Beech 200 aircraft involved in low-capacity air transport operations, with two crew and nine passengers on board. At an airspeed of 200 knots and descending through 17,000 feet en route to Sydney, New South Wales, the main cabin door separated from the aircraft. After a rapid descent was carried out to 11,000 feet, the aircraft [was] successfully landed at Sydney."

Human error played a role in 5 percent of the events. Flight crew errors caused 16 events, and errors by maintenance technicians caused 11 events (see "ASRS Insights").

Fatal Flight

There was one fatal accident among the 517 pressurization failure events studied by ATSB involving a Beech Super King Air 200 that was on a charter flight with a pilot and seven passengers from Perth to Leonora, both in Western Australia, on Sept. 4, 2000.[3]

Soon after departure, the pilot was cleared to climb to Flight Level (FL) 250 (approximately 25,000 ft). About 20 minutes later, the air traffic controller observed on his radar display that the aircraft was climbing above FL 250. When asked to verify his altitude, the pilot told the controller to stand by. Open-microphone transmissions from the aircraft during the next eight minutes included one unintelligible syllable, sounds of a person breathing and background propeller and engine noise. In its final report on the accident, ATSB said that these transmissions were symptomatic of hypobaric hypoxia, which can affect mental functions before it affects physical abilities. "For example, a hypoxic pilot may be quite capable of pressing the [microphone] transmit button but may be unable to form the words to speak," the accident report said.

About one hour and 25 minutes after departing from Perth, the aircraft overflew Leonora at 34,000 ft. The aircraft maintained a steady heading of about 050 degrees, indicating that the autopilot heading-hold and pitch-hold modes were engaged. The flight crew of a business jet that intercepted the King Air saw no lights or movement inside the aircraft. "The aircraft was probably unpressurized for a significant part of its climb and cruise for undetermined reasons," the accident report said. "The pilot and passengers were incapacitated, probably due to hypobaric hypoxia, because of the high cabin altitude and their not receiving supplemental oxygen."

Causes of Pressurization Failure Events

Cause	Number	Percentage
Control problem	228	44.1%
Door problem	62	12.0%
System failure	42	8.1%
Outflow valve problem	28	5.4%
Operator error	16	3.1%
Window failure	14	2.7%
Maintenance error	11	2.1%
Air leak	2	0.4%
Seal problem	2	0.4%
Structural problem	2	0.4%
Engine failure	1	0.2%
Not specified	109	21.1%
Total	**517**	**100.0%**

Source: Australian Transport Safety Bureau

Table 2

ASRS Insights

A search by *Aviation Safety World* of the U.S. National Aeronautics and Space Administration's Aviation Safety Reporting System database found 75 voluntary reports of "depressurization" or "decompression" events in 2001 through 2005.

Twenty-six reports included the possible cause of the depressurization/decompression. Cabin door seal failures were cited in six reports — one involving an air carrier aircraft, three involving business jets and two involving twin-turboprops. Malfunction of the cabin door seal pressure regulator caused another business jet to depressurize.

Cargo door seal failures were cited in four reports by airline flight crewmembers. Another airliner depressurization was attributed to failure of the seal around an electronics equipment compartment door.

Other causes included failures of a cabin door-position sensor, a baggage door seal, a pressurization system controller and an air-conditioning pack; a faulty weight-on-wheels sensor; a loose heater shroud hose clamp; a ground-air connection valve that failed to close after engine start; and an outflow valve that was jammed open by a "silver cloth." A cracked cabin window outer pane was cited in the depressurization of a Mitsubishi MU-2.

Some reports cited operator error, including a flight crew's failure to reselect the air-conditioning packs after takeoff, pack switches that might have been inadvertently repositioned when bumped by a logbook that was being returned to its holder, and bleed air switches left in the "OFF" position. Another report said that after returning to the departure airport, the crew of a Boeing 737-700 found that they had departed with the pressurization mode selector set to manual rather than automatic. A 737-300 crew departed with one air-conditioning pack inoperative according to the provisions of the aircraft's minimum equipment list, only to have the other pack fail during cruise at Flight Level (FL) 240.

