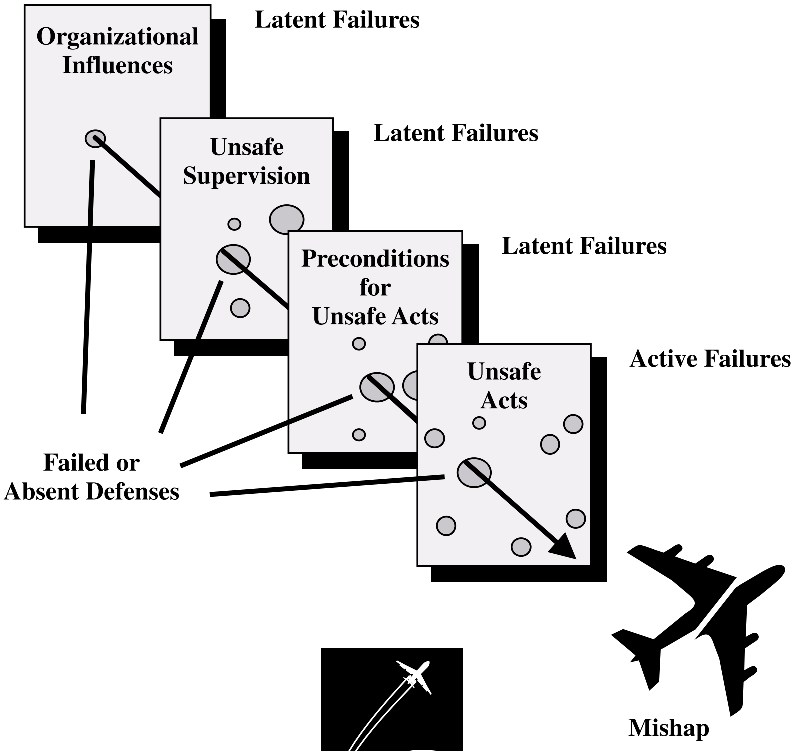
FLIGHT SAFETY FOUNDATION

FEBRUARY 2001

# FLIGHT SAFETY
# DIGEST

## Human Factors Checklist Provides Tool for Accident/Incident Investigation

## Human Factors Analysis and Classification System



FLIGHT SAFETY
FOUNDATION
SINCE 1947

FLIGHT SAFETY FOUNDATION

*For Everyone Concerned With the Safety of Flight*

**Officers and Staff**

**Carl W. Vogt**
*Chairman, Board of Governors*

**Stuart Matthews**
*President and CEO*

**Robert H. Vandel**
*Executive Vice President*

**James S. Waugh Jr.**
*Treasurer*

ADMINISTRATIVE

**Ellen Plaugher**
*Executive Assistant*

**Linda Crowley Horger**
*Manager, Support Services*

FINANCIAL

**Crystal N. Phillips**
*Director of Finance and Administration*

TECHNICAL

**James Burin**
*Director of Technical Programs*

**Joanne Anderson**
*Technical Assistant*

**Louis A. Sorrentino III**
*Managing Director of Internal Evaluation Programs*

**Robert Feeler**
*Q-Star Program Administrator*

**Robert Dodd, Ph.D.**
*Manager, Data Systems and Analysis*

**Darol V. Holsman**
*Manager of Aviation Safety Audits*

MEMBERSHIP

**Ann Hill**
*Senior Manager, Membership and Development*

**Kim Granados**
*Membership Manager*

**Ahlam Wahdan**
*Membership Services Coordinator*

PUBLICATIONS

**Roger Rozelle**
*Director of Publications*

**Mark Lacagnina**
*Managing Editor*

**Wayne Rosenkrans**
*Senior Editor*

**Linda Werfelman**
*Senior Editor*

**Karen K. Ehrlich**
*Web and Print Production Coordinator*

**Ann L. Mullikin**
*Production Designer*

**Susan D. Reed**
*Production Specialist*

**Patricia Setze**
*Librarian, Jerry Lederer Aviation Safety Library*

**Jerome Lederer**
*President Emeritus*

# Flight Safety Digest

**Vol. 20 No. 2** **February 2001**

## In This Issue

### Human Factors Checklist Provides Tool for Accident/Incident Investigation 1

*The checklist can be used in the formulation of safety programs that address key factors related to the prevention of recurring flight crew errors.*

### Human Factors Analysis and Classification System 15

*HFACS was developed as a framework for safety research to support the design of new investigative methods and accident/incident databases to systematically examine human error in aviation safety.*

### Data Show 421 Fatal Accidents Involving Large Jets and Turboprops in 1990s 29

*A study by the U.K. Civil Aviation Authority shows that the number of accidents each year during the period ranged from a low of 37 in 1998 to a high of 48 in 1995.*

### FAA Publishes Guidelines for Use of Barometric Vertical Navigation Equipment for Instrument Approaches 34

*The advisory circular describes the types of equipment that FAA considers acceptable.*

### Tire Leaves Wheel During Taxi for Takeoff 36

*The incident followed separation of the inboard rim of the Boeing 747's wheel.*

Cover: In what commonly is called the "Swiss cheese" model of human error causation, James Reason, professor of psychology at Manchester (England) University, describes four levels of human error, each influencing the next.

