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Flight Safety Foundation is an international membership organization dedicated to the continuous improvement of aviation safety. Nonprofit and independent, the Foundation was launched officially in 1947 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce positive influence on aviation safety. Today, the Foundation provides leadership to more than 850 member organizations in more than 140 countries.

Maintenance Resource Management Programs Provide Tools for Reducing Human Error

The programs include a variety of initiatives to identify and reduce human error in aviation maintenance. Specialists applaud the goal, but some say that the programs are not achieving sufficient progress.

James T. McKenna

Aviation safety specialists and maintenance specialists from air carriers, regulatory agencies and the research community have spent more than 10 years developing maintenance resource management (MRM) programs to reduce human error in aircraft inspection, repair and overhaul. Several air transport accidents have demonstrated the risks presented by such error, and safety specialists expect those risks to become a greater concern as improvements in design, training and procedures reduce the role of aircraft failures and flight crew failures as causal factors in accidents (see "Maintenance-related Accidents and Incidents," page 2).

MRM is an effort to improve the capability of an aviation maintenance operation — and all individuals within that operation — to identify and mitigate risks to safe and efficient activities by recognizing and addressing physiological limitations and psychological limitations of the people conducting those activities.

MRM programs include a variety of initiatives to identify and to institutionalize methods of reducing human error; the objectives and techniques of the initiatives vary by company, researcher, manager and worker. The initiatives have been studied and have been refined. Yet, despite widespread acceptance that human error in maintenance must be reduced, some researchers and operations personnel have said that MRM initiatives have not achieved sustained progress toward that goal.[1,2,3]

Maintenance is cited in studies by The Boeing Co. as a primary cause of 3 percent of hull-loss accidents and as a contributing factor in about 10 percent of hull-loss accidents involving Western-built large commercial jet airplanes.[4,5,6]

Several other studies indicate that maintenance error occurs frequently.

One European study, the Aircraft Dispatch and Maintenance Safety (ADAMS) project conducted from 1996 through 1999, surveyed aviation maintenance technicians about their work environments and work practices. The study was funded by the European Commission and coordinated by Trinity College in Dublin, Ireland. Of the 286 maintenance technicians surveyed, 34 percent said that they had completed maintenance tasks using a method other than that specified by the maintenance manual. Ten percent said that they had complied with the manual but had not consulted the manual before performing the tasks.[7]

A study in the United States resulted in similar findings. Researchers at the U.S. National Institute for Aviation Research at Wichita (Kansas) State University surveyed maintenance technicians on the accuracy and usability of maintenance documentation. When asked if they agreed that "the manual describes the best way to do a procedure," 62 percent of the

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Maintenance-related Accidents and Incidents

The U.S. Federal Aviation Administration and the U.K. Civil Aviation Authority cite numerous aviation accidents and incidents in which maintenance was a contributing factor, including the following:

- A May 25, 1979, accident in which an American Airlines McDonnell Douglas DC-10-10 struck terrain after its no. 1 engine and pylon separated during rotation for departure from Chicago (Illinois, U.S.) O'Hare International Airport. The accident killed 273 people. The U.S. National Transportation Safety Board (NTSB) said, in the final report on the accident, that maintenance-induced damage to the pylon led to the loss of the pylon and the no. 1 engine. The report said that the airline had modified engine-removal procedures without fully considering the effect of the change on the structure and that maintenance technicians had modified those procedures without notifying engineering;[1]

- A May 5, 1983, oil starvation and in-flight shutdown of all three engine on an Eastern Airlines Lockheed L-1011 during a flight to Nassau, Bahamas. The flight crew succeeded in restarting one engine and returning to Miami (Florida, U.S.) International Airport for landing. The NTSB report said that maintenance technicians had failed to fit O-ring seals on the master-chip-detector assembly for each of the three engines. The incident was the ninth in which chip detectors had not been sealed since procedures were revised in December 1981;[2]

- An Aug. 12, 1985, accident in which a Japan Air Lines Boeing 747 struck terrain during a flight from Tokyo (Japan) Haneda Airport to Osaka. Within 15 minutes of departure from Tokyo, the flight crew lost lateral control and pitch control of the airplane. The accident killed 520 of the 524 people on board. Investigators said that the aft pressure bulkhead had ruptured, damaging controls and hydraulics. They attributed the rupture to fatigue cracks that had propagated from an improper repair performed in 1978 and to the failure of subsequent maintenance inspections to detect the cracking;[3]

- An Aug. 22, 1985, accident in which an uncontained engine failure and subsequent fire on a British Airtours Boeing 737 at Manchester International Airport in England killed 55 people. Investigators found that one of nine combustor cans in the no. 1 Pratt & Whitney JTD-15 engine had been repaired in a manner that appeared to comply with pertinent procedures but that "failed to impart sufficient life recovery to enable it to remain in service until its next scheduled inspection." The forward section of the combustor was ejected through the engine case during the takeoff roll, puncturing a wing-fuel-tank access panel and igniting a fire that consumed the aircraft;[4]

- A July 19, 1989, accident in which a United Airlines McDonnell Douglas DC-10 struck terrain in Sioux City, Iowa, U.S., and a June 8, 1995, accident in which a ValuJet McDonnell Douglas DC-9 suffered an uncontained engine failure at Atlanta (Georgia, U.S.) Hartsfield International Airport. In the Sioux City accident, 111 of the 296 people in the airplane were killed and 47 people received serious injuries; in Atlanta, one of the 62 people in the airplane received serious injuries. Each accident involved failure of a critical rotating engine part that was later found to contain a fatigue-inducing defect that was not detected during previous manufacturer inspections or maintenance inspections;[5,6]

- A June 10, 1990, accident involving a British Airways BAC 1-11 en route from Birmingham International Airport in England to Malaga, Spain. As the aircraft was flown through 17,300 feet, the left windshield (which had been replaced before the flight) blew out. As the cabin depressurized, the captain was drawn halfway through the opening. Crewmembers held him in the aircraft while the first officer flew the airplane to Southampton Airport in England and conducted the landing. Investigators said that the shift maintenance manager who had replaced the windshield on the night shift before the flight had used smaller-than-specified bolts in the windshield's 90 attach points;[7]

- A Sept. 11, 1991, accident in which a Britt Airways Embraer 120, operating as a Continental Express flight, broke up in flight near Eagle Lake, Texas, U.S. Fourteen people were killed. NTSB, in the final report on the accident, said that the airplane's horizontal stabilizer leading edge had separated in flight, leading to a severe pitch-over and subsequent break-up. The report said that the probable cause was the failure of Continental Express mechanics and inspectors to adhere to proper procedures for removing and replacing the horizontal stabilizer deice boots;[8]

- An Oct. 2, 1996, accident involving an AeroPeru Boeing 757 en route from Lima, Peru, to Santiago, Chile. Within minutes of takeoff, the first officer radioed the Lima tower, declaring an emergency and reporting that the flight crew had no airspeed indications or altitude indications. The airplane eventually was destroyed on impact with the Pacific Ocean, killing the 70 people on board.[9] Investigators said that ground personnel cleaning the aircraft had taped over the static ports of the pitot-static systems and had failed to remove the tape before departure; and,

- A July 25, 2000, accident in which a Concorde struck the ground near Paris, France, killing all 109 people in the airplane and four people on the ground. The French Bureau Enquêtes Accidents (BEA), in its final report on the accident, said that a metal wear strip had been ejected from an engine-fan-reverser cowl on a Continental Airlines DC-10 that departed from Charles de Gaulle International Airport five minutes before the Concorde. Both aircraft used the same runway. Investigators said that the wear strip cut and destroyed one of the Concorde's main gear tires, which led to fuel tank ruptures, the loss of thrust from the no. 1 engine and the no. 2 engine and the accident. Investigators said that the 1.5-foot (0.5-meter) wear strip ejected from the DC-10, which was installed June 11, 2000, during a C check by Israel Aircraft Industries in Tel Aviv, Israel, was not made or installed according to the manufacturer's procedures. The investigators also said that, in subsequent work on the aircraft, Continental maintenance technicians did not observe the discrepancies with the strip.

(BEA investigators also said that Air France maintenance technicians had improperly replaced the left-main-landing-gear bogie on the accident aircraft during scheduled maintenance in July 2000. It was the first time that Air France maintenance technicians had changed a Concorde bogie, the BEA report said. Nevertheless, the maintenance technicians did not use the manufacturer's maintenance manual or a special tool specified in the manual. As a result, they installed the new bogie without a spacer required between two shear bolts. With the spacer missing, the bogie could move far enough side to side to completely rupture hydraulic lines to the brakes. BEA said that these discrepancies did not contribute to the accident but that they did warrant an audit of Air France's maintenance procedures by regulators.)[10]♦

— James T. McKenna

Notes

1. U.S. National Transportation Safety Board (NTSB). Aircraft Accident Report no. NTSB-AAR-79-17. *American Airlines, Inc. DC-10-10, N110AA, Chicago-O'Hare International Airport, Chicago, Illinois, May 25, 1979.*
2. NTSB. Aircraft Accident Report no. NTSB-AAR-84-04. *Eastern Airlines Flight 232, Lockheed L-101, Miami, Florida, May 5, 1983*.
3. Airclaims. *Major Loss Record* Volume 2, Issue 131 (April 17, 2002): Page HAP42.
4. U.K. Air Accidents Investigation Branch (AAIB). Aircraft Incident Report no. 8/88. *Report on the accident to Boeing 737-236, G-BGJL at Manchester International Airport on 22 August 1985*.
5. NTSB. Aircraft Accident Report no. NTSB-AAR-90-06. *United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City, Iowa, July 19, 1989*.
6. NTSB. Aircraft Accident Report no. NTSB-AAR-96-03. *Uncontained Engine Failure/Fire, ValuJet Airlines Flight 597, Douglas DC-9-32, N908V, Atlanta, Georgia, June 8, 1995.*
7. AAIB. Aircraft Accident Report no. 1/92 (EW/C1165). *Report on the accident to BAC One-Eleven, G-BJRT over Didcot, Oxfordshire, on 10 June 1990*.
8. NTSB. Aircraft Accident Report no. NTSB-AAR-92-04. *Britt Airways, Inc., d/b/a Continental Express Flight 2574 In-Flight Structural Breakup, EMB-120RT, N33701, Eagle Lake, Texas, September 11, 1991*.
9. McKenna, James T. "Peru 757 Crash Probe Faces Technical, Political Hurdles." *Aviation Week & Space Technology* Volume 145 (Oct. 7, 1996): 21–22.
10. Bureau Enquêtes Accidents. Report F-SC000725A. *Accident on 25 July 2000 at La Patte d'Oie in Gonesse (95) to the Concorde registered F-BTSC operated by Air France.*

377 respondents said that they had completed a procedure in a way they considered better than the method that was described in the manual. The technicians surveyed said that they used manuals from a diverse group of manufacturers.[8]

Other studies attribute 20 percent to 30 percent of in-flight shutdowns of turbine engines on transport aircraft to maintenance errors, with an estimated cost per shutdown of more than US$500,000.[9]

Some research has been conducted on the most typical maintenance errors and some of the factors that contribute to them. For example, a 2001 survey of maintenance personnel by the Australian Transport Safety Bureau (ATSB) said that the most frequent errors include the incorrect installation of components, the use of the wrong parts and the omission of steps in maintenance tasks.[10]

The ATSB survey cited 340 occurrences of error in the maintenance operations of high-capacity airlines. (High-capacity airlines are those that operate aircraft with more than 38 passenger seats.) Most of the occurrences happened around 0300, 1000 and 1400 local time. More high-capacity airline maintenance personnel are at work at 1000 and at 1400 than at 0300, however, and when the results were adjusted to account for the number of maintenance workers present, it was apparent that more errors were likely to occur during the early morning than at any other time of day, the survey said.

The survey said that this finding is consistent with other studies that have found that the early morning is a "high-risk period for human error" and the most frequent time (considering exposure to risk throughout the day) for such occurrences as "ship groundings and collisions, U.S. Navy aviation mishaps, truck accidents involving dozing drivers and train drivers failing to stop at danger signals."

Some specialists in safety, maintenance and human factors say that data on maintenance error are not comprehensive and that current databases on accidents and incidents are not configured for easy tracking and analysis of maintenance errors.

"A very large number of incidents that could change our view of aviation maintenance are not available to us on a worldwide basis," said Ken Smart, chief inspector of air accidents for the U.K. Air Accidents Investigation Branch. "For every safety occurrence that we have in our various databases, there are likely to be 10 [times] to 20 times as many incidents that go unreported . . . [W]here we do have data, we have not until now conducted anything like a proper analysis."[11]

Some researchers and specialists in safety and maintenance say that substantial data exist to assess a maintenance organization's vulnerability to error in inspection tasks, repair tasks and overhaul tasks. The data include time lost to on-the-job injuries, ground damage to aircraft, fines and discipline imposed by regulators, discrepancies reported during post-maintenance test flights, excess inventory to cover error-induced equipment failures and an increase in cycle time and labor hours spent on maintenance tasks.

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The possibility exists to supplement that data with regular observation of the work practices and the environment in a maintenance facility. With funding from the U.S. Federal Aviation Administration (FAA), a team of researchers at Purdue University in West Lafayette, Indiana, U.S., has developed a set of "proactive audit tools" for such observations. Practices observed include whether maintenance personnel routinely use the proper protective equipment, tools and communications procedures on the job. The observations are then analyzed with the proactive audit tools to generate a weekly assessment for management of potential safety problems and to forecast the number of accidents or "safety events" that will occur in the near future. These tools have proved successful in identifying behaviors that increase the risk of injury and equipment damage, and in forecasting accidents and incidents, said Gary Eiff, an associate professor of aeronautical technology at Purdue University.

"The same errors are produced every day," Eiff said. "Some manifest themselves as injuries, some as ground damage, some as delays and turnbacks and some as smoking holes [accidents]. But because we have so few smoking holes, we've become complacent about the errors."

One challenge of maintenance-error-reduction initiatives is to raise the awareness in aviation maintenance personnel of those errors and their potential consequences, he said.[12]

The known costs of such errors can be significant, said David Marx, a human factors consultant. Marx has estimated that maintenance errors and ground crew errors cost the U.S. airline industry more than $1 billion each year, but he said that those costs typically are overlooked.

"Maintenance error traditionally has been lumped under the cost of doing business and not categorized as a specific, quantifiable class of event," Marx said. He said that most air carriers could track the failure of equipment such as hydraulic pumps with precision, even though design improvements mean that failures of the equipment are unlikely to cause another accident.

"However, our industry can show no structured process of investigation, analysis or corrective actions" for human errors in maintenance, he said.[13]

Safety officials have expressed concern that the incidence of maintenance errors may increase as the number of aircraft increase and the number of maintenance personnel decrease.

FAA, in its strategic program plan "Human Factors in Aviation Maintenance and Inspection," cited statistics of the Air Transport Association of America (ATA) that showed that the number of passenger miles flown by the largest U.S. airlines increased 187 percent from 1983 through 1995. During the same period, maintenance costs increased by 178 percent and the number of aircraft operated by those airlines increased 70 percent. The number of aviation maintenance technicians employed by those airlines, however, increased only 27 percent.

