BY LINDA WERFELMAN

Error Management

Only in recent years have aviation maintenance errors been recognized as a symptom of wider problems in the workplace.

Maintenance error presents a "significant and continuing threat" to aviation safety, and effective management of the threat requires the proactive identification of "error-producing conditions" and an acknowledgment that maintenance error will never be completely eliminated, according to an Australian Transport Safety Bureau (ATSB) report.[1]

The report on human factors in aviation maintenance, by Alan Hobbs, said that until recently, maintenance technicians have rarely received human factors training, and maintenance personnel have been largely overlooked by human factors researchers, who focused instead on pilots, air traffic controllers and cabin crew.

The report described the aviation maintenance environment as more hazardous than most other work environments, in part because of time pressure but also because duties often are performed in difficult situations — at heights, in confined spaces and in extreme cold or heat. In addition, although some aspects of the work are physically strenuous, clerical skills and attention to detail are required, along with good communication — even in very noisy areas.

"Maintenance personnel also face unique sources of stress," the report said. "Air traffic controllers and pilots can leave work at the end of the day knowing that the day's work is complete. In most cases, any errors they made during their shift will have either had an immediate impact or no impact at all. In contrast, when maintenance personnel leave work at the end of their shift, they know that the work they performed will be relied

© Chris Sorensen Photography

on by crew and passengers for months or years. … The emotional burden on maintenance personnel whose work has been involved in accidents is largely unrecognized outside the maintenance fraternity. On more than one occasion, maintenance personnel have taken their own lives following aircraft accidents caused by maintenance error."

Tracking Human Error

The first step in understanding how maintenance errors occur is understanding the organizational context in which they occur, the report said. An individual's actions, which may trigger an accident or incident, are influenced by local conditions, such as communication and working conditions; risk controls, such as procedures and precautions designed to manage hazards; and organizational factors, such as management decisions and resource allocation (see "Major Maintenance-Related Crashes," p. 28).

"In many cases," the report said, "maintenance errors are symptoms of underlying problems within the organization."

Descriptions of errors often are *physical* descriptions — which describe the observable actions of the person who made the error and assign them to one of three categories: acts of commission in which an action is performed that should not have been performed, such as cross-connecting cables; acts of omission in which an action that should have been performed is left undone, such as failing to secure an oil cap; and acts of timing and precision in which actions are performed "at the wrong time, in the wrong order or without the necessary level of precision," such as using the wrong torque setting on a wrench to secure a fastener, the report said.

Another way of describing an error is with a *psychological* description — which evaluates the likely intentions of the person who made the error. "For example," the report said, "rather than just concluding that an engineer did not secure a plumbing connection, we would try to understand their mind set at the time of the error. … We would want to know: Did they forget? Did they intend to leave it loose? Did they assume that a colleague was going to complete the task? Obviously we can never know for certain what a person was thinking, but we can usually make reasonable judgments."

One advantage of using psychological error descriptions is that they "enable us to place the error in its organizational context and then develop countermeasures tailored to the root causes of the problem," the report said.

"For example, if we conclude that someone did not perform a necessary action because they forgot, we might consider the prompts to memory available to them, such as documentation. We might also consider what could be done in [the] future to catch similar memory lapses.

"If, on the other hand, we conclude that a person did not perform a necessary action because they thought the procedure did not require it, our investigation might lead us to organizational issues such as training or procedure design."

The report identified six types of psychological errors that are relevant to maintenance:

- Errors of perception, in which a person fails to detect an item he or she should have noticed, such as a worn tire or a visible crack in a metal part;
- Memory lapses, in which a person forgets to perform an intended action, such as forgetting to reconnect a disconnected system after a maintenance task is completed;

Continued on page 30

Major Maintenance-Related Crashes

Aloha Airlines 737, April 1988

The Australian Transport Safety Board (ATSB) cited several accidents and incidents associated with human aspects of aviation maintenance, including the April 1988 explosive decompression of an Aloha Airlines Boeing 737-200 — an accident that revealed the human factors of inspection and maintenance as a major safety issue.[1]

The decompression, during a flight from Hilo, Hawaii, U.S., to Honolulu, ripped an 18-ft (5-m) section of cabin skin away from the airplane. One cabin crewmember was killed. The flight crew diverted the airplane to Maui for an emergency landing.

The accident investigation found that the accident was a result of the airline's failure to detect the disbonding and fatigue damage that ultimately led to the separation of the section of fuselage.