Source: U.S. Federal Aviation Administration

*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 830 member organizations in more than 150 countries.*

# Human Factors Checklist Provides Tool For Accident/Incident Investigation

***The checklist can be used in the formulation of safety programs that address key factors related to the prevention of recurring flight crew errors.***

*Anthony P. Ciavarelli, Ed.D.*

When an aircraft accident occurs, investigators must attempt to learn what went wrong and why. Investigators are guided by their training and experience, and sometimes by various guidelines and template documents (see FSF *Human Factors Accident/Incident Checklist*, page 9).

The study of human factors in aviation safety has expanded over the years from the identification of pilot errors influenced by the design of the "knobs-and-dials" flight decks of the 1940s. Inadequate flight-deck design continues to affect aviation safety. In addition to the switch-selection errors and instrument-reading errors that have persisted since the knobs-and-dials era, however, today's "glass-cockpit" flight crews must avoid confusion in selecting among various automated aircraft system modes.

Beyond flight-deck design, pilot error and flight crew error have been traced to lapses of attention, noncompliance with standard operating procedures, inadequate training and inadequate crew resource management. Safety specialists now recognize that these types of errors often result from failures of organizational leadership/management.

Attention to flight-deck-design deficiencies should be an integral part of the accident/incident investigation, along with other possible influences on flight crew performance, including flight crew training and proficiency, adequacy of standards and procedures, decision processes, flight crew communication, physiological/medical impairment, supervisory practices, and other organizational factors, to name a few.

The FSF *Human Factors Accident/Incident Checklist* was derived directly from a comprehensive review of the literature on cognitive science and human performance, and an extensive review and analysis of military aircraft accidents and civilian aircraft accidents.

The checklist reflects the understanding of factors that affect individual pilot performance (see “Primer on Human Error Theory, page 3), including typical physiological phenomena such as high-altitude effects, flight acceleration (g) forces, spatial disorientation and loss of situational awareness, as well as psychological processes, including high-risk behavior and reactions to physical stressors and psychosocial stressors.

The checklist’s eight categories include a broad range of individual performance factors, team/flight crew performance factors and organizational performance factors, as described below.

**Sensory/Perceptual Factors** — These include human capabilities and limitations to see, hear and interpret correctly incoming visual, auditory and kinesthetic (muscular) sensory information. Performance factors include those related to perceptual judgment of altitude, aircraft attitude, distance, depth and object clearance.

Sensory/perceptual factors include visual cues that are absent or are misleading, acceleration/deceleration forces that affect vision and equilibrium, and sensory illusions. This category also includes perceptual errors and errors related to attention failures, spatial disorientation and loss of situational awareness.

> Example: A Beech C99 struck terrain about six nautical miles (11 kilometers) from the runway during a night visual approach to Moosonee (Ontario, Canada) Airport. The first officer was killed; the captain and both passengers received serious injuries. The Transportation Safety Board of Canada said, in its final report on the accident, that the “captain inadvertently flew the aircraft into trees during a condition of visual illusion, as a result of inadequate crew coordination in that neither pilot effectively monitored the approach.”[1] The report said that contributing to the accident was the captain’s unfamiliarity with the black-hole effect.[2]

Situational awareness refers to the flight crew’s accurate perception of the physical flying environment, alertness in monitoring and correctly predicting flight progress, and flight-deck-task completion. Loss of situational awareness is a factor in many approach-and-landing accidents (ALAs), including those involving controlled-flight-into-terrain (CFIT).[3] The FSF Approach-and-landing Accident Reduction Task Force found that lack of positional awareness was the primary causal factor of 19 percent of 279 fatal ALAs in 1980–1996 involving large jet and turboprop aircraft; lack of positional awareness was the second-most-frequent primary casual factor of the accidents.[4]

**Medical and Physiological** — This category includes potentially debilitating physiological factors (and psychological factors) resulting from aeromedical conditions such as oxygen deficiency; physical stressors such as noise, vibration, heat and cold; other physiological factors such as lack of sleep or inadequate rest, use of chemical substances (e.g., drugs and alcohol) and exposure to hazardous chemicals; and mental impairment or physical impairment caused by psychosocial stressors.

Human error in this category typically results from flying while ill, flying under the influence of drugs or alcohol, and exceeding physical-endurance limits or stress-coping limits.

> Example: A Douglas DC-8 freighter stalled and struck terrain during a visual approach to Guantanamo Bay, Cuba. The three flight crewmembers received serious injuries. The U.S. National Transportation Safety Board (NTSB) said, in its final report, that the probable causes of the accident were “the impaired judgment, decision making and flying abilities of the captain and flight crew due to the effects of fatigue; the captain’s failure to properly assess the conditions for landing and maintaining vigilant situational awareness of the airplane while maneuvering onto final approach; his failure to prevent the loss of airspeed and avoid a stall while in [a] steep bank turn; and his failure to execute immediate action to recover from a stall.”[5] The captain had been awake more than 20 hours; the first officer had been awake 19 hours; the flight engineer had been awake more than 23 hours.

**Knowledge and Skill** — Knowledge refers to the understanding of information and the ability to use information, including the procedures about aircraft systems, flying conditions, aircraft-performance limits, task requirements, weather, etc. Skill refers to the mental ability to perform tasks and task sequences at the correct time and in the correct order, and the physical ability to control the aircraft with the accuracy and precision required for specific conditions.