"The obvious conclusion is that the aviation maintenance technician must raise efficiency to match the increasing workload," FAA said. The goal of the FAA plan is to reduce maintenance-related accidents and incidents by 20 percent by 2003.[14]

Worldwide initiatives are under way to address the greatest risks to aviation safety, such as controlled flight into terrain, approach-and-landing accidents, loss of control and in-flight fires.[15] The FAA human factors strategic program plan says that efforts to reduce human error in maintenance are "one of the last 'frontiers' that can have a significant impact on aviation safety."

James C. Taylor, an adjunct professor of human factors at the engineering school of Santa Clara University in Santa Clara, California, U.S., and a researcher in aviation maintenance, said that reduction of human error has long been the objective of MRM initiatives.

"From the beginning, maintenance resource management was intended to impact error rates," he said. "It was created to improve human reliability in measurable terms."[16]

Also from the beginning, however, MRM has lacked a clear definition, Taylor and other maintenance specialists and researchers said. The objectives and techniques of MRM have varied among maintenance organizations. This inconsistency, combined with early problems in developing and implementing MRM programs, contributed to skepticism among maintenance technicians and managers about the purpose and effectiveness of the programs, they said.[17,18,19]

"We have covered under the human factors umbrella everything from human resources issues, continuous job improvement programs, quality improvement and on and on," said Ray Valieka, senior vice president of technical operations at Delta Air Lines. "We are deluding ourselves, or hiding under this umbrella, without actually dealing with the fundamental fact — human factors is all about behavior and how that behavior is manifested in operating and controlling some type of equipment."[20]

MRM evolved from crew resource management (CRM) programs developed at United Airlines in the 1970s and widely adopted by the airline industry in the 1980s as a technique for improving flight safety. Having observed the success of CRM efforts in improving communication and collaboration among flight crewmembers, maintenance specialists adapted CRM principles and tools for use among maintenance personnel and their supervisors.

The objectives and techniques of MRM have varied among maintenance organizations.

The first MRM programs began in the late 1980s and 1990s, as management philosophies placed greater emphasis on increasing profitability through internal teams or partnerships focused on continuous quality improvements. Labor organizations offered their own proposals for building partnerships to boost quality and profitability. One example is the International Association of Machinists and Aerospace Workers' (IAMAW) promotion of the "high-performance work organization," a labor-management partnership intended to encourage collaborative methods of making companies more efficient and more productive.[21] At the same time, aviation safety advocates increasingly were shifting their focus from enhancing the design of equipment to improving how humans work with that equipment.

On April 28, 1988, an accident occurred that prompted major changes in structural maintenance and inspection procedures, particularly for high-cycle airframes, and generated increased interest in MRM. The accident involved the structural failure of an Aloha Airlines Boeing 737. The airplane was being flown at 24,000 feet from Hilo, Hawaii, U.S., to Honolulu when an 18-foot (5.5-meter) section of its forward upper fuselage separated. The airplane was landed safely, but a flight attendant was killed and eight people in the airplane were injured seriously. NTSB said in the final report on the accident that a series of minor cracks around numerous rivet heads had combined, after the initial failure of a fuselage lap joint, into the large-scale failure.

The report said that the probable cause of the accident was "the failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage, which ultimately led to the failure of the lap joint … and the separation of the fuselage upper lobe."[22]

The report said that the structural-inspection procedures were difficult and "tedious" and that the task had "physical, physiological and psychological limitations." The report also said that automation and other techniques should be developed "to eliminate or minimize the potential errors inherent in human performance" of large-scale or repetitive structural inspections.

The accident investigation led to creation of the FAA National Plan for Aviation Human Factors. That plan called, in part, for CRM techniques for open and assertive communication to be applied to aviation maintenance operations.

One of the first airlines to apply CRM techniques to maintenance was Pan American World Airways, which at the time operated one of the oldest transport fleets in the United States. The company addressed its aging aircraft problems by developing technical solutions and by beginning training in 1990 for maintenance managers in open, assertive communication. The airline ceased operations in 1991, however, before the training could have much effect.[23]

Two individuals generally are credited with championing the development of MRM — Valieka and John Goglia, a member of NTSB with more than 30 years experience as a maintenance technician.

In the early 1990s, Goglia was a maintenance technician for USAir (now US Airways) and flight safety coordinator for the IAMAW. He was a founder of one of the first MRM programs, established at USAir in 1992. He advocated use of the term "maintenance resource management" in a speech in 1996 to the FAA annual conference on human factors in maintenance. He said that the term would focus error-reduction efforts not only on individual maintenance technicians but also on the broader maintenance system.[24]

As an NTSB member, Goglia has advocated greater attention to addressing human errors in maintenance.

In the early 1990s, Valieka was senior vice president of maintenance operations at Continental Airlines. He initially required maintenance personnel to attend Continental's CRM training for pilots and later established a course specifically for maintenance personnel. Taylor, who studied the Continental program for FAA, said that its successes were in large part a result of Valieka's support for the program and Valieka's expectation that his subordinate executives at the airline also would support it.[25]

In late 1991, senior officials of USAir, FAA and IAMAW began discussing maintenance errors and methods of correcting them. At the time, USAir and its maintenance personnel were being investigated and penalized by FAA for an increasing number of maintenance-related errors in paperwork that violated U.S. Federal Aviation Regulations (FARs). The same errors were repeated, often by maintenance personnel who were considered by supervisors and colleagues as among the best on the job.[26] This trend, of errors committed by the most experienced and respected maintenance personnel in the workforce, was cited in several human factors studies in the following years.

In early 1992, the airline, the union and FAA inspectors agreed that they needed to understand the causes of the paperwork errors to determine whether they were symptoms of larger maintenance errors and to identify methods of eliminating or reducing such errors. They also agreed that discipline, in the form of company punishment and FAA sanctions, was not effective in preventing or reducing these errors.

The same errors were repeated, often by maintenance personnel who were considered by supervisors and colleagues as among the best on the job.

A number of steps were undertaken. About 100 maintenance personnel and maintenance foremen were brought into group discussions of why the paperwork errors occurred and how they might be reduced or prevented. This led to USAir's implementation, with the backing of the labor union and FAA, of a paperwork-training course for all maintenance technicians in its line stations. A telephone hotline was established for USAir employees to report anonymously any safety-of-flight concern to the quality-assurance department. Separately, the airline changed the requirements for how maintenance personnel signed off specific tasks, eventually issuing sign-off stamps to eliminate the problem of confusing or illegible sign-offs.

Later, maintenance personnel were enlisted to redesign the aircraft logbook used by USAir and to assist in redesigning the airline's *Maintenance Policies and Procedures Manual*. Changes to the logbook included providing larger blocks of space for maintenance technicians to use in describing work done on an aircraft.

In 1993, the airline, the labor union and FAA agreed to expand their joint maintenance-error reduction efforts to review specific safety-related incidents. A process was established in which representatives of the airline, the union and FAA met with individual maintenance technicians involved in incidents that all three parties agreed presented significant human factors issues. Local and regional FAA officials agreed not to penalize the maintenance technicians, provided that they were forthcoming about the errors and the circumstances of the errors and that they were willing to accept remedial measures specified by the three parties. FAA did not forego its right to take additional investigative action or enforcement action if such action was considered necessary; the parties agreed that the process would not cover errors resulting from intentional or negligent violations of FARs. They also agreed that remedial measures would be specified by unanimous decision of the airline, the union and FAA. In this respect, this process was a predecessor of the aviation safety action programs established by some U.S. airlines, flight-crew unions and FAA in the late 1990s. Those programs are intended to encourage employees to voluntarily report safety issues and safety events, even if they involve involuntary violations of FARs.

In 1994, Bruce Aubin, the new senior vice president of maintenance operations, made a variety of changes in USAir's maintenance organization and work processes that prompted expansion of the efforts to reduce maintenance errors. The objective was to change the culture of the maintenance organization.[27] A 16-hour course was developed to instruct all maintenance personnel and technical operations personnel and managers in basic human factors knowledge and techniques for improving safety awareness and communication.

The training was not completed. The program at USAir corrected problems and improved the attitude and awareness of maintenance personnel, but the program was not continued.[28,29,30] Supporters of MRM among leaders at the airline, the union and FAA became involved in other matters — including the investigation of several major accidents and the ongoing financial problems of the carrier. Support for and interest in MRM faded.

At Continental Airlines in 1991, after seeing the benefits of CRM training for pilots, Valieka established a program to improve communication and collaboration among maintenance personnel. Called Crew Coordination Concepts, the program was intended for all management personnel, inspectors, engineers, analysts, schedulers and support personnel. It was expanded to include maintenance personnel.

This training course was designed to improve the efficiency and safety of Continental's maintenance operations. The objective was to train attendees to recognize common procedures and practices, or norms, that governed the way maintenance was performed at the airline. Trainees also were instructed in techniques for using assertive communication to recognize and to manage stress, to improve problem solving and decision making, and to enhance working relations with colleagues, subordinates and superiors. More than 2,100 people were trained during 2.5 years.

Before training began, Continental identified several measures of maintenance safety or dependability that would be monitored as indicators of the training's effectiveness. The measures included ground damage, occupational injuries, on-time performance and overtime costs. Criteria for these measures were that they could be examined by the work unit, that they reflected changes in human behavior and that they were independent of other performance indicators.

After training began, several measures showed improvements. Ground damage and occupational injuries had been increasing before the training, but declined after training began. On-time performance continued to improve, and overtime expenses, which had been increasing, began decreasing after training began.[31] Maintenance personnel who completed the training continued to show improvements in their behavior and performance through about 1995.

Then, attention was focused on addressing financial problems at the airline. Major management changes were made, including Valieka's departure in late 1994 to Delta. The individuals responsible for conducting the training changed several times. With those changes, support for and results from the training waned.[32]

Other efforts also addressed human errors in maintenance. In 1994, Transport Canada developed the human performance in maintenance (HPIM) program, based in part on Continental's program but designed as do-it-yourself training for maintenance technicians. United Airlines established a program based on HPIM to improve awareness among its maintenance personnel of the effects that human limitations can have on safety and errors. Air New Zealand, the Republic of Singapore Air Force and the Canadian regional airline Air Nova implemented HPIM-based training. As Air Nova and other regional airlines affiliated with Air Canada were combined into Air Canada Jazz, HPIM training was extended to those operations.[33]

One product of HPIM was "The Dirty Dozen," a listing of 12 factors that Transport Canada researchers identified as causes of maintenance errors (see "The Dirty Dozen: Leading Factors in Maintenance Error").

The development of HPIM was a response to recommendations of a special investigation of the March 10, 1989, accident involving an Air Ontario Fokker 28 at Dryden, Ontario, Canada. (The airplane struck terrain 962 meters [3,156 feet] from the departure end of Runway 29 at Dryden Municipal Airport. The airplane was destroyed, and 24 of the 69 people in the airplane were killed.)[34] Like the Aloha Airlines accident, this accident is best known for raising issues other than maintenance error. Investigations of the

The Dirty Dozen: Leading Factors in Maintenance Error

In developing its Human Factors in Maintenance (HPIM) program, Transport Canada identified 12 factors — The Dirty Dozen — that can lead to errors in maintenance. The factors are illustrated in posters that are distributed to serve as reminders to those who have completed HPIM training.

The original intention was to produce posters that could be rotated for display every month in the maintenance workplace to illustrate each of the 12 factors, said Gordon Dupont, the special programs coordinator for human factors at Transport Canada in the mid-1990s who oversaw HPIM's development.

"Since their purpose is to maintain awareness of human factors in maintenance, we didn't want the posters to become part of the wallpaper. That's how we came up with the number 12," Dupont said. "But we've never been able to come up with a 13th."[1]

The Dirty Dozen factors identified by Transport Canada are:

- Lack of communication;
- Stress;
- Fatigue;
- Complacency;
- Distraction;
- Lack of teamwork;
- Lack of assertiveness;
- Lack of resources;
- Pressure;
- Lack of knowledge;
- Lack of awareness; and,
- Norms (a group's unwritten rules that can have unintended dangerous consequences).♦

— James T. McKenna

Note

1. Dupont, Gordon. Interview by McKenna, James T. Alexandria, Virginia, U.S. May 10, 2002. Alexandria, Virginia, U.S.

Dryden accident eventually led to major changes in the methods used by air carriers and regulators to address icing-related safety concerns.

Nevertheless, the special investigation identified a number of maintenance-related factors, and Gordon Dupont, the Transport Canada official who oversaw development of HPIM, explained why Dryden was a maintenance-related accident:[35]

> Air Ontario Flight 1363 crashed on takeoff from Dryden Municipal Airport. Investigators later determined its wings had become contaminated with ice, provoking a stall just after liftoff. The captain had elected not to have the aircraft deiced. Among the reasons was the fact that the airline's procedures prohibited deicing with the engines running. The captain believed he had to keep the engines running because the Dryden airport did not have [equipment to assist in engine starting] and the F-28's auxiliary power unit (APU) had been declared inoperative by maintenance a day earlier.
>
> The APU had been written up a number of times in the preceding weeks. Crews had reported problems with APU air pressure and difficulty in starting engines with the unit. They also had reported smoke, haze or an oil smell in the cabin, all of which were believed to have been associated with the APU.
>
> On March 9, 1989, the day before the [accident], mechanics tried unsuccessfully to troubleshoot the APU [problems] by replacing a load valve. They then reinstalled the original load valve and successfully started an engine with the APU. Both the APU and its fire-detection system tested as functional at this point. That was the last time the APU fire-detection system was recorded as working. A trainee mechanic reinstalled the fire-detection system shield. Some investigators speculated that this reinstallation may have pinched a wire and rendered the detection system inoperative.
>
> Several hours later, different mechanics began to prepare the F-28 for departure and found that the APU fire-detection system did not work. Troubleshooting failed, and a decision was made by the mechanics, the captain of the outgoing flight and dispatchers to defer maintenance on the APU rather than ground the aircraft. The deferral was made under manual provisions for deferring maintenance on the fire-extinguishing system. (There was no provision for deferring fire-detection system maintenance.) A red placard reading "INOP" was placed on the APU controls in the cockpit.
>
> The APU was operative. In fact, the captain of the flight that departed late on March 9 had used the APU for engine start. He complied with manual provisions requiring that, if the fire-extinguishing system is inoperative, a ground worker must be stationed near the APU with a fire extinguisher at hand to watch for signs of fire. The captain of Flight 1363 could have shut down his engines, had his aircraft deiced and used the APU to restart engines.
>
> It is far from clear whether those maintenance errors contributed to the crash.

Nevertheless, Dupont said that the circumstances preceding the accident illustrate how subtle the influence of maintenance error can be in safety decision making.

Some of those involved in conducting or analyzing MRM initiatives say that the initiatives have failed to improve the ability to reduce human error in maintenance for two general reasons: the nature of aircraft maintenance and the scope of the initiatives.[36,37,38,39]

Researchers and maintenance specialists said that the current system of aircraft maintenance creates an environment that promotes error and hinders its discovery.