A flight attendant reported perceived deficiencies in communication and training. She was aboard an Airbus A300 that had been climbing to cruise altitude but then began to descend. After a "muffled" public-address system announcement by a pilot, another flight attendant called the flight deck and learned that a depressurization had occurred. The oxygen masks had not deployed, and the flight attendant attempted to retrieve an oxygen bottle but could not find the bracket releases in the dark storage compartment. In her report, she recommended that flight attendants receive training on the operation of emergency equipment in total darkness.

A common element among the reports by flight crewmembers is that the pilots apparently followed their training by donning their oxygen masks, initiating a descent and conducting the emergency checklist. The report by the captain of an Israel Aircraft Industries Astra SPX was typical: The aircraft was at FL 430 when a door seal deflated, causing a rapid depressurization, with cabin altitude very quickly reaching 20,000 ft. The pilots donned their oxygen masks and initiated a high-speed descent to 12,000 ft. The captain said, "I attribute [the positive outcome to] extensive simulator training with rapid-decompression awareness and procedures."

Of note, however, is that a few pilots reported that they initially mistook the cabin altitude warning horn for an aircraft configuration warning, and some pilots faulted themselves for neglecting to declare an emergency or to clearly convey to air traffic control the reason they were leaving their assigned altitudes.

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About three hours and 37 minutes after passing over Leonora, the aircraft struck terrain near Burketown, on the northern coast of Queensland. Because of extensive aircraft damage and the absence of flight data and voice recorders, ATSB was not able to determine why the cabin either did not become pressurized or lost pressurization. The aircraft had been flown the morning of the accident, and no problems with the pressurization system were noted. The report also said that the accident pilot was known for his professionalism and methodical use of checklists.

The pressurization system in the accident aircraft included visual warnings but not an aural warning of excessive cabin altitude. The report said that the accident might have been prevented if an aural warning, as well as the visual warnings, had been generated when cabin altitude exceeded 10,000 ft. An ATSB recommendation to require such warnings in pressurized aircraft was rejected by the U.S. Federal

Aviation Administration as "not necessary to meet minimum airworthiness standards" but accepted by the Australian Civil Aviation Safety Authority (CASA). However, CASA later withdrew rulemaking action after public comment opposed the cost of mandatory installation of aural warnings.

The report on the study of pressurization failure events said that several other fatal accidents recently have occurred worldwide, including the Oct. 25, 1999, Learjet 35 accident in the United States, in which professional golfer Payne Stewart and five others were killed, and the Aug. 14, 2005, Boeing 737 accident in Greece, in which all 121 occupants were killed (see "Accidents and Incidents Involving Cabin Depressurization, 1995–2005," page 40).

Hypoxia Strikes

The report said that symptoms of hypoxia, one of the greatest hazards of depressurization, include light-headedness, confusion, tremors, impaired judgment and decision making, dizziness, and ultimately loss of consciousness. Other studies have linked hypoxia to symptoms including rapid breathing, headache, fatigue, sweating, reduced coordination, impairment of vision, cyanosis — a blood oxygen deficiency that causes a blue coloring of the lips and skin beneath the fingernails, and sensations of tingling, cold and warmth.

Symptoms of hypoxia were encountered by aircraft occupants in four events. A 737-700 pilot became light-headed and nauseous when the aircraft was in cruise flight at FL 400. After observing that cabin altitude was increasing at 4,000 fpm, the flight crew conducted a descent to 10,000 ft and continued the flight to the destination. Cabin crewmembers aboard a Fokker F27 reported that they encountered mild symptoms of hypoxia at 25,000 ft. The pilot of a Rockwell Commander 685 encountered symptoms of hypoxia after the pressurization system failed during climb. The symptoms encountered by the occupants in the other event were not specified.