Human performance factors in this category include misinterpreting information, misconceiving information, forgetting or misapplying rules or instructions, using the wrong procedure for a given task or situation, omitting a step or steps in a specific sequence, and exercising inadequate flight control or loss of flight control because of inadequate proficiency or because of a failure to follow prescribed procedures required to achieve flying accuracy and precision.

> Example: A Beechcraft C99 struck a hillside while being maneuvered to land at Anniston (Alabama, U.S.) Metropolitan Airport. The captain and two passengers were killed; the first officer and two passengers received serious injuries. NTSB said, in its final report, that the probable causes of the accident were “the failure of senior management [of the airline] to provide adequate

> training and operational support … , which resulted in the assignment of an inadequately prepared captain with a relatively inexperienced first officer in revenue passenger service, and the failure of the flight crew to use approved instrument flight procedures, which resulted in a loss of situational awareness and terrain clearance."[6]

Research on human skill development — e.g., learning how to fly or how to operate complex electronic equipment — has provided insight on why pilots commit errors related to habit: As pilots progress in developing flying skills, the physical activities become automatic, causing some pilots to make control inputs "by habit" in certain situations.[7] For example, a pilot accustomed to a flight deck with the flap selector on the left side of the center console and the landing-gear selector on the right side of the center console could become confused when flying an aircraft in which the selector positions are reversed.

A pilot's lack of knowledge or skill may lead to unsafe actions, such as flying the aircraft into an unrecoverable stall, deviating from an established route or deviating from a prescribed flight profile.

**Personality and Safety Attitude** — Personality refers to stable patterns of behavior or persistent patterns of behavior that epitomize a person's interpersonal style and social interactions. Safety attitude refers to the combined belief, feeling and intended behavior toward safety. Although personality cannot be modified readily, attitudes can be changed by training and experience.

### Primer on Human Error Theory

Psychologists have formulated several human error models. Most human error models are based on research, case studies and theories of human performance on complex tasks, such as operating an aircraft or a nuclear power plant.

Areas of disagreement remain among scientists on the human error issue, but a reasonable consensus has been reached concerning some basic principles for classifying various forms of human failure in the operation and maintenance of complex systems.

Human error models or taxonomies are convenient systems of classification that help us organize the types of human errors that can be expected during the operation and maintenance of complex systems.

Various categories of human error are based upon our understanding of underlying physiological and psychological processes that govern our capabilities and limitations in sensory awareness, perception, memory and learning, information processing, motivation and emotional control, judgment, and decision making, as well as our abilities to lead others and communicate our ideas, and to work cooperatively with people.

One of the most influential human error models was developed by James Reason, a professor of psychology at Manchester (England) University.[1,2] Reason's "Unsafe Acts Model" includes the following *unintended actions*:

- *Slips* typically occur during the *execution phase* of task performance and involve errors of commission, in which an action does not proceed as planned. For example, a pilot inadvertently moves the landing gear selector instead of the flap selector during a touch-and-go landing. This type of error is believed to occur because the pilot's attention is diverted or is captured by some other mental activity or by an outside distraction; and,
- *Lapses* also typically occur during the execution phase of task performance but involve errors of omission, in which a known correct action is not taken. For example, a pilot does not extend the landing gear before landing. This type of error also is believed to occur because of inattention or diversion of attention.

Reason's Unsafe Acts Model includes the following *intended actions*:

- *Mistakes* occur during the *cognitive phase* or *conscious stage* of task performance and include such factors as inadequate risk assessment, an erroneous plan or use of an incorrect procedure. For example, a pilot is not advised of a notice to airmen concerning mountain landing field precautions and fails to observe a runway upslope; he or she flies a normal three-degree glide path (applied a typical rule) and lands short of the runway (because he lacked specific knowledge and misperceived risk and runway condition); and,
- *Violations* are different from the unintentional slips and lapses that are primarily problems with information processing and retrieval. Violations are considered to be related to motivation and attitude. For example, a military flight crew flies to their home town and performs an unauthorized air show (intentional violation of a safety standard). Of course, there are "degrees" of violation; Reason distinguishes minor *infractions* from *exceptional* violations.

Later development of Reason's model by Maurino, Reason, Johnston and Lee expanded the human error categories to include *perceptual error*.[3] A perceptual error occurs when a pilot, or an equipment operator, does not accurately perceive an event, condition or situation. For example, a pilot perceives incorrectly that the aircraft is higher than normal during an approach on a dark night without a visible horizon or ground-reference cues, when the aircraft actually is dangerously low. In the aviation environment, such perceptual errors also include spatial disorientation and loss of positional awareness or situational awareness.

Professional accident investigators have begun to move away from the idea that accidents are simply the result of errors made by the operator or the maintainer of a system. The human error accident, in many cases, is rooted in antecedents that are not necessarily in the hands of the worker. Maurino et al. have helped to bring into sharper focus the influence of organizational factors on accident causation. Their model of accident causation, for example, includes defining the link between *active failures* (errors made by operators and maintainers) and *latent failures* (failures at organizational levels and managerial levels).