Some of those individuals, along with other researchers and maintenance specialists, said that the current system of aircraft maintenance creates an environment that promotes error and hinders its discovery and correction. They said that conditions fertile for error are common in the individual performance of maintenance technicians and that these conditions persist in relationships between maintenance technicians and their supervisors and extend to a maintenance organization's standing in its company and to the procedures that govern the execution and safety of maintenance. Some researchers also said that these conditions stem in part from the nature of aircraft mechanics themselves.[40]

CRM was adopted to address, among other factors, the phenomenon of the autocratic captain, who does not want his authority or decisions on the flight deck challenged, even if others are certain that those decisions could lead to disaster. The communication techniques espoused by CRM are intended to permit a discussion of decisions in the framework of an effort to improve situational awareness, not as a challenge to the captain's authority.

Taylor and Jean Watson, manager of the FAA Human Factors in Aviation Maintenance and Inspection Program, have said that the traits common in pilots are even more pronounced in mechanics. "Mechanics share a taciturn self-reliance," they said. "As an occupational group [, they] are still more individualistic and egalitarian than their counterparts in flight operations." [41]

Because of these traits, they said, "mechanics' communication leaves plenty of room for improvement."

Taylor and Watson, as well as other researchers, said that individualism and self-reliance can limit the ability to trust others. They said that this reluctance to trust is aggravated by an atmosphere in aviation maintenance that breeds distrust. The atmosphere is what researchers and maintenance specialists call a "culture of blame"; that is, the assumption that admitting to an error will bring punishment and blame. As a result, errors are not reported. Another consideration is that maintenance personnel generally doubt that reporting an error will result in any changes in maintenance procedures or improvements in the conditions that may have contributed to the error.[42]

(This culture is not unique to aviation maintenance. In the mid-1990s, human factors researchers found a similar culture among personnel at the Kennedy Space Center who prepare the U.S. National Aeronautics and Space Administration space shuttles for launch. Workers there assumed that they would be suspended without pay if they were found to have committed errors.)[43]

In the ATSB survey of Australian maintenance personnel, 63 percent of the respondents said that they had corrected errors made by other mechanics within the preceding year "without documenting their actions in order to protect the person from blame." Of 4,600 surveys distributed, 1,359 were returned, for a response rate of 30 percent.[44]

Modern safety practices consider incidents and errors as opportunities to identify and eliminate safety threats.

The ATSB survey found that 88 percent of incidents in which an aircraft was damaged were reported officially, but half of the less serious incidents (including those in which errors were detected and corrected) were not reported. One reason for the failure to report may be the culture of blame, the survey said.

The study by the U.S. National Institute for Aviation Research at Wichita State University on the accuracy and usability of maintenance documentation found that about 35 percent to 45 percent of responding maintenance personnel said that they occasionally find errors or often find errors. Fifty-three percent said that they officially report errors found in documentation occasionally, rarely or never.[45]

Modern safety practices consider incidents and errors as opportunities to identify and eliminate safety threats. A culture in which such incidents routinely go unreported permits potential safety risks to persist.

The ADAMS project found that 45 percent of maintenance technicians surveyed routinely used what they considered easier and quicker methods of performing maintenance tasks than the methods described on job cards and in maintenance manuals. In the Wichita State survey, 62 percent of respondents said that they had completed a procedure in a way they considered better than the method described in the manual. The ADAMS project report said that maintenance line personnel regard procedures "as something that makes the job less satisfying and more difficult."

This points to a major disparity in aircraft maintenance.

"There is an official way of doing things," the ADAMS report said. "This is laid out in maintenance documentation, which has legal status. But that documentation objectively does not meet user needs. Then there is the way in which work is actually done, which is supported by unofficial documentation and which frequently diverges from the official way."[46]

Researchers and maintenance specialists have cited a number of reasons for this disparity.

The necessary documentation may not be available at the location where the task is done. For maintenance performed during turnarounds of flights, this can be a major problem. Traveling to the location where the documentation is stored and retrieving the pertinent information can take longer than the time scheduled for the turn.

Maintenance technicians often say that the documentation is difficult to use. Manuals and engineering orders often can be difficult to understand. Computers and other devices for reading technical documentation can be scarce and difficult to use. The ADAMS project reported that "almost every technician" who responded to the survey said that he or she had found errors in maintenance manuals. The Wichita State survey found that nearly three-quarters of respondents said that maintenance manuals were very useful to their jobs. But when asked if they agreed that "the manual describes the best way to do a procedure," 47 percent of respondents disagreed or strongly disagreed. When asked if "the manual writer understands the way I do maintenance," 54 percent of respondents disagreed or strongly disagreed.[47]

The Joint Aviation Authorities working group on Human Factors in Maintenance said, "Inaccuracies, ambiguities, etc., in maintenance data may lead to maintenance errors. Indirectly, they may also encourage or give good reasons to maintenance personnel to deviate from these instructions."[48]

The ADAMS report said that maintenance technicians routinely use "black books" — personal collections of technical data and shortcuts for performing regular maintenance duties. These black books may be illegal under civil aviation regulations in many parts of the world, in part because there is no way to control whether the notebooks contain the most current technical data.

"Almost everyone who works on aircraft or their components will probably possess a 'black book,'" said David Hall, deputy regional manager of the U.K. Civil Aviation Authority. "This is a sad indictment of the state of our maintenance data when we have to keep our own record of those correct dimensions or that impossible-to-find 'O' seal part number."[49]

Transport aircraft are certificated as safe and airworthy based on designs that are fail-safe or damage-tolerant. Extensive analyses are performed to develop maintenance programs that preserve airworthiness through the service life of the aircraft. The safe operation of the aircraft is based on the assumption that the maintenance program is being executed as prescribed. The fact that maintenance technicians routinely use procedures other than those prescribed undercuts that assumption.

The other aspect cited by those involved in conducting and analyzing MRM initiatives as a general reason for their failure is that they were limited in their scope, objectives or duration.

The initiatives were based on CRM, but there are differences between maintenance operations and flight operations that require different solutions. Valieka said that, although pilots work in confined areas and in close proximity to other pilots, maintenance technicians often work alone and in relatively far-flung locations. "Mechanics may work as members of a crew, but each crewmember may be doing a different task," he said.[50]

He said that, although pilots' actions on the job typically have direct and immediate operational effects, the consequences of a maintenance technician's actions may not be apparent for days, weeks or months. If the technician is performing preventive maintenance, the consequences may never be apparent.

Both pilots and mechanics perform repeated, predictable tasks, he said. But pilots most often get feedback on those tasks in short order.

"Mechanics may never get any feedback," Valieka said.

Clyde R. Kizer, president of Airbus Service Co. and a veteran maintenance executive, said that another difference is that CRM is used in a structure in which the composition of the team is clear. In maintenance operations, however, the composition of the team changes from crew to crew, and even from task to task, complicating the communications channels and techniques that must be used to mitigate errors.[51]

Communication is essential in the reduction of errors. Inadequate communication about the status of work from one shift of maintenance personnel to the next has been cited in a number of accident investigations, including the Sept. 11, 1991, in-flight breakup of a Continental Express Embraer EMB-120 during a flight from Laredo, Texas, U.S., to Houston, Texas. The airplane was destroyed, and all 14 people in the airplane were killed.

NTSB said that the airplane's horizontal stabilizer leading edge had separated in flight and that the probable cause of the accident was the "failure of Continental Express maintenance and inspection personnel to adhere to proper maintenance and quality assurance procedures for the airplane's horizontal stabilizer deice boots that led to the sudden in-flight loss of the partially secured left horizontal stabilizer leading edge and the immediate severe nose-down pitchover and breakup of the airplane." The report also said that, during a shift change, incoming maintenance personnel were not told about work that had begun on the deice boots during the previous shift, including the fact that screws had been removed from the top of the left leading edge assembly of the horizontal stabilizer.[52]

Inadequate communication about the status of work from one shift of maintenance personnel to the next has been cited in a number of accident investigations.

Although most early MRM efforts sought to raise awareness among maintenance personnel for better communication, they did not include training on techniques for improving communication. They also did not include recurrent training and often did not include all maintenance personnel. Continental's first efforts included maintenance supervisors, support personnel and inspectors, but not maintenance technicians. USAir's first efforts did not include first-tier maintenance supervisors, who in turn considered the training as a threat.[53]

The steady turnover of maintenance managers has been a factor in the temporary nature of the success of past MRM efforts. Bruce Aubin, who was a senior maintenance executive at Air Canada and at USAir, said that the effective tenure of a maintenance manager is about five years, which correlates with studies of management turnover.[54] Changes in management often resulted in a loss of support for or loss of interest in MRM training.

Researchers and maintenance specialists said that the interruption of early MRM programs by changes in personnel and in labor and management priorities reinforced the skepticism of maintenance technicians and first-tier maintenance supervisors who had considered MRM training a passing company fad. The training, almost without exception, resulted in increased individual awareness of the detriment of stress, fatigue and miscommunication and of personal commitments to lessen those factors. But managers and maintenance technicians who were enthusiastic supporters of the training were embarrassed when it faltered, an experience that undoubtedly made them less enthusiastic for future maintenance-error-reduction efforts, the researchers and maintenance specialists said.[55,56,57]

"You only get one good shot," said David Hanson, program manager for maintenance human factors training at FlightSafety Boeing. If an organization fails to take full advantage of that opportunity, "when you try to bring it back again, the mechanics who were skeptical the first time are even more skeptical."[58]

Taylor and Watson said that the early MRM initiatives were vulnerable to the disruption that bred skepticism and frustration because none were planned as a strategic endeavor of the air carrier concerned, with quantifiable objectives spelled out in advance. Rather, the programs sought general goals of improving worker awareness or reducing paperwork errors.[59]

Researchers and maintenance specialists said that another reason for the failure of early MRM efforts was the near impossibility of establishing a return on investment for the training.[60,61,62] This was partly because of the general inability of air carriers to compile data that are clear and distinct indicators of the cost of maintenance errors. Many individuals involved in MRM and other human factors initiatives say that error reduction has financial benefits. Researchers for the U.S. Naval Postgraduate School, assessing the cost of major accidents involving U.S. Navy aircraft and U.S. Marine Corps aircraft, projected that a 10 percent reduction in maintenance error "can result in a significant savings of lives and resources.[63]

Maintenance specialists and human factors specialists expect that such regulatory changes will encourage adoption of MRM, just as regulatory changes spurred the acceptance of CRM.

Kizer said, "Maintenance resource management is always going to come under the same scrutiny as any other thing a company has to spend money on."[64]

MRM continues to evolve, and among the most significant aspects of the newer programs is the adoption in Europe and Canada of requirements for human factors training and consideration of human factors elements in aviation maintenance operations.

Joint Aviation Requirements (JARs) 66 requires maintenance technicians seeking certification by a member of the JAA to demonstrate basic knowledge of human factors. Compliance with JARs 66 became mandatory June 1, 2001. In addition, JAA has proposed under JARs 145 that certificated repair stations provide recurrent human factors training to maintenance technicians.

Transport Canada has proposed changes to Canadian Aviation Regulations, to take effect in 2003, that will require human factors training for all staff with technical responsibilities in commercial air service operations, including flight training units, and in approved maintenance organizations.[65]

The regulatory changes follow revisions by the International Civil Aviation Organization to its international standards and recommended procedures calling for maintenance organizations' training programs to include training in knowledge and skills related to human performance.[66]

Maintenance specialists and human factors specialists expect that such regulatory changes will encourage adoption of MRM, just as regulatory changes spurred the acceptance of CRM in the 1980s in North America and Europe.

Some maintenance training curricula already include a new emphasis on human factors. For example, a consortium called Specialised Training for Aviation Maintenance Professionals (STAMP) was established by the European Commission to improve the quality of human factors training for maintenance personnel. Although STAMP was established before JARs 66 requirements took full effect, the training has been adjusted to satisfy those requirements. The consortium, which is scheduled to operate through November 2003, is made up of FLS Aerospace, the National Aerospace Laboratory (NLR)–Netherlands, Scandinavian Airlines System and Trinity College. It is a follow-on to the Safety Training for the Aircraft Maintenance Industry (STAMINA) consortium that developed aviation maintenance human factors training.[67]

MRM also is being used more frequently as a business tool. For example, FlightSafety Boeing offers free training in the basics of human factors principles and techniques to air carrier managers and maintenance organization managers. The free training is intended in part to increase industry utilization of the Maintenance Error Decision Aid (MEDA) developed by Boeing in the mid-1990s for investigating maintenance incidents. Boeing has trained representatives of more than 100 air carriers around the world in use of MEDA (see "Maintenance Error Investigation Tools," page 12).

FlightSafety Boeing has commissioned a study to identify effective means of establishing an airline's return on the investment in the form of less damage to aircraft and equipment, fewer worker injuries and better efficiency.

"We know that errors in maintenance cost a lot of money," said Hanson of FlightSafety Boeing. "I have to convince them [airline executives] that they can do something about it."[68]

Cockpit Management Resources, Terryville, Connecticut, U.S., provides MRM training using a technique called the "concept alignment" process.

Maintenance Error Investigation Tools

Since the early 1990s, air carriers, manufacturers and vendors have sought to develop analytical tools to aid efforts to investigate and eliminate the causes of maintenance error.

The "high-performance work organization" process adopted by USAir (now US Airways), the International Association of Machinists and Aerospace Workers and the U.S. Federal Aviation Administration (FAA) was among the first systematic attempts to unearth underlying causes of those errors. By design, the process saw limited use. It focused on incidents in which all three groups agreed that there were strong indications that human factors contributed to the error. Between 1994 and 1996, about 20 investigations were conducted using this process, in which management, the labor union and FAA cooperated to identify and implement methods of making each company more efficient and more productive.[1]

The Boeing Co. developed its Maintenance Error Decision Aid (MEDA) to collect more data on maintenance errors. MEDA was expanded into a project to give maintenance organizations a standard process for analyzing the factors that contribute to errors and developing possible corrective actions. One primary purpose of MEDA is to help "airlines shift from blaming maintenance personnel for errors to systematically investigating and understanding contributing causes."

The MEDA process is based on three assumptions. First, maintenance technicians want to do the best job possible and do not make errors intentionally. Second, errors result from the contributions of multiple factors. Boeing said that these factors typically include misleading or incorrect information, design issues, inadequate communication and time pressure. Third, most factors that contribute to errors can be managed.

Some requirements for the success of tools like MEDA are a commitment from management to implement and adhere to the standard investigation process for a relatively long period of time and the provision of feedback to employees on how MEDA results have been used to improve maintenance operations. Boeing said that air carriers using MEDA have reported an overall 16 percent reduction in mechanical delays.[2,3]

The Aurora Mishap Management System was developed by Aurora Safety and Information Systems of Edgewood, New Mexico, U.S., as a group of tools to computerize the investigation and analysis of mishaps in maintenance, ground operations and flight operations, and to assist in developing prevention strategies.[4]

The Aircraft Maintenance Procedures Optimization System (AMPOS) is an investigative tool developed by a partnership of Airbus, the National Aerospace Laboratory (NLR)-Netherlands, FLS Aerospace in Dublin, Ireland, and Trinity College in Dublin. The partners describe AMPOS as a continuous improvement process that transforms inputs into a process of change.

AMPOS consists of a methodology for assessing and managing situations in which technical systems and operational systems can be improved and an information technology system for processing and exchanging data on those situations.