'Dormant' Errors

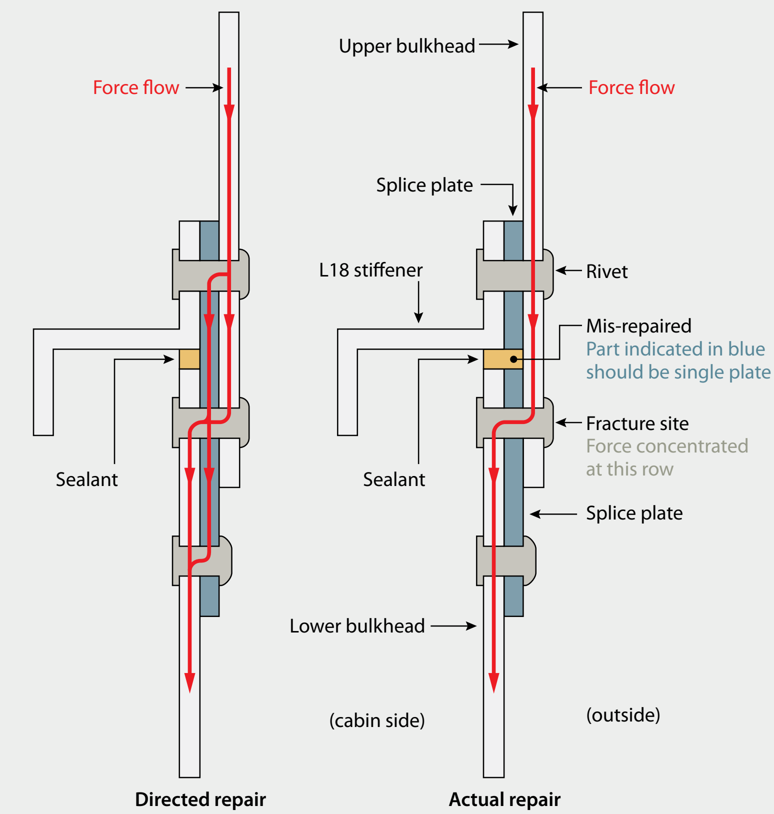
Three years earlier, in August 1985, a Japan Airlines 747-100 crashed, killing 520 people — the greatest number of fatalities in any single-aircraft accident.

The airplane was in cruise flight at 24,000 ft during a domestic flight from Tokyo to Osaka when a rear pressure bulkhead failed, causing a sudden decompression that resulted in the separation of most of the airplane's vertical stabilizer and rudder and the loss of pressure from all four hydraulic systems.

The flight crew tried to steer the 747 using engine power, but they were unable to maintain control. About 30 minutes after the decompression, the airplane struck a mountain northwest of Tokyo.

Investigators attributed the failure of the bulkhead to a fatigue fracture in an area that had been repaired following a tail scrape years earlier.

"The repair had included replacing the lower half of the bulkhead," the ATSB report said. "The new lower half should have been spliced to the upper half using a doubler plate extending under three lines of rivets. However, part of the splice was made using two plates instead of a single plate, as



Note: Faulty repair work on a Japan Airlines 747-100 was cited in an August 1985 crash that killed 520 people.

Source: Australian Transport Safety Board, citing Kobayashi, H.; Terada, H. *Crash of Japan Airlines B-747 at Mt. Osutaka* (2006). In Japan Science and Technology Agency Failure Knowledge Database.

intended. … As a result, the join relied on only a single row of rivets."

After that repair, the airplane was flown more than 12,000 flights and underwent six C checks — major maintenance checks that included visual inspections of the airframe, including the rear pressure bulkhead — before the accident, which the ATSB report said "highlighted the potential for maintenance errors to remain dormant for long periods before having their effect."

Japan Airlines 747, August 1985

Windshield Failure

In June 1990, the windshield of a British Airways BAC-111 was blown out during climb to cruising altitude after departure from Birmingham, England, for a flight to Málaga, Spain, partially ejecting the captain through the broken window. Flight attendants held him in place while the first officer flew the airplane to Southampton Airport for an emergency landing.

The accident investigation found that, during maintenance the previous night, a shift manager had used smaller-than-specified bolts to hold the windshield in place.

"The manager's errors did not occur in isolation, however," the ATSB report said. "The mobile stand set up at the aircraft did not give easy access to the windscreen, and the shift manager had to stretch to install the bolts, giving him a poor view of his work. Partly as a result of this, he did not notice the excessive amount of countersink left unfilled by the small bolt heads."

The ATSB report said that the accident highlighted issues involving parts storage, night shift work, staffing levels and the involvement of supervisors in hands-on maintenance.

Rigging Error

In January 2003, an Air Midwest Beech 1900D crashed after takeoff from Charlotte, North Carolina, U.S., killing all 21 people in the airplane.

The accident investigation found that the pilots had been unable to control the airplane's pitch attitude, partly because its center of gravity was outside limits and partly because the elevator control system had been incorrectly rigged during maintenance two days before the crash.