A loss of consciousness occurred during a Royal Australian Air Force training flight in a civilian aircraft on June 21, 1999.[4] The pilot and two passengers were en route from Edinburgh, South Australia, to Oakey, Queensland. Passing through 10,400 ft, the pilot was conducting the "Climb" checklist when he received a change in routing from air traffic control (ATC). The pilot reprogrammed the global positioning system (GPS) receiver and then completed the checklist.

The aircraft was nearing the assigned altitude, FL 250, when ATC told the pilot that the aircraft was not maintaining the assigned track. The passenger in the copilot seat, who was a certificated pilot but not rated in type, noticed that the pilot was repeatedly performing a task required to reprogram the GPS receiver. "The pilot was not familiar with the GPS receiver and had received no formal training in its operation," the incident report said. "The controller advised the pilot again that the aircraft was still off track; however, the pilot did not reply to this transmission."

Soon thereafter, the pilot became unconscious. The passenger in the copilot seat took control of the aircraft and began an emergency descent. "The other passenger unstowed the pilot's oxygen mask and took several breaths of oxygen from it before fitting it to the unconscious pilot," the incident report said.

The pilot regained consciousness during the descent. While returning to Edinburgh, he noticed that both "BLEED AIR OFF" annunciator lights were illuminated and that the bleed air switches were set to "ENVIR OFF," a position at which the cabin bleed air inflow valves would be closed. The "Climb" checklist calls for repositioning the vent blower switches. "These switches were located very near to the bleed air valve switches, and it is probable that the pilot inadvertently moved both bleed air switches to 'ENVIR OFF' during the climb checks instead of moving the two blower switches," the incident report said.

Barotrauma

In four events, passengers sustained minor ear problems, "most likely otic barotrauma," the report said. All four events occurred during emergency descents in airline aircraft. One event involved an emergency descent at 1,500 fpm following a depressurization at 37,000 ft.

"Most barotrauma of the ears and sinuses is generally a consequence of descent [into higher ambient pressure] rather than the initial depressurization event," the report said. "This is true in the present study, with most of the injuries being ear-related pressure pain due to the emergency descent."

None of the events involved decompression illness, in which a sudden reduction in pressure causes gases in body cavities — such as the sinuses, ears, abdomen and teeth — to expand. Decompression illness also can be caused by gases that escape from solution in the blood and body tissues, causing various problems, including blurring of vision, inability to speak or understand what is spoken, and pain in joints, a condition commonly called the bends. The report said that the absence of decompression illness in the events studied probably was due to the "generally slow average rate of aircraft decompression, the relatively low maximum cabin altitude reached (14,000 feet) and the subsequent emergency descent."

The report said that although the study showed that the risk of loss of cabin pressurization is low and the risk of injury to occupants is low if it should happen, complacency must be avoided. "The inherent risks of operating in the hostile environment at high altitude must not be taken for granted," the report said. "While the rate of decompression events is low, the potential risks involved with such an event are considerable, especially if the event is rapid, not recognized by the crew and emergency procedures are not carried out promptly. … Often, the failure of the cabin pressurization system is unexpected. Given the significant potential risk of hypoxia, pilots need to always be prepared for this contingency." ●

Ground damage by a tug might have led to a rupture of an MD-83's fuselage and rapid depressurization at FL 240 (see page 41).

Notes

1. Newman, David G. *Depressurisation Accidents and Incidents Involving Australian Civil Aircraft, 1 January 1975 to 31 March 2006.* Australian Transport Safety Bureau (ATSB) Research and Analysis Report B2006/0142. June 2006.

2. European Aviation Safety Agency Certification Specifications CS 25.841. U.S. Federal Aviation Regulations Part 25.841.