This is supplemented by an organizational system for handling investigation of those situations. Teams of coordinators are deployed throughout a maintenance or production organization to assess potential situations and recommend steps for handling them. One training program is included that is based on the results of the European Safety Training for the Aircraft Maintenance Industry (STAMINA) consortium. This includes fundamental human factors training.[5]♦

— James T. McKenna

Notes

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3. Hanson, David. Interview by McKenna, James T. Alexandria, Virginia, U.S. May 7, 2002. Alexandria, Virginia, U.S. Hanson is program manager for maintenance human factors training at FlightSafety Boeing.

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5. Gaynor, Des. "Human Performance Tools – AMPOS." Presented at the 16th Human Factors in Aviation Maintenance Symposium. April 4, 2002.

Under this process, work begins with a briefing on the overall goal, the tasks involved, the rules and procedures governing them and the equipment needed. Special conditions and potential problems are reviewed. Every member of a crew must agree on all of the points in the briefing. If a point does not receive full agreement, the process requires that an outsider must be brought in to resolve that point, which is called a "counter" — or a counterpoint. Every team member is responsible for affirming the work plan in full or for discussing concerns.

Skip Mudge, president of Cockpit Management Resources, said that the advantages of this approach are that questioning becomes part of the process of performing maintenance, not a challenge to authority.

"We try to get to point of looking further into the manual, or checking with the manufacturer before we get to 'I'm right, you're wrong,' when people get caught up in defending a position" instead of finding what the correct information or procedure is, Mudge said.

Counters to the process can arise at any time, he said.

"The counter may be a statement," he said. "It may be that the part doesn't seem to be fitting right. There are a lot of cues we tend to dismiss because they don't fit into our mental model of how the work is supposed to go."[69]

At Delta Air Lines, Valieka began human factors training for maintenance personnel in August 2001 to supplement efforts to improve the quality and efficiency of processes used and work done in the technical operations organization. That organization in 1994 began implementing a continuous-improvement team process to improve quality and efficiency. That was followed by adoption of the Six Sigma philosophy for quality improvement, which originated at Motorola in the 1980s. The Six Sigma management philosophy is intended to improve customer satisfaction — and profitability — through a reduction of defects achieved by implementing a five-step program to "define, measure, analyze, improve and control."[70] Those efforts have succeeded in changing the behavior of technical operations personnel, Valieka said, and those personnel now better understand and better utilize the principles and techniques of human factors in aircraft maintenance.

Valieka noted that most past MRM efforts, including his prototype program at Continental Airlines in the early 1990s, addressed human factors in maintenance as a stand-alone issue. The results show that achieving the behavioral changes required to resolve human factors problems is difficult, he said, unless there is an operational underpinning for that change. The various quality-improvement campaigns undertaken by airlines and other businesses in recent years can provide that underpinning if they take root in an organization, as Valieka said he believes they have at Delta.

"Now you have a culture that will absorb human factors because it's in the continuum of improvement for the organization," he said.[71]♦

Notes

1. Taylor, James C. Interview by McKenna, James T. Alexandria, Virginia, U.S. May 2, 2002. Alexandria, Virginia, U.S. Taylor is an adjunct professor of human factors at the engineering school of Santa Clara University in Santa Clara, California, U.S., and a researcher in aviation maintenance.
2. Goglia, John J. Interview by McKenna, James T. Washington, D.C., U.S. Jan. 6, 2002. Alexandria, Virginia, U.S. Goglia is a member of the U.S. National Transportation Safety Board with more than 30 years experience as a maintenance technician.
3. Valieka, Ray. Interview by McKenna, James T. Alexandria, Virginia, U.S. Jan. 15, 2002. Alexandria, Virginia, U.S. Valieka is senior vice president of technical operations at Delta Air Lines.
4. Western-built large commercial jets are defined by The Boeing Co. as commercial jet airplanes with maximum gross weights of more than 60,000 pounds/27,000 kilograms. The category excludes airplanes manufactured in the Commonwealth of Independent States because of a lack of operational data and commercial airplanes in military service.
5. The Boeing Co. *Statistical Summary of Commercial Jet Airplane Accidents: Worldwide Operations — 1959–2001*. June 2002.
6. Rankin, William L. Interview by McKenna, James T. Alexandria, Virginia, U.S. Oct. 7, 2002. Alexandria, Virginia, U.S. Rankin is a technical fellow at The Boeing Co.
7. Van Avermaete, Jurgen A.G.; Hakkeling-Mesland, Martine Y. "Maintenance Human Factors from a European Research Perspective: Results from the ADAMS Project and Related Research Initiatives." Presented at the 15th Symposium on Human Factors in Aviation Maintenance, March 27–29, 2001.
8. Chaparro, Alex; Groff, Loren. "Human Factors Survey of Aviation Maintenance Technical Manuals." Presented at the 16th Human Factors in Aviation Maintenance Symposium. April 3, 2002.
9. Rankin, William L.; Allen, Jerry P. Jr.; Sargent, Robert A. "Maintenance Error Decision Aid: Progress Report." The 11th FAA [U.S. Federal Aviation Administration] Human Factors in Aviation Maintenance and Inspection Workshop. March 12–13, 1997.
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Separately, a report prepared for FAA — “Reducing Installation Error in Airline Maintenance,” by William B. Johnson and Jean Watson — and published in December 2000, cited a 1999 human factors study by the Air Transport Association of America’s Maintenance Human Factors Committee that said that installation error was the most common maintenance error. This and other reports and research on maintenance human factors are available at <http:// hfskyway.faa.gov/>.

11. Smart, Ken. “Practical Solutions for a Complex World.” Presented at the 15th Symposium on Human Factors in Aviation Maintenance, March 27–29, 2001.

12. Eiff, Gary M. Interview by McKenna, James T. Alexandria, Virginia, U.S., May 14, 2002. Alexandria, Virginia, U.S. The proactive audit tools can be downloaded from <www.tech.purdue.edu/at/resources/hfrp/softwaretools/sftindex.htm>.

13. Marx, David A. *Learning From Our Mistakes: A Review of Maintenance Error Investigation and Analysis Systems*. Prepared for FAA through Galaxy Scientific Corp., Jan. 10, 1998.

14. FAA. *Human Factors in Aviation Maintenance and Inspection — Strategic Program Plan*. 1998.

15. Controlled flight into terrain (CFIT) occurs when an airworthy aircraft under the control of the flight crew is flown unintentionally into terrain, obstacles or water, usually with no prior awareness by the crew. This type of accident can occur during most phases of flight, but CFIT is more common during the approach-and-landing phase, which begins when an airworthy aircraft under the control of the flight crew descends below 5,000 feet above ground level (AGL) with the intention to conduct an approach and ends when the landing is complete or the flight crew flies the aircraft above 5,000 feet AGL en route to another airport.

16. Taylor, James C. *The Evolution and Effectiveness of Maintenance Resource Management (MRM)*, FAA grant no. 96-G-003.

17. Taylor. Interview

18. Eiff. Interview.

19. Goglia. Interview.

20. Valieka, Ray. “Humanizing Human Factors in Maintenance.” Presented at the Society of Automotive Engineers (SAE) Airframe/Engine Maintenance and Repair Conference and Exposition. Vancouver, British Columbia, Canada. Aug. 5, 1997.

21. Aubin, Bruce. Interview by McKenna, James T. Alexandria, Virginia, U.S. May 10, 2002. Alexandria, Virginia, U.S. Aubin is a retired senior vice president of maintenance operations at USAirways; he previously held a similar position at Air Canada.

22. U.S. National Transportation Safety Board (NTSB), *Aloha Airlines, Flight 243, Boeing 737-200, N73711, Near Maui, Hawaii, April 28, 1988*. NTSB-AAR-89-03. June 14, 1989. The report said that factors contributing to the accident were “the failure of Aloha Airlines management to supervise properly its maintenance force; the failure of the FAA to evaluate properly the Aloha Airlines maintenance program and to assess the airline’s inspection and quality control deficiencies; the failure of the FAA to require Airworthiness Directive 87-21-08 inspection of all the lap joints proposed by Boeing Alert Service Bulletin SB 737-53A1039; and the lack of a complete terminating action (neither generated by Boeing nor required by the FAA) after the discovery of early production difficulties in the B-737 cold bond lap joint, which resulted in low bond durability, corrosion and premature fatigue cracking.

23. Taylor, James C. *The Evolution and Effectiveness of Maintenance Resource Management (MRM.)*

24. Goglia, John J. Speech to the 10th FAA/AAM Meeting on Human Factors in Aviation Maintenance and Inspection. Alexandria, Virginia, U.S., Jan. 17, 1996.

25. Taylor. Interview.

26. The description of the USAir (now US Airways) and Continental Airlines efforts is based on numerous interviews by the author since the early 1990s with participants in those efforts, including representatives of maintenance management at the airlines, the International Association of Machinists and Aerospace Workers, the FAA flight standards office, the FAA counsel’s offices, research organizations and the Air Transport Association of America. This information is supplemented by a review of numerous reports by James C. Taylor, one of the primary human factors researchers involved, on the evolution and progress of the USAir efforts.

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28. Ibid.

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30. Aubin. Interview.

31. Taylor. *The Evolution and Effectiveness of Maintenance Resource Management (MRM).*

32. Ibid.

33. Dupont, Gordon. Interview by McKenna, James T. Alexandria, Virginia, U.S. May 10, 2002. Alexandria, Virginia, U.S. Dupont was the Transport Canada official who oversaw development of the human performance in maintenance program.

34. Moshansky, Virgil P. *Commission of Inquiry Into the Air Ontario Crash at Dryden, Ontario, Final Report.* Minister of Supply and Services Canada. 1992.

35. Ibid.

36. Taylor. Interview.

37. Valieka. Interview.

38. Goglia. Interview.

39. Dupont. Interview.

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44. ATSB.

45. Chaparro et al.

46. Van Avermaete et al.

47. Ibid.

48. Joint Aviation Authorities. *Human Factors in Maintenance Working Group Report*. May 8, 2001.

49. Hall, David. *Aviation Maintenance Data in the United Kingdom*. Presented at the 16th Human Factors in Aviation Maintenance Symposium." April 3, 2002.

50. Valieka. Interview.

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52. NTSB. Aircraft Accident Report no. NTSB/AAR-92/04. *Britt Airways Inc., d/b/a Continental Express Flight 2574 In-flight Structural Breakup, EMB-120RT, N33701, Eagle Lake, Texas, September 11, 1991.*

53. Goglia. Interview.

54. Aubin. Interview.

55. Ibid.

56. Goglia. Interview.

57. Taylor. Interview.

58. Hanson, David. Interview by McKenna, James T. Alexandria, Virginia, U.S., May 7, 2002. Alexandria, Virginia, U.S.

59. Taylor et al. *Evaluating the Effect of Maintenance Resource Management (MRM) in Air Safety.*

60. Taylor. Interview.

61. Valieka. Interview.

62. Kizer. Interview.

63. Schmidt, John; Schmorrow, Dylan; Figlock, Robert. "Forecasting Return on Investment for Naval Aviation Maintenance Safety Initiatives." In *Proceedings of the 2000 Advances in Aviation Safety Conference*. Warrendale, Pennsylvania, U.S. April 2000.

64. Kizer. Interview.

65. Transport Canada, *Notices of Proposed Amendment* NPA 2000-033, NPA 2000-036 and NPA 2000-037.

66. ICAO. *Annex 6, Operation of Aircraft, Part 1, International Commercial Air Transport — Aeroplane.*

67. Van Avermaete et al.

68. Hanson. Interview.

69. Mudge, Skip. Interview by McKenna, James T. Alexandria, Virginia, U.S. May 7, 2002. Alexandria, Virginia, U.S.

70. Carnegie Mellon Software Engineering Institute. "Six Sigma." *Software Technology Review.* <www.sei.cmu/str/descriptions/sigma6_body.html>. Sept. 19, 2002.

71. Valieka. Interview.

About the Author

James T. McKenna is managing editor of Aviation Maintenance *magazine in Potomac, Maryland, U.S. As a journalist, he has written on aviation and aviation safety for more than 20 years for such media outlets as* Aviation Week & Space Technology, The New York Times, *Cable News Network*, *Agence-France Presse*, Professional Pilot *and* The World Book Encyclopedia. *He holds a private pilot certificate and an airframe mechanic certificate.*

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Data Show 32 Accidents in 2001 Among Western-built Large Commercial Jets

Twenty of the accidents were classified as hull-loss accidents. Data show an accident rate in 2001 of 1.75 per 1 million departures and a hull-loss/fatal accident rate of 1.17 per 1 million departures.

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Data compiled by The Boeing Co. show that 32 airplanes in the worldwide fleet of Western-built large commercial jets were involved in accidents in 2001 (Table 1, page 17).

The data include commercial jet airplanes with maximum gross weights of more than 60,000 pounds/27,000 kilograms. The data exclude airplanes manufactured in the Commonwealth of Independent States because of a lack of operational data. Commercial airplanes in military service also are excluded.

Of the 32 accidents, 20 (63 percent) were classified as hull-loss accidents. Boeing defines a hull-loss accident as one in which damage to an airplane is substantial and beyond economic repair; or in which an airplane is missing, a search for the wreckage has been terminated without the airplane being located or an airplane is substantially damaged and inaccessible.

Ten of the 32 accidents resulted in 417 fatalities — 92 percent of which resulted from the following two accidents:

- A Nov. 12 accident involving an American Airlines Airbus A300-600, which struck terrain after takeoff from John F. Kennedy International Airport in New York City, New York, U.S. The accident killed 265 people; and,

- An Oct. 8 runway collision at Linate Airport in Milan, Italy, involving a Scandinavian Airlines System (SAS) McDonnell Douglas MD-87 and a Cessna Citation. The accident killed 118 people.

The data showed that there were 16,144 certified Western-built large commercial jets in 2001, including those in temporary non-flying status and those in use by operators other than airlines (Figure 1, page 18). The aircraft were flown 34.06 million flight hours in 2001; there were 17.15 million departures (Figure 2, page 18). From 1966 through 2001, flight hours totaled 644.5 million, and departures totaled 395.8 million.

The data showed that there were 1,307 accidents between 1959 and 2001, including 1,033 accidents (79.0 percent) involving passenger aircraft, 169 accidents (12.9 percent) involving cargo aircraft, 103 accidents (7.9 percent) involving ferry/test aircraft and two accidents (0.2 percent) involving military service aircraft (Table 2, page 19). Of the 1,307 accidents, 758 (58.0 percent) were hull-loss and/or fatal accidents in which 24,700 people were killed.

The 1,307 accidents comprise 681 hull-loss accidents, including 421 fatal accidents; 534 substantial-damage accidents, including 19 fatal accidents; and 92 personal-injury accidents, including 58 fatal accidents (and less-than-substantial damage; Figure 3, page 19). Boeing defines substantial damage as "damage or structural failure that adversely affects the structural strength, performance or flight characteristics of the airplane and would normally require major repair or replacement of the affected component."

The accident rate was 1.75 per 1 million departures in 2001, and the hull-loss/fatal accident rate was 1.17 per 1 million departures (Figure 4, page 20).