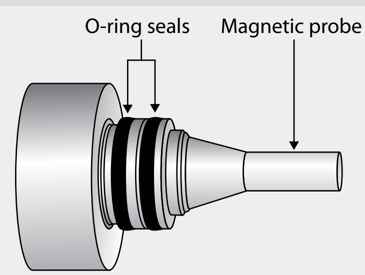
The maintenance work was performed by a technician who had not done the task before and who, in tightening the cables, "inadvertently restricted the amount of nose-down elevator travel," the ATSB report said, adding that the accident highlighted "the difficulties of capturing maintenance errors once they have been made."

Missing O-Rings

In May 1983, an incident involving an Eastern Airlines Lockheed L-1011 illustrated "the potential for preventative maintenance to introduce risk, and how a single error could be carried across multiple systems," the ATSB said.

The L-1011 was descending to Nassau, Bahamas, after a flight from Miami with 172 people aboard, when the "LOW OIL PRESSURE" light for the center engine illuminated. The captain shut down the engine and decided to return to Miami; en route, at 20,000 ft, the "LOW OIL PRESSURE" lights for the two wing-mounted engines illuminated, and both engines flamed out. The passengers were told to prepare for a ditching, but at 4,000 ft, the crew restarted the center engine; minutes later, they landed the airplane at Miami International Airport. No one was injured.

Investigators found that magnetic chip detectors (MCDs) had been installed without O-rings on all three engines and that, as a result, oil leaked from the engines during flight. The maintenance personnel involved in the task assumed that O-rings were — as



Note: The installation of magnetic chip detectors without O-rings was cited in a May 1983 incident involving an Eastern Airlines Lockheed L-1011.

Source: Australian Transport Safety Board, citing Marx, D.; Graeber, R.C. "Human Error in Aircraft Maintenance." In N. Johnson, N. McDonald and R. Fuller (editors). *Aviation Psychology in Practice* (1994): 87–104. Aldershot, U.K.: Ashgate, 1994.

usual —attached to the replacement MCDs, the ATSB report said, noting that another complicating factor was the fact that the replacement MCDs were installed by feel, "with no direct view of the task."

The MCD replacement was performed in accordance with the airline's practice of removing and inspecting MCDs "at 22-hour intervals, whenever the aircraft overnighted at an Eastern Airlines maintenance station," the ATSB report said. The inspections were designed to check for the presence of metal particles — an early warning of engine failure.

Estimates were that, in the 18 months that the practice had been in place, maintenance technicians had performed the task an average of 100 times each. The airline had experienced 12 incidents of in-flight engine shutdowns and unscheduled landings because of problems with O-rings and MCD installation. The ATSB quoted the U.S. National Transportation Safety Board accident report, which said, "In every incident … management investigated the circumstances and concluded that the problem was with the mechanics and not with the maintenance procedure."

The ATSB added, "Rather than addressing the wider system problems such as poor procedures and undocumented norms, the incidents resulted in individual disciplinary action and training."

— LW

Note

1. Hobbs, Alan. *An Overview of Human Factors in Aviation Maintenance.* ATSB Transport Safety Report, AR-2008-055. December 2008.

- Slips, in which a familiar skill-based action is absent-mindedly performed at an unintended time or place, such as automatically signing off a task while not intending to do so;
- Technical misunderstandings, in which a maintenance technician does not possess the knowledge required to perform a given task;
- Wrong assumptions, in which a person misidentifies a familiar situation, such as incorrectly assuming that a colleague will perform a specific step in an assigned task — for example, assuming that the power supply will be disconnected by a colleague who always does so; and,
- Procedure violations, in which someone strays from the specified process for accomplishing a task, either in a way that is *routine,* such as driving a few kilometers faster than the speed limit, or *exceptional*, in response to an unusual situation.

Past surveys of maintenance personnel in Australia, Europe and the United States have indicated that procedure violations are widespread, and that they often are committed in an effort to complete a task on time, the report said.

"The issue of maintenance violations is one of the most difficult human factors issues currently facing the aviation industry," the report said. "Yet many aviation professionals outside the maintenance field are either unaware of the issue or else take a simple moralistic approach when they hear of the extent to which maintenance workers routinely deviate from procedures to accomplish tasks. Maintenance personnel are often confronted with a double standard of task performance: On the one hand, they are expected to comply with a vast array of requirements and procedures while also being expected to complete tasks quickly and efficiently."

Local Conditions

Individual actions — and individual errors — typically reflect local conditions in the workplace when the actions are taken.