Human error theory typically is based upon our understanding that there are several basic forms of human information processing, as defined below (adapted from Reason, 1990):

- *Controlled (knowledge-based)* information processing occurs under conscious control; responses are executed while "thinking about" the situation, evaluating alternatives and making decisions from a knowledge base. This mode of processing is characterized by internal verbalization about the task requirements when the pilot is learning a new procedure or encounters a novel situation. *Knowledge-based errors* include incorrect interpretation of information, inability to solve a problem because of insufficient knowledge or because of a specific problem-solving skill;

- *Rule-based* information processing occurs when we encounter familiar problems for which we have memorized specific procedures, or when we use previously learned "production rules" that govern the execution of tasks under defined conditions. *Rule-based errors* commonly are related to misclassification of a situation, resulting in the application of an incorrect procedure for the flight circumstances encountered; and,

- *Automatic (skill-based)* information processing occurs without conscious awareness and represents the unfolding of preprogrammed sensory-motor response sequences similar to a stored computer program. *Skill-based errors* are related to response selection, timing and coordination. A *slip* occurs when a pilot performs an unintended action during the execution of well-practiced and familiar tasks. For example, the pilot inadvertently retracts the landing gear while intending to open the cockpit canopy on a hot day following a normal runway landing. A *lapse* occurs when a pilot omits a required step in an operational task sequence. For example, a flight crew fails to complete an item on their preflight checklist because they were interrupted during the checklist task by a call from ATC indicating a runway closure.

All highly skilled performances have automatic components. For example, a well-practiced golf swing, once begun, moves smoothly without conscious thought by the golfer. What would happen to that well-practiced golf swing, however, after the golfer received advice from a friend about his technique? Thinking while performing the physical component of a skill interrupts automatic control and typically has the effect of impairing smooth and precise skilled performance.

The mechanisms of human information processing pose possible problems of attention errors. The paradox of human attention error is that both inexperience and high levels of proficiency can lead to human attention errors. Inexperience is more often associated with task overload and distraction, because the inexperienced pilot requires more time to process incoming data. The highly proficient pilot, operating on automatic, would be more prone to attention errors caused by the influence of habits.♦

– Anthony P. Ciavarelli, Ed.D.

## References

1. Reason J. *Human Error*. New York, New York, United States: Cambridge Press, 1990.
2. Reason J. "Identifying the Latent Causes of Aircraft Accidents Before and After the Event." In *ISASI Forum Proceedings*, International Society of Air Safety Investigators, 1991.
3. Maurino, D.E.; Reason, J.; Johnston, N.; Lee, R.B. *Beyond Aviation Human Factors*. Brookfield, Vermont, United States: Averbury Aviation, 1997.

Human-performance factors under this category are intentional commission of unsafe acts or violations of regulations/procedures. Some of these factors may be traced to personality-driven exhibitions or stress reactions that result in demonstration of hostility and aggression, overestimation of flying ability, anti-authority attitudes and disregard for regulations.

> Example: A Beech Super King Air 300 struck a mountain ridge near Winchester (Virginia, U.S.) Regional Airport during a visual flight rules flight in instrument meteorological conditions. The three crewmembers, all employees of the U.S. Federal Aviation Administration (FAA), were killed. NTSB, in its final report, said that the probable causes of the accident were "the failure of the pilot-in-command to ensure that the airplane remained in visual meteorological conditions over the mountainous terrain and the failure of [FAA] executives and managers responsible for the FAA flying program

> to: (1) establish effective and accountable leadership and oversight of flying operations; (2) establish minimum mission and operational performance standards; (3) recognize and address performance-related problems among the organization's pilots; and (4) remove from flight operations duty pilots who were not performing to standards." The pilot-in-command had a history of inadequate performance and flight-rule violations.[8]

**Judgment and Risk Decision** — This category includes capabilities and limitations in the accurate assessment of hazards and their effects on safety. Human-performance failures include flying aircraft outside safe limits, flying into known adverse weather, continuing flight with a known low-fuel state and intentional violation of established safety regulations/procedures.

Some pilots seem predisposed to taking high risks and exercising poor judgment. They typically overestimate their flying ability, resent authority or strive to gain attention.

> Example: A Beech C99 was being operated on a pilot-proficiency check flight near Shelton, Nebraska, U.S., when it struck terrain during an aerobatic maneuver. Both pilots were killed. NTSB said, in its final report, that the probable causes of the accident were "the deliberate disregard for Federal Aviation Regulations, [airline] procedures and prudent concern for safety by the two pilots in their decision to execute an aerobatic maneuver during a scheduled check ride flight, and the failure of [airline] management to establish and maintain a commitment to instill professionalism in their pilots consistent with the highest levels of safety necessary for an airline operating scheduled passenger service."[9]

The concept of recognition-primed decision making explains how pilots make very quick decisions, particularly under conditions that require a rapid response to cope with a hazardous situation or to make a flight-path correction.[10] Such rapidity of action is possible because the pilots have acquired a substantial base of similar experiences and can apply quickly a previously learned procedure that is applicable to the current situation. When an inexperienced pilot encounters a hazardous situation, the absence of previous experience with such a situation results in more time taken to assess the situation and to decide upon a correct course of action, which can lead to an unsafe outcome.

**Communication and Crew Coordination** — This category includes capabilities and limitations in transmitting information (speaking) and in receiving information (listening) using unambiguous (standard) phraseology to coordinate flight-deck activity and divide task loading, and to interpret correctly and act on information essential for task performance.

The effectiveness of human communication is affected by individual interpersonal styles, team performance and organizational influences that sometimes create communication barriers. For example, junior flight officers might defer to a captain's seniority or might find the captain intimidating or overbearing. This can result in a reluctance to challenge the captain on possible erroneous decisions or erroneous procedures.