The events excluded from the accident analysis included 10 hostile actions, each of which resulted from "a premeditated, overt act originating from terrorism, sabotage or suicide," the report said (Table 3, page 20). Four of the events were

Table 1
Accidents Involving Western-built Large Commercial Jet Airplanes,[1] 2001

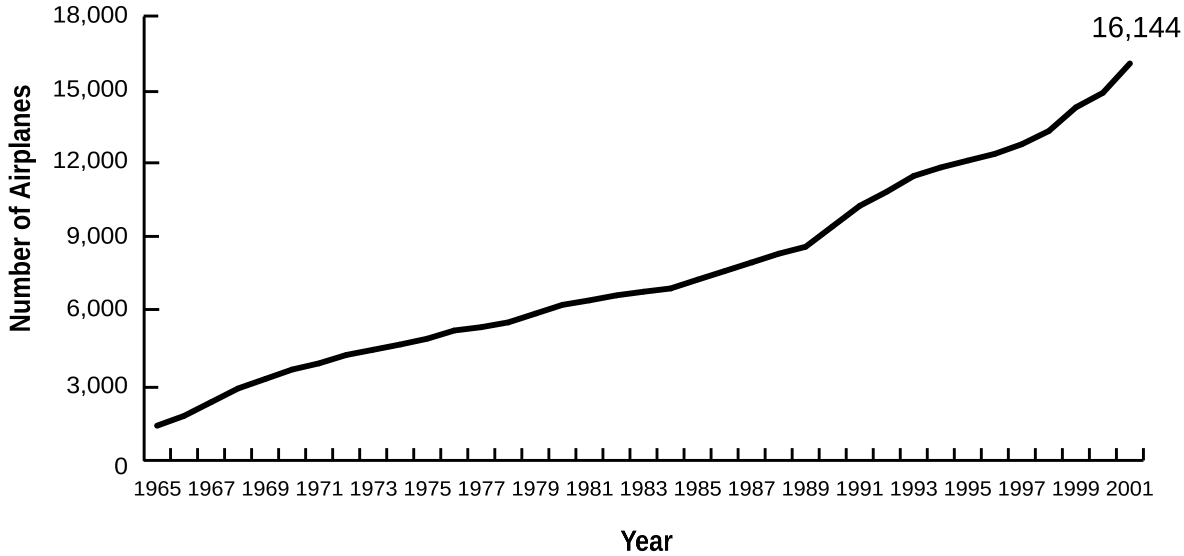
Date	Airline	Airplane Type	Accident Location	Hull Loss	Fatalities[2]	Phase	Description
Jan. 5, 2001	Air Gemini	Boeing 727-100	Dundo, Angola	Yes	1	Landing	Struck terrain during landing
Jan. 9, 2001	LAB	Boeing 727-200	Buenos Aires, Argentina	Yes	—	Landing	MLG collapsed, wing damaged
Jan. 31, 2001	L.A. Suramericanas	Caravelle 10R	El Yopal, Colombia	Yes	1	Landing	Landed short after go-around
Feb. 7, 2001	Iberia	Airbus A320	Bilbao, Spain	Yes	—	Landing	Hard landing, NLG collapsed
March 3, 2001	Thai Airways	Boeing 737-400	Bangkok, Thailand	Yes	1	Parked	Airplane destroyed by fire
March 6, 2001	Federal Express	McDonnell Douglas DC-10-10F	Boston, Massachusetts, U.S.	No	—	Takeoff	Fan blade/fire damage
March 7, 2001	Skymaster Airways	Boeing 707-300C	São Paulo, Brazil	Yes	—	Landing	Hard landing, off runway
March 11, 2001	Express One	Boeing 727-200	Pohnpei Island, Micronesia	Yes	—	Landing	RMLG separated, LMLG collapsed
March 17, 2001	Northwest Airlines	Airbus A320	Detroit, Michigan, U.S.	No	—	Takeoff	Tail strike, runway overrun
March 22, 2001	Tunis Air	Airbus A320	Djerba, Tunisia	No	—	Landing	Landing overrun, NLG collapsed
March 23, 2001	Luxor Air	Boeing 707-300C	Monrovia, Liberia	Yes	—	Landing	Dragged engines 3 and 4
April 4, 2001	Canada 3000 Cargo	Boeing 737-200F	St. Johns, Newfoundland, Canada	No	—	Landing	Off-runway excursion
April 4, 2001	Fine Air	McDonnell Douglas DC-8-62F	Cali, Colombia	Yes	2	Landing	NLG collapsed, (2 stowaway fatalities)
May 10, 2001	Angola Air Charter	Boeing 727-100F	N'zagi, Angola	Yes	—	Landing	Landed short, RMLG collapsed
May 22, 2001	First Air	Boeing 737-200	Yellowknife, Northwest Territories, Canada	Yes	—	Landing	Bounced hard landing
May 23, 2001	American Airlines	Fokker F100	Dallas, Texas, U.S.	Yes	—	Landing	RMLG separated
July 6, 2001	Air Transat	Lockheed L-1011-150	Lyon, France	No	—	Climb	Hail storm damage in flight
July 17, 2001	TAME	Fokker F28-4000	Tulcan, Ecuador	No	—	Landing	Veered off runway
Aug. 1, 2001	Yemenia	Boeing 727-200	Asmara, Eritrea	Yes	—	Landing	Landing overrun
Aug. 24, 2001	Air Transat	Airbus A330	Praia Da Vitoria, Azores	No	—	Landing	Dual engine flameout, evacuation injuries
Aug. 28, 2001	Eagle Aviation	British Aircraft Corp. BAC 1-11	Libreville, Gabon	No	—	Landing	Runway overrun
Sept. 6, 2001	Aeropostal	McDonnell Douglas DC-9-51	Port of Spain, Trinidad	No	—	Taxi	Off runway, NLG collapsed
Sept. 7, 2001	HC Airlines	Boeing 707-320C	Lubumbashi, Congo	Yes	—	Landing	Veered off runway, MLG failed
Sept. 16, 2001	Varig	Boeing 737-200	Goiania, Brazil	Yes	—	Landing	Runway offside excursion
Sept. 18, 2001	TAM	Fokker F100	Belo Horizonte, Brazil	No	1	Cruise	Uncontained engine, passenger fatality
Oct. 8, 2001	SAS	McDonnell Douglas MD-87	Milan, Italy	Yes	118	Takeoff	Runway incursion with Cessna Citation
Oct. 14, 2001	Jet Airways	Boeing 737-400	Chenni, India	No	—	Parked	Flight attendant fell from doorway, injury
Oct. 17, 2001	Pakistan International	Airbus A300-B4	Dubai, United Arab Emirates	Yes	—	Landing	Runway excursion, landing gear collapsed
Oct. 20, 2001	Tunis Air	Airbus A300-600	Djerba, Tunisia	No	1	Parked	Flight attendant fell from doorway
Nov. 12, 2001	American Airlines	Airbus A300-600	New York City, New York, U.S.	Yes	265	Initial Climb	Struck terrain after takeoff
Nov. 24, 2001	Crossair	Canadair RJ100	Zurich, Switzerland	Yes	24	Approach	CFIT — Struck terrain short of runway
Nov. 27, 2001	MK Airlines	Boeing 747-200F	Port Harcourt, Nigeria	Yes	3	Landing	CFIT — landed short, altimeter error
Total				**20**	**417**		

[1]Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.
[2]Includes on-board and other fatalities.

CFIT = Controlled flight into terrain   MLG = Main landing gear   NLG = Nose landing gear   RMLG = Right-main landing gear   LMLG = Left-main landing gear

Source: The Boeing Co.

Western-built Large Commercial Jet Airplanes in Service,* 1966–2001

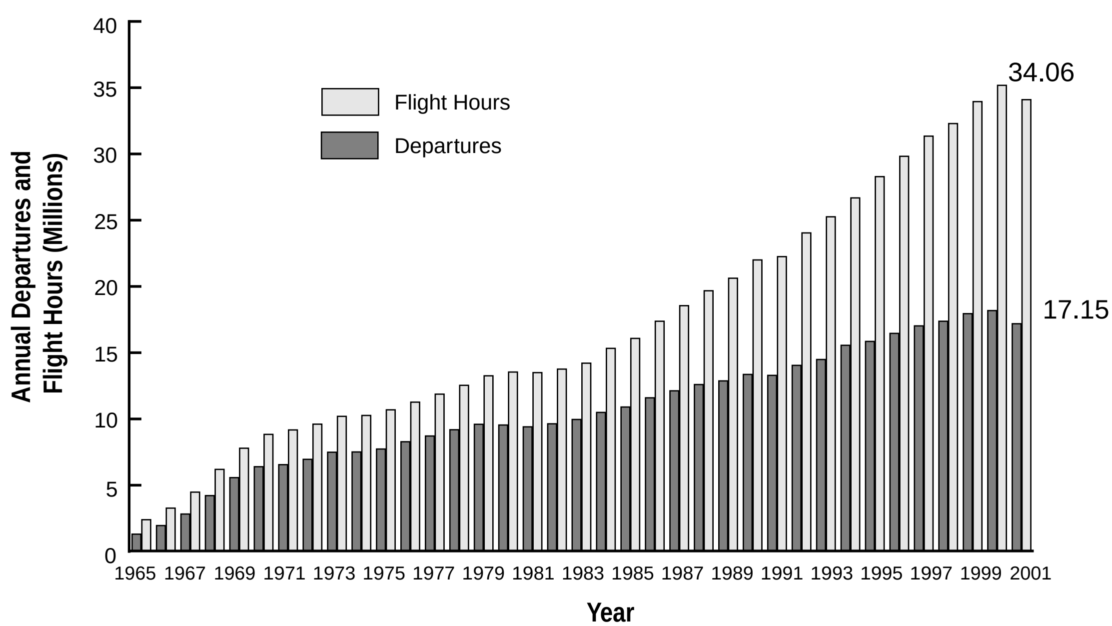


*Certified jet airplanes heavier than 60,000 pounds/27,000 kilograms maximum gross weight, including those in temporary non-flying status and those used by non-airline operators. Excluded are airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 1

Departures and Flight Hours, Western-built Large Commercial Jet Airplanes,* 1966–2001



*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 2

Table 2
Accident Summary by Type of Operation, Western-built Large Commercial Jet Airplanes*

	All Accidents		Hull-loss and/or Fatal Accidents		On-board Fatalities	
Type of Operation	**1959–2001**	**1992–2001**	**1959–2001**	**1992–2001**	**1959–2001**	**1992–2001**
Passenger	1,033	299	576	166	24,283	6,621
Cargo	169	79	119	57	217	59
Ferry, test	103	15	61	10	189	34
Military service	2	0	2	0	11	0
Total	**1,307**	**393**	**758**	**233**	**24,700**	**6,714**

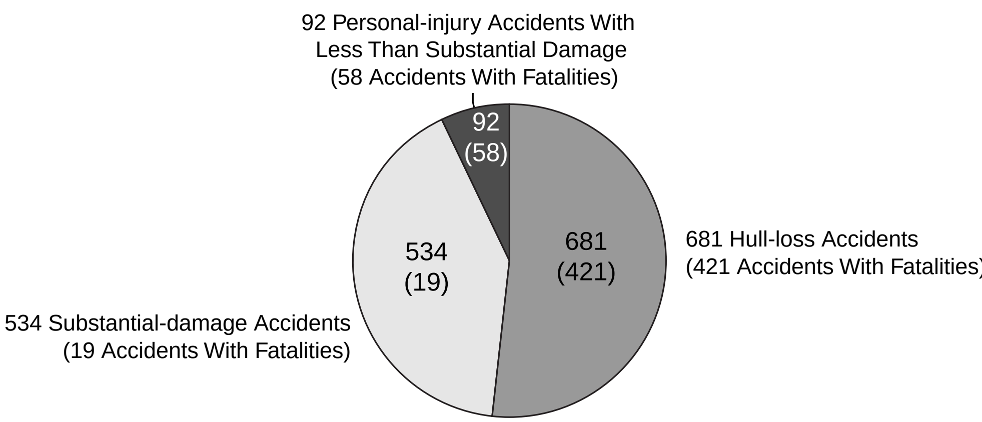
*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

the Sept. 11 hijackings of two Boeing 767s and two B-757s, which were flown into buildings in New York City and near Washington, D.C., and into the ground near Johnstown, Pennsylvania; 265 people aboard the aircraft were killed. The other six events were military actions in Colombo, Sri Lanka, that destroyed six Airbus airplanes on the ground; the airplanes were not occupied. All 10 events were classified as hull-loss events. Boeing said that the list might be incomplete because of incomplete reporting.

Data showed that the sabotage/terrorist rate per 1 million departures was about 0.58 percent (Figure 5, page 21), and

Accident Summary by Damage and Injury All Accidents Western-built Large Commercial Jet Airplanes,* 1959–2001



Excludes:

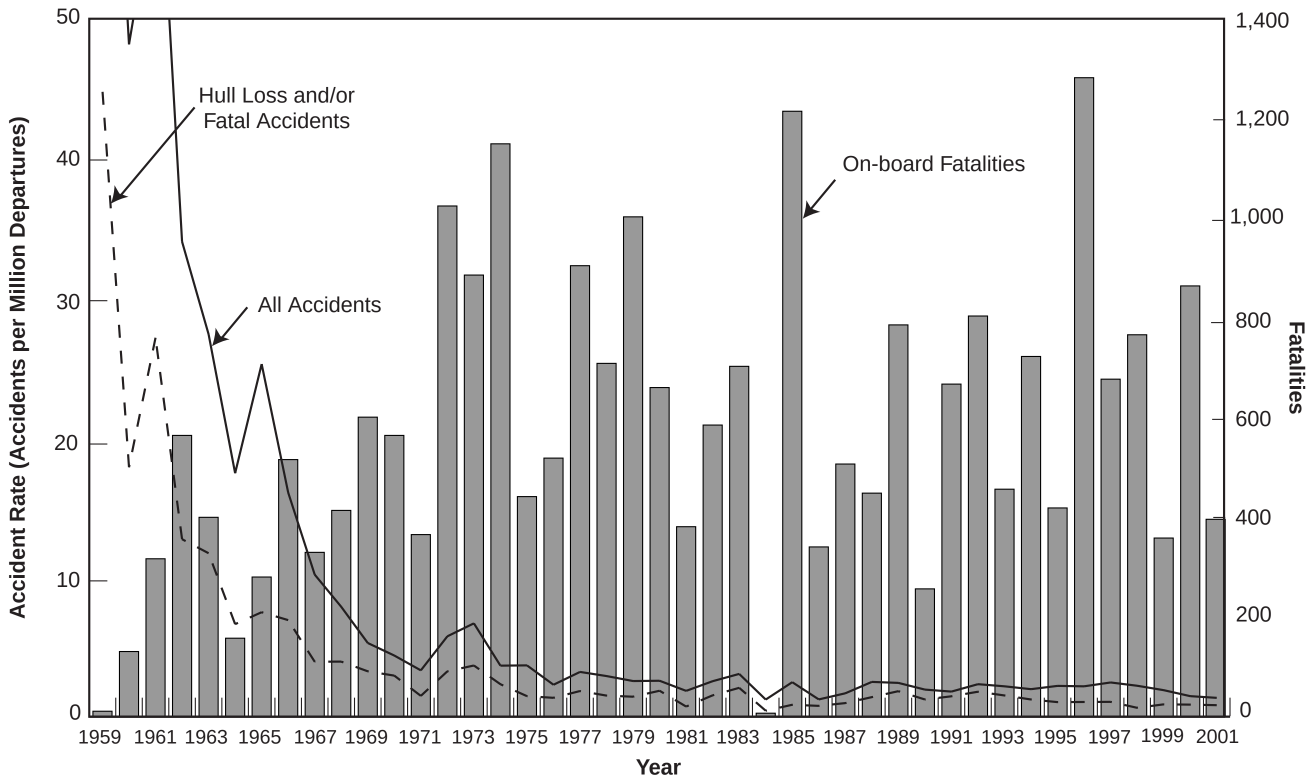
- Fatal injuries from natural causes or suicide;
- Experimental test flights;
- Military airplanes;
- Sabotage, hijacking, terrorism or military action; and,
- Nonfatal injuries involving:
  - Atmospheric turbulence, maneuvering or loose objects;
  - Boarding, disembarking or evacuation;
  - Maintenance and servicing; and,
  - People not in the airplane.