3. ATSB Aviation Safety Report BO/2000371, *Pilot and Passenger Incapacitation; Beech Super King Air 200, VH-SKC; Wernandinga Station, Qld, 4 September 2000.*

4. ATSB Air Safety Occurrence Report 199902928, *Inflight Pilot Incapacitation 72 km East of Edinburgh Aerodrome.*

Appendix

Accidents and Incidents Involving Cabin Depressurization, 1995–2005

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Jan. 5, 1995	Isfahan, Iran	Lockheed Jetstar	destroyed	12 fatal
The aircraft, operated by the Iranian air force, was climbing through 2,000 ft when a pilot reported a problem with the pressurization system and requested clearance to return to base. Soon thereafter, the aircraft struck terrain.				
July 9, 1995	Chicago	ATR 72-200	minor	1 minor, 64 none
A recently installed main cabin door, with a handle that moved in the opposite direction, opened soon after takeoff and separated from the aircraft as the flight crew returned for landing. A flight attendant seated near the door when it opened received injuries to her arm when she fell while moving away from the door.				
Aug. 9, 1995	Cordoba, Argentina	CASA CN-235-200	minor	1 fatal, 29 none
The aircraft was climbing through 6,000 ft when the main cabin door opened. A flight attendant standing near the door was lost overboard.				
Aug. 23, 1995	Pacific Ocean	Lockheed L-1011	substantial	236 none
A rapid decompression occurred at Flight Level (FL) 330. The flight crew conducted an emergency descent, turned back to Los Angeles and landed without further incident about two hours later. The aft pressure bulkhead had separated from the fuselage crown due to the failure of improperly fastened stringers.				
Aug. 25, 1995	Budapest, Hungary	Boeing 737-300	substantial	85 none
The flight crew was not aware that the tail had struck the runway during takeoff. During climb, the crew encountered cabin pressurization problems and decided to return to Budapest.				
Feb. 14, 1996	Caracas, Venezuela	Douglas DC-9-50	substantial	91 none
The aircraft was climbing through 20,000 ft when a rapid depressurization occurred. The flight crew returned to Caracas. Part of the rear pressure bulkhead had failed due to fatigue cracks that initiated near the cutout for the cabin door.				
May 12, 1996	Indianapolis	Boeing 727-200	none	11 minor, 101 none
The aircraft was en route from Chicago to St. Petersburg, Florida, at FL 330 when the cabin altitude warning horn sounded. The captain, the pilot monitoring, noticed that the right air-conditioning pack was off, and he and the flight engineer attempted to re-engage the pack without using a checklist. The flight engineer inadvertently opened the outflow valve, causing the cabin to depressurize fully. The captain, flight engineer and lead flight attendant became unconscious. The oxygen masks deployed in the cabin and were donned by the other flight attendants and the passengers. The first officer, who had donned his oxygen mask when the first warning occurred, conducted an emergency descent. The other crewmembers regained consciousness during the descent, and the aircraft was landed in Indianapolis without further incident.				
Feb. 13, 1997	Atlanta	Boeing 727-200	minor	92 none
The flight crew continued the takeoff after the aft cargo door warning light illuminated. The crew heard a "pop," and the cabin depressurized as the aircraft was climbing through 900 ft. Ground service personnel had failed to properly close the door.				
July 30, 1997	Berlin	Lockheed Electra	substantial	5 none
The aircraft was climbing through 11,500 ft when the main cargo door opened. The flight crew returned to Berlin and landed without further incident. The cargo door had not been secured properly before takeoff, and the cockpit warning light had been dimmed so low that it could not be seen.				
Aug. 8, 1998	Baker, Nevada, U.S.	Piper Cheyenne	destroyed	3 fatal
Soon after the pilot reported a loss of pressurization at FL 270, the aircraft descended rapidly and struck terrain. The aircraft had been restricted to a maximum operating altitude of 12,500 ft after an inspection 10 months earlier found that the oxygen system required maintenance.				