Sources of communication error include the use of nonstandard phraseology, reluctance to speak or to listen, failure to acknowledge a message or to read back an instruction, failure to use available crew resources, and, most seriously, failure to respond to, or act on, a warning from another crewmember.

> Example: A Boeing 707 was en route from Bogota, Colombia, to New York, New York, U.S., when all four engines lost power because of fuel exhaustion. Seventy-three occupants were killed and 81 occupants received serious injuries when the aircraft struck terrain about 16 nautical miles (30 kilometers) from the destination airport. NTSB said, in its final report, that the probable cause of the accident was "the failure of the flight crew to adequately manage the airplane's fuel load and their failure to communicate an emergency-fuel situation to air traffic control before fuel exhaustion occurred." The crew had told air traffic control that they required priority handling, but the crew had not declared an emergency.[11]

Some communication failures result from the absence of leadership or inadequate task management.

> Example: A Boeing 737 overran the end of the runway during takeoff from La Guardia Airport in Flushing, New York, U.S., and came to rest in Bowery Bay. Of the 63 occupants, two passengers were killed, and two passengers received serious injuries. NTSB said, in its final report, that the probable cause of the accident was "the captain's failure to exercise his command authority in a timely manner to reject the takeoff or take sufficient control to continue the takeoff, which was initiated with a mistrimmed rudder."[12]

> Example: A McDonnell Douglas DC-9 was being taxied in dense fog when it collided with a Boeing 727 that was rolling for takeoff on the active runway at Detroit (Michigan, U.S.) Metropolitan/Wayne County Airport. Of the 44 DC-9 occupants, eight were killed, and 10 received serious injuries; none of the B-727 occupants was killed or injured. NTSB, in its final report, said that the probable cause of the accident was "a lack of proper crew coordination, including a virtual reversal of roles by the DC-9 pilots, which led to their failure to stop taxiing their airplane and alert the ground controller of their positional uncertainty in a timely manner before and after intruding onto the active runway."[13]

**System Design/Operation** — This category includes aircraft-design deficiencies and/or support-system-equipment design deficiencies, including inadequate placement of controls or displays, inadequate displayed data and inadequate documentation of system operation or maintenance procedures.

These types of design problems are sources of pilot error because they may contribute to different forms of control-action errors and misinterpretation of display data. Inadequate flight-deck design also may increase flight crew workload, leading to physical fatigue or mental fatigue, which can impair flight crew performance.

> Example: An airline first officer, in a report to the U.S. National Aeronautics and Space Administration Aviation Safety Reporting System, said that he neglected to specify the temperature scale when entering the airport temperature in the aircraft's airborne communications addressing and reporting system (ACARS) computer, to determine maximum allowable takeoff weight. He entered 18 (degrees) but did not enter C for Celsius. The ACARS computer calculated maximum allowable takeoff weight based on 18 degrees Fahrenheit (-8 degrees C). As a result, the aircraft was 700 pounds to 1,000 pounds (318 kilograms to 454 kilograms) over maximum allowable takeoff weight on takeoff.[14]
>
> Example: An Airbus A300B4 stalled during a go-around and struck terrain at Nagoya (Japan) Airport. Of the 271 occupants, 264 were killed and seven received serious injuries. The final report by the Japanese Aircraft Accident Investigation Commission said that the causes of the accident were as follows:
>
> "While the aircraft was making an [instrument landing system] approach to Runway 34 of Nagoya Airport, under manual control by the F/O [first officer], the F/O inadvertently activated the 'GO' lever, which changed the FD (flight director) to go-around mode and caused a thrust increase. This made the aircraft deviate above its normal glide path.
>
> "The [autopilots] were subsequently engaged, with go-around mode still engaged. Under these conditions, the F/O continued pushing the control wheel in accordance with the CAP's [captain's] instructions. As a result of this, the THS (horizontal stabilizer) moved to its full nose-up position and caused an abnormal out-of-trim situation.
>
> "The crew continued [the] approach, unaware of the abnormal situation. The [angle-of-attack] increased, the alpha-floor function [automatic application of full engine power] was activated, and the pitch angle increased.
>
> "It is considered that, at this time, the CAP (who had now taken the controls), judged that landing would be difficult and opted for [a] go-around. The aircraft began to climb steeply with a high-pitch-angle attitude. The CAP and the F/O did not carry out an effective recovery operation, and the aircraft stalled and crashed."[15]

**Supervisory and Organizational** — This category includes leadership factors, cultural factors and organizational factors, chief among which is the general organizational climate: the policies and practices established by the organization leadership to motivate, supervise, control and reward organization personnel. Also considered are the level of supervisory control in the organization and accountability for enforcing specific flight regulations, training requirements, maintenance requirements and quality assurance.

The concept of the high-reliability organization (HRO) holds that some organizations are more adept at managing the risks associated with hazardous operations.[16] An HRO experiences a relatively low number of accidents and incidents because of such factors as leadership commitment to safety, accurate risk perception and effective risk-management processes. HROs conduct frequent safety reviews and audits. They train often to maintain reliable work performance and high quality standards, and they promote a strong safety culture that reinforces safe behavior.

Organizations that lack leadership commitment to safety and effective risk-management processes have a higher risk of accidents and incidents.