One of the most common conditions is time pressure, which sometimes leads maintenance technicians to use a procedural shortcut to complete a job more quickly and enable an on-time aircraft departure. As an example, the report cited the following event, which was reported to the U.S. National Aeronautics and Space Administration Aviation Safety Reporting System:

> *I was notified by my shop steward that the hydraulic shutoff valve I removed from a Fokker 100 was the same serial number of the new parts tag. … I removed the valve from the aircraft during which I had gotten [hydraulic fluid] in my eyes and could not see for about 30 minutes. I tried to keep working because time was short and I needed to complete the job [as soon as possible]. I apparently installed the old valve back on the aircraft. I completed a flap test with no faults.*

Other local conditions include "unworkable or awkward" procedures described in manuals — a problem often cited by maintenance personnel as leading to a procedural violation; misunderstandings and ineffective communication with coworkers; group norms, or unspoken informal rules about how work is done in a specific workplace; fatigue, especially fatigue associated with long work shifts and/or working at night; insufficient knowledge or training for a specific task; and a lack of specialized tools for the job, the report said.

Risk Controls

Risk controls are the defenses established in the workplace to manage safety hazards. In aviation maintenance, most controls are one of two types: preventive risk controls, which are designed to reduce the chances of human error — for example, streamers attached to rigging pins to help maintenance personnel notice the pins and remember to remove them — and recovery risk controls, designed to identify a developing dangerous situation and prevent it from continuing — for example, functional checks.

Other actions, such as read-backs of verbal instructions, also can help identify errors. However, the report said, "checks, inspections and read-backs rely on human performance and are themselves subject to human fallibility. In a survey of airline maintenance personnel, over 30 percent of respondents reported that they had skipped a required functional check (such as an engine run) in the preceding 12 months."

Risk controls differ in their effectiveness, the report said, noting that engineered solutions, such as reverse threaded connections that prevent two parts from being connected, usually are more reliable than self-checks of work.

Organizational Influences

The report said that investigations of airline accidents and incidents involving maintenance actions often have identified organizational factors in those events, including training and qualifications systems, allocation of resources and the culture within the organization.

"For example, a maintenance violation, such as using an incorrect tool, may occur because the correct tool was not available, which in turn may reflect equipment acquisition policies or financial constraints," the report said. "One of the most common reasons given for maintenance violations is time pressure, and this in turn may be symptomatic of organizational conditions such as planning, staffing levels or work scheduling."

New Emphasis on SMS

The first human factors training courses for maintenance personnel were not offered until the 1990s, about 20 years after airlines begin providing similar instruction for flight crewmembers, the report said. This early training in maintenance resource management emphasized communication skills and assertiveness, stress management and conflict resolution.

More recent human factors training has been developed in the aftermath of new requirements by the International Civil Aviation Organization and national civil aviation authorities for maintenance personnel to understand human factors principles. In some cases, this training has been incorporated into development of an organization's safety management system (SMS) — a coordinated approach to managing safety that includes an emphasis on error management and development of a just safety culture.

SMS typically includes a nonpunitive confidential reporting system to encourage disclosure of events that may present threats to safety, and the report said that the industry is making progress in developing such systems.

"If a maintenance engineer has a difficulty with a maintenance procedure at 3 a.m. in a remote hangar, the problem may remain unknown to the organization unless the engineer chooses to disclose the issue," the report said. "Once a maintenance error has been made, years may elapse before it becomes apparent, by which time it may be difficult to establish how it occurred."

The report said that the "culture of maintenance around the world" has discouraged the reporting of problems.

"This is because the response to errors has frequently been punitive," the report said. "In some companies, common errors such as leaving oil filler caps unsecured will result in several days without pay or even instant dismissal. It is hardly surprising that many minor maintenance incidents are never officially reported."

The report cited a 1998 survey of Australian maintenance personnel in which more than 60 percent said they had corrected an error made by a colleague but never documented their action because they hoped to avoid any disciplinary action against the colleague.

The organizational response to maintenance error should involve efforts to identify and counteract error-producing conditions, as well as an acknowledgement that maintenance error can be reduced but not eliminated.

"Airlines can learn to manage the inevitable threat of maintenance error in the same way they deal with natural hazards such as weather," the report said. "Organizational resilience in the face of human error can be maximized by ensuring that appropriate risk controls are in place to identify and correct errors and minimize the consequence of those errors that remain undetected despite the best efforts of the organization."

Note

1. Hobbs, Alan. *An Overview of Human Factors in Aviation Maintenance.* ATSB Transport Safety Report, AR-2008-055. December 2008.

Further Reading From FSF Publications

Werfelman, Linda. "Working to the Limit." *AeroSafety World* Volume 3 (April 2008): 14–18.

Johnson, William B.; Hackworth, Carla. "Human Factors in Maintenance." *AeroSafety World* Volume 3 (March 2008): 34–40.

McKenna, James T. "Maintenance Resource Management Programs Provide Tools for Reducing Human Error." *Flight Safety Digest* Volume 21 (October 2002).