*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 3

Accident Rates and Fatalities by Year, Western-built Large Commercial Jet Airplanes,* 1959–2001



*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 4

Table 3
Hostile Actions Involving Western-built Large Commercial Jet Airplanes,[1] 2001

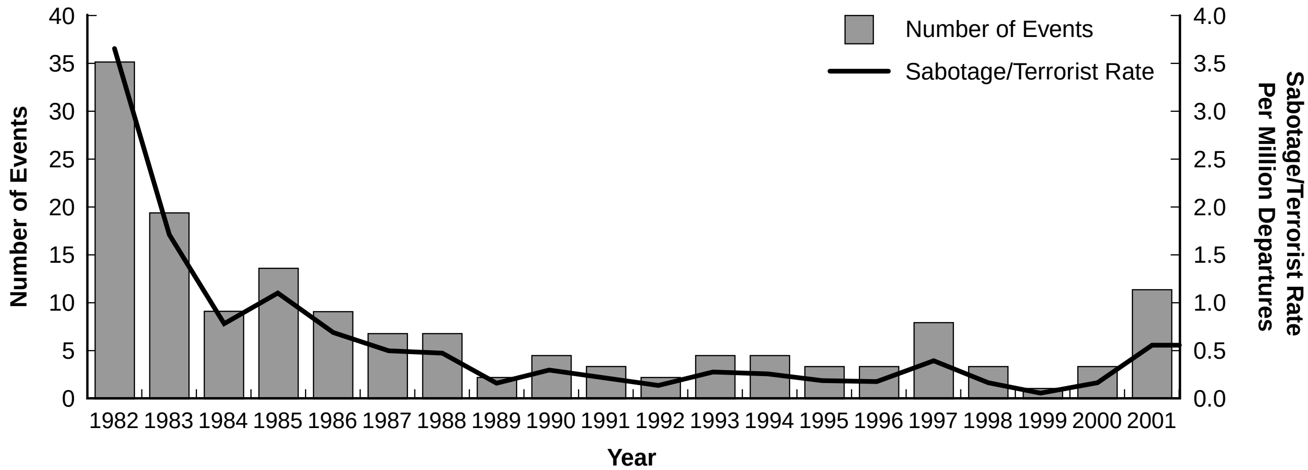
Date	Airline	Airplane Type	Accident Location	Hull Loss	On-board Fatalities	Description
July 24, 2001	SriLankan Airlines[2]	Airbus A340	Colombo, Sri Lanka	Yes	0	On ground, military action
July 24, 2001	SriLankan Airlines	Airbus A330	Colombo, Sri Lanka	Yes	0	On ground, military action
July 24, 2001	SriLankan Airlines	Airbus A320	Colombo, Sri Lanka	Yes	0	On ground, military action
July 24, 2001	SriLankan Airlines	Airbus A340	Colombo, Sri Lanka	Yes	0	On ground, military action
July 24, 2001	SriLankan Airlines	Airbus A330	Colombo, Sri Lanka	Yes	0	On ground, military action
July 24, 2001	SriLankan Airlines	Airbus A320	Colombo, Sri Lanka	Yes	0	On ground, military action
Sept. 11, 2001	United Airlines	Boeing 767	New York, New York, U.S.	Yes	65	Hijacked and struck building
Sept. 11, 2001	United Airlines	Boeing 757	Johnstown, Pennsylvania, U.S.	Yes	64	Hijacked and struck terrain
Sept. 11, 2001	American Airlines	Boeing 767	New York, New York, U.S.	Yes	92	Hijacked and struck building
Sept. 11, 2001	American Airlines	Boeing 757	Arlington, Virginia, U.S.	Yes	44	Hijacked and struck building
Total				**10**	**265**	

[1]Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

[2]SriLankan Airlines was formerly Air Lanka.

Source: The Boeing Co.

Hostile Actions Involving Western-built Large Commercial Jet Airplanes,* 1982–2001

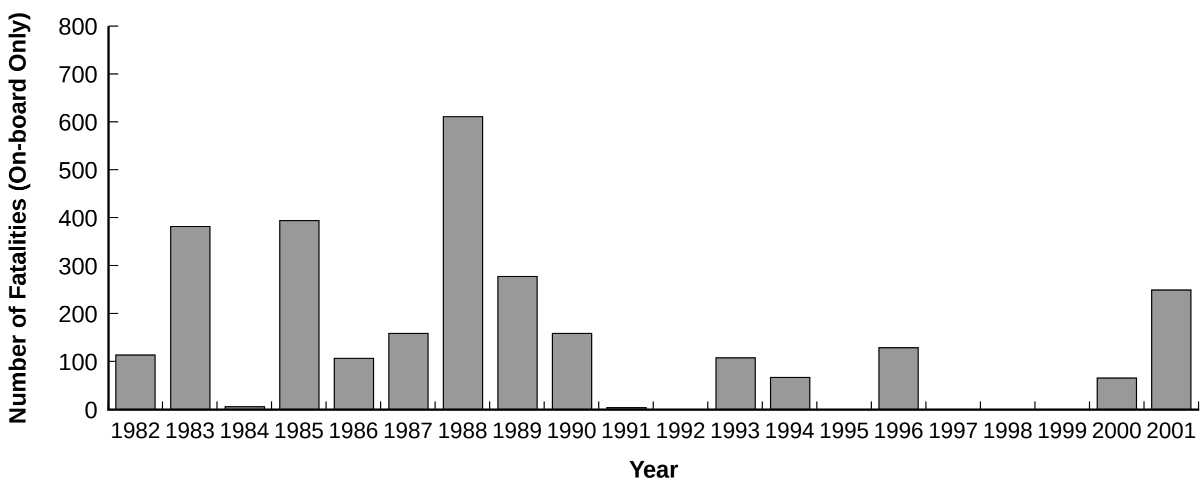


*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 5

On-board Fatalities Resulting From Hostile Actions Involving Western-built Large Commercial Jet Airplanes,* 1982–2001



*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 6

that the number of onboard fatalities was the highest since 1989 (Figure 6).

Excluded non-hostile events in 2001 included one fatality in which a passenger fell from portable stairs and 12 events in which flight attendants or passengers were injured during turbulence (Table 4, page 22). Turbulence was the cause of most excluded non-hostile events from 1992 through 2001; during that period, 127 events involved turbulence (Figure 7, page 22).♦

Table 4

Non-hostile Events Involving Western-built Large Commercial Jet Airplanes,* 2001

Turbulence:

- Flight attendant injury — 7 events
- Passenger injury — 5 events

Evasive maneuver — 2 injury events

Boarding:

- Passenger fell from portable stairs — fatal

Emergency evacuation:

- Passenger slide injury — 4 events

Pushback:

- Tug overran aircraft — aircraft damage
- Tow bar failed — aircraft overran tug — aircraft damage
- Tug stopped — gear collapsed — aircraft damage
- Wing-walker injury

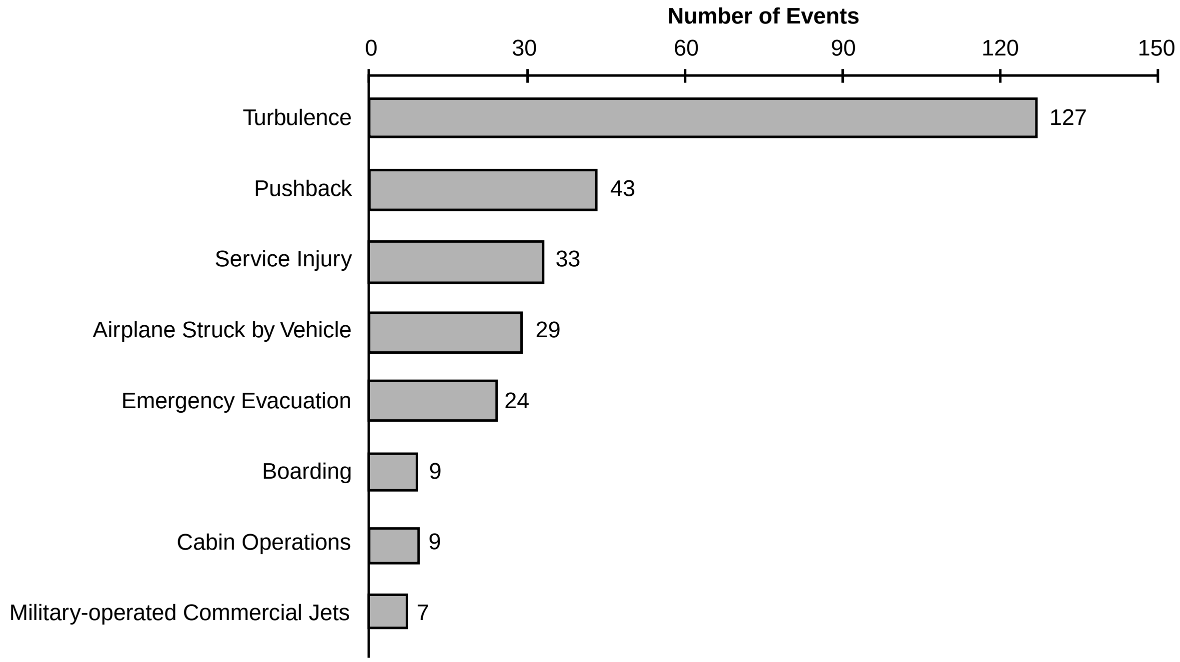
Ground operations:

- Refueling fire
- Service truck struck aircraft
- Aircraft positioning — 2 damage events

*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Non-hostile Events Involving Western-built Large Commercial Jet Airplanes,* 1992–2001



*Heavier than 60,000 pounds/27,000 kilograms maximum gross weight; excludes airplanes manufactured in the Commonwealth of Independent States and commercial airplanes in military service.

Source: The Boeing Co.

Figure 7

Publications Received at FSF Jerry Lederer Aviation Safety Library

Study Analyzes Differences in Rotating-shift Schedules

The report on the study, conducted by the U.S. Federal Aviation Administration, said that changing shift rotation for air traffic controllers probably would not result in improved sleep.

FSF Library Staff

Reports

A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules, Part I. Sleep. Cruz, C.; Detwiler, C.; Nesthus, T.; Boquet, A. U.S. Federal Aviation Administration (FAA) Office of Aerospace Medicine (OAM). DOT/FAA/AM-02/8. May 2002. 22 pp. Figures, tables, references. Available on the Internet at <www.cami.jccbi.gov> or through NTIS.*

The authors reviewed literature about shift work (nonstandard work schedules in which most of the hours worked are outside the period between 0800 and 1600) and discussed the ongoing debate about the benefits of rotating-shift schedules and fixed-shift schedules. On a fixed-shift schedule, each person reports to work at the same time every day (or night) that he or she is scheduled to work. On a rotating-shift schedule, scheduled work hours change — or rotate — regularly. (Rotation may be rapid, changing every one day to three days, or longer, changing every four weeks to six weeks.) Shifts may rotate clockwise — with the work schedule being moved forward from days to evenings to nights — or counterclockwise — with the work schedule being moved backward, from nights to evenings to days.

Some specialists say that with counterclockwise rotation, workers experience greater disruption of circadian rhythms (behavioral rhythms and physiological rhythms associated with the 24-hour cycle of the earth's rotation) and shortened sleep periods as a result of reduced time off; other specialists say that circadian rhythms and the sleep-wake cycles would be similarly affected regardless of the rotation direction.

Air traffic controllers in the United States have worked variations of counterclockwise, rapidly rotating shift schedules since the early 1970s. The most common schedule is the "2-2-1" schedule in which individuals work two afternoon shifts, followed by two morning shifts, followed by one midnight shift.

The authors examined whether clockwise shift rotation would result in better adaptation and better performance. Thirty study participants, representing a range of professional occupations and trade occupations, provided objective data and subjective data as they worked clockwise shift-rotation schedules and counterclockwise shift-rotation schedules.

The data showed that most participants experienced longer concentrated sleep before the midnight shift on a clockwise rotation. Nevertheless, the data did not support the authors' hypothesis that clockwise rotation results in less sleep disruption. The authors said that the results of the study revealed that reversing the direction of shift rotation for FAA controllers from counterclockwise to clockwise probably would not produce improvements.

Collaborative Decision Making, Improving Airport Operations Through CDM: Zaventem 2001 Project. Delain, O.; Florent J.P. France: Eurocontrol Experimental Centre (EEC), 2002. EEC Report 371. 88 pp. Figures, tables, glossary, appendix, references. Available on the Internet at <www.eurocontrol.fr> or from the Eurocontrol Experimental Centre.**

This report says that, despite the attention given to reducing air traffic delays in Europe, little has been done to analyze the causes of delays at airports or the methods of alleviating them.

Airport operations involve many different entities: airport authorities, air traffic control, aircraft operators, ground handling, a central flow-management unit (Eurocontrol) and passengers. Improvements by one entity may not result in improvements for all. The report says that airports are natural environments for collaborative decision making, in which successful performance often involves interaction among several entities through communication, teamwork, leadership, coordination, monitoring, feedback and backup assistance.

The European air traffic management community has been working on many initiatives to improve cooperation, communication and the sharing of information. The EEC, which has been involved in collaborative decision-making studies since 1998, developed two projects on airport operations to address performance, flow management, economics and efficiency. The projects involve airports in Brussels, Belgium, and Barcelona, Spain.

This report discusses the status of initiatives and results of the collaborative decision-making (CDM) project in Brussels. New CDM concepts developed in the Brussels project are being applied to the Barcelona project.

The Aviation Accident Experience of Civilian Airmen With Refractive Surgery. Nakagawara, V.B.; Montgomery, R.W.; Wood, K.J. U.S. Federal Aviation Administration (FAA) Office of Aerospace Medicine (OAM). DOT/FAA/AM-02/10. June 2002. 16 pp. Figures, tables, references. Available on the Internet at <www.cami.jccbi.gov> or through NTIS.*

Pilots must have optimum vision (near vision, intermediate vision and distance vision) to ensure safe flight operations. Blurred vision can interfere with a pilot's ability to perform tasks and can compromise aviation safety.

Blurred vision may be caused by refractive error, defined in the report as "an optical defect that prevents light rays entering the eye [from being] focused as a single, clear image on the retina."

Common refractive conditions may be corrected with ophthalmic devices, such as eyeglasses and contact lenses, or with surgical procedures, such as radial keratotomy and laser procedures.

The authors reviewed published medical studies about the effectiveness of corrective devices and procedures and said that the criteria for measuring success in correcting visual acuity are less stringent for the general population than the criteria acceptable for pilots. Pilots are concerned with the quality of vision correction, side effects in the aviation environment and the potential for surgical complications, the report said.