> Example: A Beech E18s was on an air-tour flight when it struck a mountain in Maui, Hawaii, U.S. The nine occupants were killed. NTSB said, in its final report, that the probable cause of the accident was "the captain's decision to continue visual flight into instrument meteorological conditions that obscured rising mountainous terrain and his failure to properly use available navigational information to remain clear of the Island of Maui." The report said that the pilot had provided false information to the company about his flight experience, and that the company had failed to conduct an adequate background check of the pilot.[17]

The human factors checklist is designed as a user-friendly aircraft-accident-investigation tool to identify potential sources of human error and some specific human performance factors. The checklist also can be used in the formulation of safety programs that address key factors related to the prevention of recurring flight crew errors.♦

## Notes and References

1. Transportation Safety Board of Canada *Aviation Occurrence Report: Frontier Air Ltd. Beechcraft C99 Airliner, C-GFAW; Moosonee, Ontario; 30 April 1990.* Report no. A90H0002.

2. The *black-hole effect* occurs typically during a visual approach conducted on a moonless or overcast night, over water or over dark and featureless terrain where the only visual stimuli are lights on and/or near the airport. The absence of visual references in the pilot's near vision affects depth perception and causes the illusion that the airport is closer than it actually is and, thus, that the aircraft is too high. The pilot may respond to this illusion by conducting an approach below the correct flight path (i.e., a low approach).

3. 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 phases, which typically comprise about 16 percent of the average flight duration of a large commercial jet.

4. Flight Safety Foundation. "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999): 1–121.

5. U.S. National Transportation Safety Board (NTSB) *Aircraft Accident Report: Uncontrolled Collision With Terrain; American International Airways Flight 808; Douglas DC-8-61, N814CK; U.S. Naval Air Station, Guantanamo Bay, Cuba; August 18, 1993*. Report no. NTSB/AAR-94/04.

6. NTSB *Aircraft Accident Report: Controlled Collision With Terrain; GP Express Airlines, Inc., Flight 861, a Beechcraft C99, N118GP; Anniston, Alabama; June 8, 1992*. Report no. NTSB/AAR-93/03.

7. Fitts, P.M.; Posner, M.I. *Human Performance*. New York, New York, United States: Academic Press, 1967.

8. NTSB *Aircraft Accident Report: Controlled Flight Into Terrain; Federal Aviation Administration Beech Super King Air 300/F, N82; Front Royal, Virginia; October 26, 1993*. Report no. NTSB/AAR-94/03.

9. NTSB *Aircraft Accident/Incident Summary Report: Controlled Flight Into Terrain; GP Express Airlines, Inc., N115GP, Beechcraft C-99; Shelton, Nebraska; April 28, 1993*. Report no. NTSB/AAR-94/01/SUM.

10. Klein, G.A. "Recognition-primed Decision Model of Rapid Decision-making," edited by Rouse, W.B. In *Advances in Man-machine System Research*, 5, 47–92. Greenwich, Connecticut, United States: JAI Press, 1989.

11. NTSB *Aircraft Accident Report: Avianca, the Airline of Colombia, Boeing 707-321B, HK 2016; Fuel Exhaustion; Cove Neck, New York; January 25, 1990*. Report no. NTSB/AAR-91/04.

12. NTSB *Aircraft Accident Report: USAir, Inc., Boeing 737-400; LaGuardia Airport, Flushing, New York; September 20, 1989*. Report no. NTSB/AAR-90/03.

13. NTSB *Aircraft Accident Report: Northwest Airlines, Inc. Flights 1482 and 299; Runway Incursion and Collision; Detroit Metropolitan/Wayne County Airport, Romulus, Michigan; December 3, 1990*. Report no. NTSB/AAR-91/05.

14. U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS). "Degrees of Default." *Callback* Number 13 (March 1997). NASA ASRS is a confidential incident-reporting system. The ASRS Program Overview said, "Pilots, air traffic controllers, flight attendants, mechanics, ground personnel and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised. … ASRS de-identifies reports before entering them into the incident database. All personal and organizational names are removed. Dates, times, and related information, which could be used to infer an identity, are either generalized or eliminated." ASRS acknowledges that its data have certain limitations. ASRS *Directline* (December 1998) said, "Reporters to ASRS may introduce biases that result from a greater tendency to report serious events than minor ones; from organizational and geographic influences; and from many other factors. All of these potential influences reduce the confidence that can be attached to statistical findings based on ASRS data. However, the proportions of consistently reported incidents to ASRS, such as altitude deviations, have been remarkably stable over many years. Therefore, users of ASRS may presume that incident reports drawn from a time interval of several or more years will reflect patterns that are broadly representative of the total universe of aviation-safety incidents of that type."

15. Japanese Aircraft Accident Investigation Commission *Aircraft Accident Investigation Report 96-5*: *China Airlines Airbus Industrie A300B4-622R, B1816; Nagoya Airport; April 26, 1994.*

16. Roberts, K.H. "Managing High-reliability Organizations." *California Management Review*, 32 (4), 1990: 101–103.

17. NTSB *Aircraft Accident Report: Tomy International, Inc. d/b/a Scenic Air Tours Flight 22, Beech Model E18S, N342E; In-flight Collision With Terrain; Mount Haleakala, Maui, Hawaii; April 22, 1992*. Report no. NTSB/AAR-93/01.