Continued on next page

Appendix
Accidents and Incidents Involving Cabin Depressurization, 1995–2005

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 25, 1999	Aberdeen, South Dakota, U.S.	Gates Learjet 35	destroyed	6 fatal
The aircraft was on a charter flight from Orlando, Florida, to Dallas. Radio communication was lost soon after the flight crew reported climbing through FL 230 and was cleared to FL 390. The aircraft continued flying on a northwesterly heading for 3.7 hours and reached an altitude of 40,600 ft. The aircraft began descending after the left engine flamed out.				
June 13, 2000	Rio de Janeiro, Brazil	Boeing 737-200	NA	85 none
A rapid decompression occurred at FL 290. A 28-in (71-cm) crack was found in the fuselage above the forward service door.				
Sept. 15, 2001	Belo Horizonte, Brazil	Fokker 100	substantial	1 fatal, 88 none
The aircraft was en route from Recife to São Paulo when an uncontained engine failure occurred. Debris penetrated the cabin, killing one passenger. The flight crew conducted an emergency landing at Belo Horizonte.				
Feb. 17, 2002	San Juan, Argentina	Boeing 737-200	NA	NA
The flight crew conducted an emergency landing following a cabin depressurization. A small crack was found in the fuselage aft of the forward left door.				
Aug. 23, 2003	Denver	Beech 1900D	minor	16 none
The aircraft was climbing through 8,000 ft when the cabin door opened. The flight crew returned to Denver. The report said that the first officer had failed to ensure that the cabin door was secure before takeoff.				
Dec. 5, 2004	Anchorage, Alaska, U.S.	Boeing 747-100SR	minor	3 none
After a rapid depressurization occurred during cruise at FL 300, the flight crew returned to Anchorage. A 12-in (30-cm) tear was found along a line of rivets between the nosewheel well and the electronics service bay.				
May 13, 2005	Denver	McDonnell Douglas MD-88	substantial	98 none
A broken nose landing gear actuator rod penetrated the forward pressure bulkhead during initial climb. After confirming with tower controllers that the landing gear appeared to be down and locked, the flight crew landed without further incident.				
Aug. 14, 2005	Grammatikos, Greece	Boeing 737-300	destroyed	121 fatal
The cabin altitude warning horn sounded as the aircraft was climbing through 12,000 ft during a flight from Larnaka, Cyprus, to Athens. A preliminary report said that the captain was in radio communication with airline maintenance personnel until the aircraft passed through 28,900 ft. The aircraft, apparently being flown on autopilot, entered a holding pattern near Athens at FL 340. Both engines flamed out more than an hour later, and the aircraft descended to the ground.				
Aug. 24, 2005	Shanghai, China	Airbus A340-310	minor	256 none
The flight crew was not aware that a tail strike had occurred, causing substantial damage on takeoff from Shanghai. Indications of a cabin pressurization problem appeared as the aircraft climbed through 9,900 ft. The crew returned to Shanghai.				
Nov. 9, 2005	Tanta, New South Wales, Australia	Boeing 737-700	none	none
About 11 minutes after the aircraft reached FL 400, the captain felt a stomach upset and ear discomfort, and noticed that cabin pressure altitude was climbing at 4,000 fpm. The cabin altitude warning horn sounded about 44 seconds after the crew began an emergency descent to 10,000 ft. The aircraft was landed at the destination, Melbourne. Both positive pressure relief valves had failed.				
Dec. 26, 2005	Seattle	McDonnell Douglas MD-83	substantial	142 none
The aircraft was climbing through 24,000 ft when the flight crew heard a loud bang and the cabin rapidly depressurized. The crew returned to Seattle and landed without further incident. A six- by 12-in (15- by 30-cm) hole was found in the right fuselage, between the middle and forward cargo doors. A ground service worker said that he had grazed the aircraft with a tug; he had not reported the incident before the aircraft departed.				

NA = not available

Sources: Airclaims, Australian Transport Safety Bureau, Hellenic Air Accident Investigation and Aviation Safety Board, U.K. Air Accidents Investigation Branch, U.S. National Transportation Safety Board