The report said that the review of published medical studies found "statistically significant associations between certain visual conditions and aircraft accidents"; refractive surgery, however, was not included in those studies.

For their study, the authors reviewed records in FAA's Consolidated Airman Information System for airmen who were active from 1994 through 1996 and who had undergone refractive surgery or general eye surgery. The records were cross-referenced with FAA's Accident/Incident Data System to determine which of those airmen were involved in aircraft accidents. The findings showed a higher accident rate for airmen with refractive surgery than those without refractive surgery. This was true for all three classes of medical certification. Further analysis of the data revealed no statistically significant differences among medical certification classes or among the total airman population, however. The authors recommended continued monitoring to determine whether newer laser refractive procedures produce satisfactory results for airmen.

Books

The Field Guide to Human Error Investigations. Dekker, S. Aldershot, England: Ashgate Publishing, 2002. 170 pp. Figures, tables, references.

The author says that, in the investigation of an incident or an accident involving a significant human contribution, human error can be considered as the cause of the mishap — and therefore the conclusion of the investigation — or as the starting point in the investigation.

The first approach represents the old way of perceiving human error. The second approach represents the new view of human error as "a symptom of trouble deeper inside a system," the author said. "To explain failure, do not try to find where people went wrong. Instead, find how people's assessments and actions made sense at the time, given the circumstances that surrounded them."

Part I of the book discusses the old view, its related problems and the biases or "traps" that influence investigators. Part II discusses methods by which the investigator can "reverse-engineer" human error in the same way that other components and events are reconstructed during an accident investigation. The goal is to help investigators understand the evolving situation in which particular behaviors occurred and why specific actions were taken.

Climatology for Airline Pilots. Quantick, H.R. Oxford, England: Blackwell Science, 2001. 248 pp. Figures, tables, glossary, appendixes.

This book is included on the Joint Aviation Authorities' Joint Aviation Requirements syllabus. The author is a former military pilot and commercial airline pilot with experience operating on world air routes. The book says that, as aircraft have become more sophisticated and have been flown at higher altitudes and for longer distances, pilots have faced new challenges as a result of radical climatic variations.

The book discusses new routings over the North Pole and direct ocean crossings, and focuses on difficult and demanding natural environments. Part 1 discusses global weather and meteorological conditions. Part 2 discusses route climatology and area climatology and explains weather, climatic conditions and meteorological anomalies in various regions of the world, such as occur during flights from the Arabian Gulf to Singapore, Singapore to Japan, Singapore to Australia, and in the Southwest Pacific.

Regulatory Materials

Aircraft Wake Turbulence. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 90-23F. Feb. 20, 2002. 17 pp. Figures. Available from GPO.***

The purpose of this AC is to alert pilots to the hazards of aircraft wake turbulence and to recommend related operational procedures. The AC discusses the generation by aircraft of wake turbulence, vortex behavior, aircraft operational problems and procedures for avoiding wake turbulence. Sections on communications procedures between air traffic controllers and pilots have been expanded to include new information. New sections on "Pilot Responsibility" and "Pilot Awareness Intervention" have been added. Some illustrations are unchanged, and others have been deleted, added or altered for clarification.

[This AC cancels AC 90-23E, *Aircraft Wake Turbulence*, dated Oct. 1, 1991.]

JAR-STD 3H Helicopter Flight and Navigation Procedures Trainers (FNPT). Joint Aviation Authorities Joint Aviation Requirements (JARs) JAR-STD 3H. May 1, 2002. 14 pp. Tables, appendixes. Available on the Internet at <www.jaa.nl> or from IHS.****

This regulation applies to individuals and organizations seeking JAA qualification of helicopter flight-and-navigation-procedures trainers. JAA defines an FNPT as "a training device which represents the flight deck/cockpit environment, including the assemblage of equipment and computer programs necessary to represent a helicopter in flight conditions to the extent that the systems appear to function as in a helicopter."

JAR-STD 4A Basic Instrument Training Devices (BITD). Joint Aviation Authorities Joint Aviation Requirements (JARs) JAR-STD 4A. May 1, 2002. 16 pp. Tables, appendixes. Available on the Internet at <www.jaa.nl> or from IHS.****

This regulation applies to manufacturers and operators seeking qualification of basic instrument training devices (BITD). JAA defines a BITD as "a ground training device which represents the student pilot's station of a class of airplanes. It may use screen-based instrument panels and spring-loaded flight controls, providing a training platform for at least the procedural aspects of instrument flight."

North American Route Program (NRP). U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 90-91F. July 30, 2002. 17 pp. Appendixes. Available from GPO.***

This AC provides guidance for participating in the North American Route Program (NRP). The NRP is a route-planning tool for operating aircraft with on-board communication and navigation equipment required by U.S. Federal Aviation Regulations Part 91.205 and Part 121.349 The NRP is a joint program of FAA and Nav Canada (the company that provides air traffic control, flight information, weather information, airport advisory services and electronic aids to navigation in Canada). The NRP was developed to harmonize procedures for random-route flight operations at and above Flight Level 290 (approximately 29,000 feet) within the United States and Canada. The program allows domestic operators and international operators to select operationally advantageous routings based on factors such as time allowance, costs, fuel supply, weather avoidance and aircraft limitations. The AC includes guidelines, filing requirements and procedures.

[This AC cancels AC 90-91E, *North American Route Program*, dated March 1, 2000.]♦

Sources

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5285 Port Royal Road
Springfield, VA 22161 U.S.
Internet: <www.ntis.gov>

** Eurocontrol Experimental Centre
Publications Office
Centre de Bois des Bordes
B.P. 15
F-91222 Brétigny-sur-Orge CEDEX
France

*** Superintendent of Documents
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Washington, DC 20402 U.S.
Internet: <www.access.gpo.gov>

**** IHS Global Engineering Documents
15 Inverness Way East
Englewood, CO 80112-5776 U.S.

B-767 Flap Component Separates During Flight

The airplane was being flown on an approach to land when a section of a wing-flap-deflection control track separated from the airplane, fell through the roof of a warehouse and struck the floor.

FSF Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Special Inspection Failed to Detect Problem

Boeing 767. Minor damage. No injuries.

The airplane was being flown on approach to land at an airport in New Zealand after a flight from Australia when a section of a wing-flap-deflection control track separated from the airplane. The section, which weighed three kilograms (6.6 pounds), penetrated the roof of a warehouse and fell to the floor. The flight crew was not aware of the event and conducted a normal landing.

After the previous flight, from New Zealand to Australia, two passengers in window seats had told the captain that the "left outboard flap and spoiler were not sitting flush with the wing at their outboard ends." They also said that they had observed an object 50 centimeters (20 inches) long move out from beneath the outer edge of the "outboard spoiler"; the object disappeared into the wing when the flaps were retracted after landing. Maintenance engineers inspected the spoilers and flaps and found no damage or loose items. They said that the spoilers, flaps and ailerons functioned normally during ground tests.

An investigation revealed that the flap control track had failed because of a fatigue crack. The report said that the failure was accelerated by "the coincidental inclusion of slag" (residue from metal processing) during manufacture and by extended aircraft operations at relatively low temperatures.

After the incident, the operator began requiring additional regular inspections of the flap control track, and the manufacturer began development of an inspection schedule to allow for identification of a cracked flap control track before failure.

Airplane Slides Off Runway During Landing in Snow Shower

Antonov An-124-100. Minor damage. No injuries.

Night instrument meteorological conditions prevailed for the instrument landing system (ILS) approach to Runway 25 at an airport in Canada. Weather 33 minutes before the landing included winds from 80 degrees at four knots; visibility of 1.5 statute miles (2.4 kilometers) in light snow; broken clouds at 900 feet above ground level (AGL) and overcast clouds at 1,300 feet AGL; a temperature of minus nine degrees Celsius (C; 16 degrees Fahrenheit [F]); and a dew point of minus 10 degrees C (14 degrees F).

The airplane had been landed with a four-knot tail wind component on Runway 25 (which had the airport's only ILS approach). The report said that because of the low ceiling and visibility, the crew probably would not have been able to land the aircraft if they had conducted a nonprecision approach to Runway 7.

About 20 minutes before the airplane was landed, a report on the condition of the 200-foot-wide (61-meter-wide) runway said that the center 120 feet (37 meters) were 90 percent covered with traces of loose snow and 10 percent covered with ice patches; the remaining 40 feet (12 meters) on each side were 75 percent covered with one inch (2.5 centimeters) of loose snow and 25 percent covered with ice patches. The report said that snow and ice were plowed and swept from the runway before the airplane's arrival.

The airplane touched down about 3,400 feet (1,037 meters) past the runway threshold, continued on the remaining 4,450 feet (1,357 meters) and about 340 feet (104 meters) beyond the runway, and stopped 20 feet (six meters) from the airport boundary fence. Tire skid marks could be seen beginning about 100 feet (31 meters) before the end of the runway.

An investigation revealed that the captain had used an airplane flight manual chart to calculate an estimated landing distance of 6,890 feet (2,101 meters). In calculations, the touchdown point was considered to be 984 feet (300 meters) past the runway threshold. He used another chart in the airplane flight manual to calculate a stopping distance of about 3,280 feet (1,000 meters). The chart did not include a correction for reduced braking friction resulting from a runway covered with snow and ice.

The airplane's normal approach speed is 145 knots. The crew intended to fly the airplane at 148 knots, but the indicated airspeed for the final approach segment was 151 knots. The airplane crossed the runway threshold at about 70 feet; the typical crossing altitude is 50 feet AGL. Two other large airplanes were landed on Runway 25 within 22 minutes before the accident airplane, and one flight crew described braking action as "moderate." That report was provided to the crew of the accident airplane.

The report said that because "moderate" is not standard terminology to describe braking action, its use might have led the crew to believe that braking action was adequate for a normal approach and landing. Air traffic control did not provide the crew with a report that runway conditions were at a level representing a low braking coefficient of friction, according to the Canadian Runway Friction Index.

Reworked Engine Fails During First Flight

Airbus A321. Minor damage. No injuries.

The flight crew had complied with a maintenance recommendation to use takeoff/go-around thrust for the takeoff from an airport in England on the first flight after installation of a reworked no. 1 engine. The report said that the takeoff appeared to be proceeding normally until rotation, when an electronic centralized aircraft monitoring (ECAM) master warning occurred that read "ENG 1 OIL LO PR."

The warning was followed by a loud bang, a flash of flame from the intake of the no. 1 engine and a "significant jolt" throughout the airframe; the crew observed a decrease in instrument indications for the no. 1 engine.

The report said, "The [captain] considered the apparent engine surge so severe that he ordered the first officer to close the thrust lever for the no. 1 engine. As the thrust lever was retarded, it became apparent from the instruments that this engine had suffered a major malfunction."

The flight crew conducted ECAM actions for "Engine Severe Damage," continued the takeoff and flew the airplane to a nearby airport with longer runways, where they landed the airplane.

An investigation revealed metallic debris in the engine jet pipe and extensive damage within the engine; there was no damage to any other part of the airplane. An investigation was continuing to identify the cause of the engine failure.

Engine Fire Prompts Emergency Landing

Boeing 747. Minor damage. Two serious injuries, six minor injuries.

Visual meteorological conditions prevailed for the departure from an airport in the United States, and an instrument flight rules flight plan had been filed for the flight to Spain. During the initial climb, at about 1,500 feet, the no. 2 engine fire-warning light illuminated. The flight crew discharged both no. 2 engine fire-extinguisher bottles, but the light remained illuminated. The flight crew declared an emergency and conducted an emergency landing at the departure airport.

After landing, the crew began an emergency evacuation of the 386 people in the airplane. The report said that they planned to evacuate passengers using the five evacuation slides on the right side of the airplane. Two of the slide/rafts, however, did not operate properly, and neither was used for the evacuation.

An examination of the airplane revealed that there had been a fire involving the no. 2 engine accessory gearbox. Most of the accessory gearbox case was consumed by fire, and the underside of the engine was damaged. Investigation of the accident was continuing.

Air Taxi Commuter

Elevator Control Cables Found Severed After Lightning Strike

Embraer EMB-145LR. Minor damage. No injuries.

Night instrument meteorological conditions prevailed for the instrument flight rules flight in the United States. The captain said that the airplane was being flown on descent and was between 13,000 feet above mean sea level (MSL) and 11,000 feet MSL on an instrument approach to an airport.

There was rain and snow, and the airplane's weather radar was operating. The flight crew had not observed lightning for about 20 minutes, and the weather radar did not depict any thunderstorm cells. The report said that the airplane was "noticeably struck by lightning."

The flight instruments and the autopilot appeared to continue functioning normally, and no caution messages were observed. The flight was continued to the destination airport, where "more than usual force" was required to flare the airplane for landing, the report said. The report also said that during the landing rollout, the gust lock could not be engaged and the elevator stuck in a "middle position."

An inspection revealed that two of the four elevator-control cables had been severed and that there was a "baseball-size" hole in the left elevator, the report said.

Pilot's Distraction Cited in Landing-gear Accident

Piper PA-31-350 Chieftain. Substantial damage. No injuries.

The airplane was one of six aircraft operated by the same company that departed about the same time from the same airport in Australia with the same destination. (The accident aircraft was being flown on a scheduled passenger flight; the five other aircraft were being flown on charter flights.) The Chieftain was the first airplane to approach the destination airport.

The pilot said that he conducted a global positioning system (GPS) instrument arrival because clouds were too low for a normal visual approach. He said that he extended the landing gear as required by company standard operating procedures (SOPs) and the airplane checklist. The airplane was flown out of clouds about two nautical miles (3.7 kilometers) from the airport at about 1,000 feet, and the pilot conducted a left circling approach to Runway 19. He retracted the landing gear before conducting the circling approach. Late in the landing flare, the pilot heard the landing-gear warning horn and the sound of metal scraping the runway. He conducted a go-around, extended the landing gear and landed the airplane. Damage was reported to both propellers, radio antennas beneath the fuselage and inboard sections of the flaps.

The accident report said that throughout the descent and approach, the pilot was responding to questions from pilots of the five other aircraft about the cloud base and weather, and listening to the air traffic control radio frequency. He said that light rain had reduced visibility and had increased his workload. The report said that the pilot was "probably distracted by the radio broadcasts and weather conditions at the time, which resulted in [his] forgetting to lower the landing gear."

After the accident, the company introduced new procedures for traffic separation between company aircraft, for reducing radio frequency congestion and for actions following a propeller strike.

Smoke, Fumes Prompt Return to Departure Airport

Avro 146-RJ100. No damage. No injuries.

The airplane was deiced at an airport in England before the flight crew's arrival for a flight to the Netherlands. In preparation for departure, the flight crew configured the airplane for taxi and takeoff using bleed air from the auxiliary power unit (APU) for cabin air conditioning, as required by the operator's standard operating procedures.

During takeoff, the crew smelled an odor "similar but not identical to deicing fluid," the incident report said. When the odor became stronger, the captain changed the conditioning air supply from the APU to the engines. At the same time, he observed smoke at the base of a left-hand windshield panel. He declared an emergency, and the flight crew donned oxygen masks.

The smoke dissipated before the crew had completed the "Smoke or Fire on Flight Deck" checklist. They returned to the departure airport and conducted a normal landing.