## *About the Author*

*Anthony P. Ciavarelli is associate provost for instruction at the Naval Postgraduate School in Monterey, California, U.S. A professor of psychology, he has developed and has taught specialized courses on safety psychology and human factors at the school. Ciavarelli was a human factors engineer, responsible for advanced flight deck design and engineering, at The Boeing Co. and has served as a senior technical adviser to the U.S. Navy, U.S. Air Force and U.S. Federal Aviation Administration. He has conducted extensive research in flight crew training and performance assessment, and has designed and has evaluated advanced flight crew training systems. He currently is conducting research on organizational factors in accident causation. Ciavarelli holds a doctorate in education from the University of Southern California.*

## Further Reading From FSF Publications

Lawton, Russell. "Steep Turn by Captain During Approach Results in Stall and Crash of DC-8 Freighter." *Accident Prevention* Volume 51 (October 1994).

Lawton, Russell. "Lack of Management Oversight Cited in Controlled-flight-into-terrain Accident of FAA Aircraft." *Accident Prevention* Volume 51 (August 1994).

Pope, John A. "Aerobatic Maneuver Blamed in Fatal Commuter Crash." *Accident Prevention* Volume 51 (June 1994).

FSF Editorial Staff. "Fatal Commuter Crash Blamed on Visual Illusion, Lack of Cockpit Coordination." *Accident Prevention* Volume 50 (November 1993).

Duke, Thomas A. "Poor Management Decisions, Inadequate Flight Crew Training and Inexperience Cited in Fatal Commuter Crash." *Accident Prevention* Volume 50 (July 1993).

Duke, Thomas A. "Six Hours and 26 Minutes into a Four Hour, 40 Minute Flight." *Flight Safety Digest* Volume 11 (March 1992): 1–12.

Pope, John A. "Anatomy of a Runway Collision." *Accident Prevention* Volume 48 (October 1991).

Pope, John A. "When a Rejected Takeoff Goes Bad." *Flight Safety Digest* Volume 10 (February 1991): 1–16.

# Flight Safety Foundation
# Human Factors Accident/Incident Checklist

## 1. Sensory/Perceptual Factors

- ☐ Misjudgment of distance, clearance, altitude, speed, etc.
- ☐ False perception because of visual illusion.

  Conditions that contribute to impaired visual performance:
  - ☐ Featureless terrain (e.g., desert, dry lake, water);
  - ☐ Darkness/low visibility;
  - ☐ "Black-hole effect"; [1]
  - ☐ No horizon or false horizon (unreliable visual attitude reference);
  - ☐ Mountainous terrain or sloping runway;
  - ☐ Helicopter-rotor downwash effects;
  - ☐ Anomalous light effects (e.g., causing flicker vertigo[2]);
  - ☐ Low contrast of objects to background or poor illumination;
  - ☐ View into bright sunlight/moonlight; and,
  - ☐ Shadows.
- ☐ False perception because of vestibular (inner-ear) disturbance.

  Types:
  - ☐ Coriolis (spinning sensation because of vestibular overstimulation);
  - ☐ Somatogravic (gravity-induced false sensation of a pitch-up); and,
  - ☐ Somatogyral (false sensation of rotation).
- ☐ Spatial disorientation/vertigo.

  Types:
  - ☐ Unrecognized (loss of attitudinal awareness);
  - ☐ Recognized (vertigo); and,
  - ☐ Incapacitating (e.g., vestibular-ocular decoupling induced by rapid acceleration/deceleration forces).

  Conditions that affect sense of body position or aircraft attitude:
  - ☐ Loss of visual cues/attitude reference (especially with no natural horizon);
  - ☐ Acceleration (g) forces; and,
  - ☐ Adverse medical condition or physiological condition (e.g., alcohol/drug effects, hangover, dehydration, fatigue, etc.).

- ☐ Loss of situational awareness.

  Types:

  - ☐ Geographic disorientation (e.g., deviation from route, operation outside chart limits, loss of position awareness);
  - ☐ General loss of situational awareness (e.g., failure to perceive hazardous condition, such as controlled flight into terrain);
  - ☐ Erroneous situational assessment (misinterpretation of situation or condition);
  - ☐ Failure to predict/anticipate changing conditions; and,
  - ☐ False hypothesis/confirmation bias (persistent false perception or misconception of situation).

- ☐ Attention failure (e.g., failure to monitor or respond when correct information was available).

  Types:

  - ☐ Omission of checklist items, standard call or crew challenge;
  - ☐ Failure to monitor flight progress or to maintain instrument scan;
  - ☐ Failure to respond to communication or warning; and,
  - ☐ Control-action error:
    - ☐ Failure to set/move/reset control switch (lapse[3]);
    - ☐ Unintentional activation of control switch (slip[4]);
    - ☐ Control-substitution error (slip);
    - ☐ Control-reversal error (slip); or,
    - ☐ Control-adjustment/precision error (slip).

  Conditions that affect attention and situational awareness:

  - ☐ Inattention (focus on information unrelated to flight-deck tasks/flying);
  - ☐ Channelization, fixation (psychological narrowing of perception);
  - ☐ Distraction (preoccupation with internal [mental] event or with external event);
  - ☐ Task overload (excess tasking with or without schedule pressure or task-performance-time pressure);
  - ☐ Cognitive workload (problem-solving concentration or information overload);
  - ☐ Habit influence/interference;
  - ☐ Excessive flight crew stress or fatigue;
  - ☐ Excessive mission tasking or workload;
  - ☐ Inadequate briefing/flight preparation;
  - ☐ Inadequate training/experience for mission;
  - ☐ Negative learning transfer (e.g., during transition to new aircraft);
  - ☐ Adverse meteorological conditions;
  - ☐ Tactical-situation overload/display-information overload;
  - ☐ Inadequate flight crew motivation/inadequate flight vigilance; and,
  - ☐ Inadequate flight-deck design (control/display location or data format).