An examination of the airplane revealed that the APU intake and the surrounding area were flooded with deicing fluid, which also had entered the air-conditioning system. The APU was operated on the ground for about 40 minutes to dissipate the odor; there was no smoke.

A similar incident occurred later the same day in another of the company's Avro 146-RJ100s. That airplane also had been deiced before takeoff. The flight crew observed smoke and fumes soon after takeoff, donned oxygen masks and returned to the departure airport. An examination revealed deicing fluid around the APU intake and exhaust.

"The elapsed time between aircraft deicing and takeoff suggests that in both cases, deicing fluid was carried toward the APU intake by the airflow generated along the fuselage during the takeoff run," the report said.

After the incidents, the operator changed procedures so that APU air is not typically selected for takeoff after deicing. The operator also provided additional training to the deicing staff and complied with the aircraft manufacturer's service bulletin 53-163-50299A to divert fluid from the APU intake.

Seaplanes Collide en Route to Tourist Area

De Havilland DHC-2 Beaver. Minor damage. No injuries.
De Havilland DHC-3 Turbine Otter. Substantial damage. No injuries.

Visual meteorological conditions prevailed for the departures of both airplanes from a seaplane base in the United States. Both airplanes were float-equipped, and both were being flown on charter flights, carrying cruise-ship passengers to a bear-viewing area.

The DHC-2 was the first of three company airplanes to leave the airport; the DHC-3 departed about three minutes later. The pilot of the DHC-2 said that after he had flown a distance from the departure airport, he began monitoring a common traffic advisory frequency (CTAF). The accident report said that about 15 minutes after departure, while flying the airplane in level, cruise flight about 2,000 feet above a channel, he felt "a sudden thump, followed by a pronounced airframe shudder."

The report said, "[The DHC-2 pilot] said that he originally thought this was just the airplane flying through turbulence but immediately observed the top of the left wing of the DHC-3 … to his left side, just under the floats of his airplane."

The pilot said that because he had full flight control, he flew the airplane to the departure airport. He said that he called the pilot of the DHC-3 on the CTAF but received no response.

The pilot of the DHC-3 said that he was flying the airplane about 2,200 feet above the channel when he heard a passenger yell "airplane."

"About two seconds later, the pilot heard a loud scrape on the top portion of the airplane," the report said. "He then started a descending left turn while attempting to transmit a 'mayday' radio call on the [CTAF]."

The pilot said that he regained "partial control" of the airplane and landed it on the waters of the channel. He then assessed the damage and determined that he could step-taxi (a high-speed taxi in a float-equipped airplane) the airplane over the water to the departure airport.

Post-accident inspections revealed that the DHC-2 had received minor damage to the undersides of both floats. The DHC-3 had received substantial damage to the tops of both wings, the fuselage and the vertical stabilizer; in addition, communications antennas that were mounted on the tops of the wings and fuselage were destroyed.

Corporate
Business

'Jerking Motion' Felt as Airplane Departs Runway During Landing

Piper PA-46-350P Malibu Mirage. Substantial damage. No injuries.

Visual meteorological conditions prevailed and an instrument flight plan had been filed for the flight to an airport in the United States. The pilot said that during landing, as the nose wheel contacted the runway, he felt "a hard bump, followed by a violent jerking motion to the left." The airplane departed from the runway on the left side and stopped parallel to the runway.

A preliminary investigation revealed that the bottom of the engine cowling, the air inlet and the nose-landing-gear doors were scraped; the tips of the propellers were bent, and the outboard eight inches to 10 inches (20 centimeters to 25 centimeters) of the propellers were scratched; and the right side of the nose-gear-actuator aft attach point had separated from the tube cluster on the mount assembly. The actuator had been pushed aft into the firewall, and a three-inch by 12-inch (7.6-centimeter by 30-centimeter) section of the firewall behind the nose-landing-gear actuator was crushed upward.

Airplane Strikes Volcano During Approach

Cessna 310R. Destroyed. Five fatalities.

Visual meteorological conditions prevailed for the mid-morning departure of the business flight from an airport in Guatemala, and an instrument flight rules flight plan had been filed. About four minutes before the accident, the pilot had told air traffic control that the airplane was about 12 nautical miles (22 kilometers) from the destination airport in El Salvador and that he was flying the airplane in a descent through 4,000 feet.

Wreckage of the airplane was found on the slope of a volcano just below 4,000 feet. The mountains were obscured when the accident occurred.

Engine-fire Warning Prompts Emergency Landing

Cessna 560 Citation V. Minor damage. No injuries.

The airplane was being flown through 12,000 feet after departure from an airport in Canada when the left-engine fire-warning light illuminated. The crew reduced power in accordance with the checklist and the light extinguished, indicating that there was not a fire but a bleed-air leak.

The crew declared an emergency and landed the airplane at an en route airport. An inspection by maintenance personnel revealed that a gasket on a bleed-air line was damaged and improperly seated and that the bleed-air line was too close to the fire-sensing element. (The engines had been replaced not long before the incident.)

The gasket was replaced, the bleed-air line was repositioned, and tests were conducted on the ground and in the air before passengers boarded and the flight was resumed. About seven minutes after takeoff, as the airplane was flown through 15,000 feet, the left-engine fire-warning light illuminated. When the crew reduced power, the light extinguished. The crew returned the airplane to the same en route airport, where maintenance personnel found a badly seated connector on the fire-detector control unit in the aft fuselage. The connector was reinstalled, and the airplane was returned to service.

Other General Aviation

Airplane Flips on Taxiway in 46-Knot Crosswind

Piper J4A. Minor damage. No injuries.

The airplane was one of several vintage aircraft being flown from an airport in Scotland. High winds and low clouds on the morning of the flight had delayed the departures. At 1500 local time, one hour before the airport was to close, the surface wind was from 190 degrees at 23 knots and the en route weather had improved; the pilots decided to depart.

The pilot of the accident airplane began to taxi at 1530, when winds were from 200 degrees at 20 knots, and conducted a 180-degree turn to leave the parking space and to begin a crosswind taxi to Runway 25. Air traffic control reported at 1535 that winds had increased to 25 knots, and several minutes later, to 32 knots.

The report said, "Other aircraft in the group started to have problems with the strength of the wind, and the accident aircraft began to rock badly. The pilot started having difficulty holding the stick in position, and he therefore brought the aircraft to a halt, set the throttle to idle and applied the brakes with the aircraft heading approximately 330 degrees. He considered turning the aircraft into the wind, but … was concerned about how the aircraft would react as he turned it through 90 degrees to the wind."

The wind increased to 46 knots, and the airplane moved left, the left wing lifted and the airplane flipped inverted.

The pilot told investigators that the accident might have been prevented if he had turned the airplane into the wind when the wind speed increased to 25 knots.

Airplane Rolls Over Chocks, Into Hangar Wall as Pilot Swings Propeller

Jodel D.112. Substantial damage. One minor injury.

The airplane was being prepared for departure from an airport in England for the return leg of a round-trip flight. The airplane did not have a starter motor or a hand brake, so the pilot placed chocks in front of the main wheels and used a seat belt to hold the control column in the aft position before hand-swinging the propeller to start the engine.

The report said, "The engine proved reluctant to start and became flooded on two or three occasions. Following each of these events, the pilot adopted his usual procedure of opening the throttle and pulling the propeller backward in order to clear the cylinders. Prior to his final attempt … the pilot checked that the throttle was just in the open position and that the friction was only slightly tightened."

After the pilot swung the propeller, the engine started and accelerated, and the airplane rolled forward over the chocks. The pilot ran toward the left wing tip "in an attempt to arrest its advance," the report said. When the pilot touched the left wing, however, the tail wheel began moving, the airplane turned, and the right wing tip struck the pilot. The airplane stopped when it struck a hangar wall.

The pilot said that he had started the airplane many times by swinging the propeller and that he had done nothing unusual on this occasion. He said that the engine probably started when it was flooded and that vibration moved the throttle toward the open position.

Rubber Disc Found in Fuel Tank After Loss of Power

Sukhoi Su-26M2. Substantial damage. No injuries.

The airplane was being flown in formation with another airplane at 2,400 feet after departure from an airport in England when the pilot moved the fuel selector from the main tank to the M2 tank. (The airplane has two fuel tanks in the fuselage — the main tank and the M2 tank.) Fuel pressure decreased, and the engine lost power. The pilot conducted an emergency landing in a field. After touchdown, the landing gear contacted ruts left in the ground by the wheels of an agricultural vehicle; the landing gear collapsed and punctured the M2 fuel tank.

An inspection revealed a rubber disc 1.5 inches (3.8 centimeters) in diameter inside the M2 fuel tank.

The accident report said, "It had the characteristics of being the center part of a 'homemade' gasket, which appeared to have been cut out to form the aperture, but after the gasket had been installed. It is believed that this piece of rubber had fallen into the tank and blocked the tank outlet, interrupting the flow of fuel to the engine. It was not possible to establish when the gasket had been installed."

Airplane Veers off Runway Onto Beach After Pilot's Loss of Control

Piper PA-23-250B Aztec. Substantial damage. No injuries.

Visual meteorological conditions prevailed for the morning flight from the U.S. Virgin Islands to the British Virgin Islands. The pilot said that, because of a direct crosswind, he had flown the airplane at a slightly faster-than-usual airspeed on final approach. The airplane landed hard, then bounced about three times.

The pilot said that he had difficulty controlling the airplane in the crosswind and that he applied power for a go-around. The airplane did not climb and instead veered off the runway and across a rocky beach, stopping in about three feet or four feet (0.9 meter or 1.2 meters) of water.

Floatplane With 'Heavy' Float Fails to Gain Altitude

Cessna 185 Skywagon. Substantial damage. Minor injuries.

The float-equipped airplane was being flown from a lake in Canada. The pilot knew that one of the five compartments of the right float leaked, and he pumped out water before the flight. He also checked the other compartments and found no abnormalities.

The report said that during the takeoff run, the right float was "heavy and may have been partly submerged." The right wing remained low as the airplane was flown to an altitude about five feet to 10 feet above the water. Then the right wing "dropped abruptly" and struck the surface of the water. The airplane flipped inverted. The pilot told his two passengers to open the airplane's doors; the pilot and both passengers exited the airplane.

Rotorcraft

Plastic or Rubber in Fuel System Cited in Engine Failure

Aerospatiale AS 350B2. Destroyed. One minor injury.

The helicopter was being flown in a lime-spreading operation in Sweden. After delivering several loads of lime, the helicopter was landed near the lime-refilling station for fueling.

After fueling, the pilot lifted the helicopter into a hover and flew it into the wind, intending to land at the lime-refilling station. About 98 feet above ground level, the engine failed. The pilot began an autorotation, intending to land the helicopter on a nearby road. The helicopter speed decreased, and the helicopter struck trees and terrain and tipped onto its right side in a ditch.

An investigation revealed no technical reason for the engine failure. The report said that the fuel line connecting the fuel-control unit and the combustion chamber injector wheel was "partially clogged with coke that consisted of the carbonized remains of spent rubber and/or plastic. … This would indicate that a small piece of plastic or rubber entering the engine fuel system and blocking the flow of fuel to the injector wheel could have caused the engine failure."

The report said that investigators could not determine when or how the rubber or plastic entered the fuel system. The report said that the accident was caused by "an engine failure occurring at low speed and height" and that the engine failure probably was caused by plastic or rubber in the fuel system.

Broken Tie-down Chain Found at Site of Takeoff Accident

Robinson R44. Substantial damage. No injuries.

Visual meteorological conditions prevailed for the late-morning takeoff from an airport in the United States. The pilot said that he lifted the helicopter to a hover four feet or five feet above the ground and turned the helicopter 10 degrees left.

The report said that the pilot "pushed forward on the cyclic to initiate forward flight, and in a matter of 10 feet to 15 feet, the rear portion of the left skid went down abruptly." The pilot added forward right cyclic to compensate, and the helicopter began to level at two feet to three feet, then settled hard on the front portion of the left skid.

The report said that an investigator at the accident site found "a broken tie-down chain … that had been attached to the aft portion of the helicopter skid." The pilot said that he had not placed the chain there the night before the accident. An inspection of the helicopter showed that the lower portion of the vertical stabilizer was wrinkled, that there was a tear in the leading edge, that the left side of the fuselage was damaged near the forward-skid cross tube and that the main-rotor mast fairing had buckled.

Engine Failure Prompts Emergency Landing

Bell 206B JetRanger III. Minor damage. One minor injury.

The helicopter was being flown on approach to a heliport in England and was at 1,000 feet, about 1,400 meters (0.75 nautical mile) from the runway, when the pilot heard loud popping and banging noises from the engine, accompanied by a loss of power.

The pilot lowered the collective lever to begin autorotation and declared an emergency. During descent, he observed that the turbine outlet temperature was between 950 degrees Celsius (C; 1,742 degrees Fahrenheit [F]) and 1,000 degrees C (1,832 degrees F).

The report said that between 200 feet and 300 feet, the pilot "raised the collective lever, but there was no response from the engine" and that the low-rotor revolutions per minute warning horn sounded. The helicopter was at 10 feet over the landing platform, and the pilot began a flare to prevent the helicopter from overrunning the runway and raised the collective lever to cushion the touchdown. The aircraft "fell vertically from about five feet, achieving a very firm zero-speed landing," the report said.

An investigation determined that the compressor bleed valve had failed in the closed position, resulting in a compressor stall.

Pilot Struck by Rotor Blade While Aiding Injured Crewmember

McDonnell Douglas (Hughes) 369E. Minor damage. One serious injury, one minor injury.

The helicopter had been flown to a private landing site in England, where the two rear-seat passengers disembarked. As the passengers exited the helicopter, the crewmember in the right-front seat, who was an experienced helicopter pilot, disembarked to assist them, and the pilot reduced engine power to flight idle.

As the crewmember climbed back into the helicopter, he struck his head on the doorframe and received a cut that began to bleed heavily. He then disembarked and walked to the front of the helicopter.

The accident report said, "The pilot, in the left seat, seeing that his colleague's head wound was bleeding heavily, decided to shut down the engine and go to his assistance. The helicopter was not fitted with a rotor brake. While the main rotor was still slowing down, the pilot disembarked and walked toward his colleague, who was standing ahead and just to the right of the nose of the helicopter. As the pilot approached the edge of the rotor disc, he was struck on the back of the head by a main-rotor blade and sustained a serious head injury."

The pilot said later that he had landed the helicopter into a 20-knot easterly wind and that there was a four-foot-high earthen mound about 20 meters (66 feet) in front of the landing site. The pilot said that the mound helped generate turbulence that caused the main-rotor blades to "sail" as they slowed.

The report said that although the helicopter was equipped with high skids and normally had a rotor-tip height of 10 feet, in this instance, there was considerably less rotor-tip clearance.

"In light of this experience, both occupants expressed the opinion that no person should enter or leave a helicopter until the main rotor has stopped," the report said.♦

Call for Nominations

Flight Safety Foundation–Airbus Human Factors in Aviation Safety Award

The Flight Safety Foundation–Airbus Human Factors in Aviation Safety Award was established in 1999 to recognize "outstanding achievement in human factors contributions to aviation safety." The award was instituted to encourage human factors research that would help reduce human error — one of the most common elements in aviation accidents.

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