## 2. Medical and Physiological

- ☐ Self-medication (without medical advice or against medical advice).
- ☐ Influence of drugs/alcohol.
- ☐ Cold or flu (or other known illness).

- ☐ Excessive personal stress/fatigue.
- ☐ Inadequate nutrition (e.g., omitted meals).
- ☐ G-induced loss of consciousness or g-induced illusion.
- ☐ Hypoxia.
- ☐ Other medical or physiological condition.

Conditions that may cause adverse medical/physiological state:

  - ☐ Mission tasking or job fatigue (e.g., on duty more than 14 hours, late-night operations or early morning operations);
  - ☐ Cumulative fatigue (e.g., excessive physical workload, mental workload, circadian disruption or sleep loss);
  - ☐ Cumulative effects of personal stress or occupational stress (beyond stress-coping limit);
  - ☐ Emergency-flight-condition/workload transition (from normal operation to emergency operation); and,
  - ☐ Medical or physiological preconditions (health/fitness, hangover, dehydration, etc.).

## 3. Knowledge and Skill

- ☐ Inadequate knowledge of systems, procedures, etc. (knowledge-based error[5]).
- ☐ Inadequate flight control/airmanship, or inadequate accuracy and precision of flight maneuvering (skill-based error[6]).
- ☐ Misuse of procedures or incorrect performance of flight-deck tasks (rule-based error[7]), e.g.:
  - ☐ Failure to perform required procedure;
  - ☐ Use of wrong procedure or rule(s); and/or,
  - ☐ Failure to conduct step(s) in prescribed sequence.

Conditions that lead to inadequate operational performance:

  - ☐ Demonstration of performance below required proficiency standards or currency standards;
  - ☐ Demonstration of inadequate performance or documented flight-aptitude deficiencies;
  - ☐ Low flight hours (total/type);
  - ☐ Inadequate essential training for specific task(s);
  - ☐ Inadequate recent experience or inadequate experience in flight condition (e.g., instrument flight rules, night, weather, etc.); and,
  - ☐ Transition (learning new aircraft system).

## 4. Personality and Safety Attitude

- ☐ Demonstration of overconfidence in flying ability.
- ☐ Demonstration of excessive motivation to achieve mission.
- ☐ Reckless operation.
- ☐ Demonstration of anger/frustration on the job.
- ☐ Demonstration of stress-coping failure (e.g., anger).
- ☐ Overly assertive or nonassertive.
- ☐ Inadequate confidence to perform tasks/activities.
- ☐ Acquiescence to social pressure (from organization or peers) to operate in hazardous situation/condition.

## 5. Judgment and Risk Decision

- ☐ Acceptance of a high-risk situation/mission.
- ☐ Misjudgment of mission risks (complacency).
- ☐ Failure to monitor flight progress/conditions (complacency).
- ☐ Use of incorrect task priorities.
- ☐ Intentional deviation from safe procedure (imprudence).
- ☐ Intentional violation of standard operating procedure or regulation.
- ☐ Intentional disregard of warning (by human or aircraft system).
- ☐ Noncompliance with personal limits.
- ☐ Noncompliance with published aircraft limits.
- ☐ Noncompliance with prescribed mission profile/parameters.
- ☐ Acquiescence to social pressure (from organization or peers).

Conditions leading to poor safety attitude and risky judgment:

- ☐ History of taking high risks (personality-driven);
- ☐ Pattern of overconfidence (aggrandized self-image);
- ☐ Documented history of marginal performance/failure;
- ☐ Excessive motivation (did not know limits);
- ☐ Reputation as a reckless pilot;
- ☐ Failure to cope with life stress (anger/frustration);
- ☐ Overly assertive or nonassertive (interpersonal style); and,
- ☐ Influenced by inadequate organizational climate/safety culture (e.g., lack of adequate supervision).

## 6. Communication and Crew Coordination

- ☐ Inadequate mission plan/brief or preflight.
- ☐ Failure to communicate plan/intentions.
- ☐ Failure to use standard/accepted terminology.
- ☐ Inadequate understanding of communication or failure to acknowledge communication.
- ☐ Inadequate crew coordination (challenge, cross-check).
- ☐ Intentional withholding, by a crewmember, of vital safety data.
- ☐ Failure of the pilot-in-command to lead/delegate.
- ☐ Failure of the pilot-in-command to use all available resources.
- ☐ Interpersonal conflict/crew argument during flight.

Conditions leading to inadequate communication/coordination:

- ☐ Inadequate training in communication/crew coordination;
- ☐ Inadequate standard operating procedures for use of crew resources;
- ☐ Inadequate support from organization for crew-coordination doctrine; and,
- ☐ Failure of organizational safety culture to support crew resource management.

## 7. System Design/Operation

- ☐ Use of wrong switch/lever or control.
- ☐ Misinterpretation of instrument indication.
- ☐ Inability to reach/see control.
- ☐ Inability to see/interpret instrument/indicator.
- ☐ Failure to respond to warning.
- ☐ Selection/use of incorrect avionics system operating mode (mode confusion).
- ☐ Over-reliance on automated system (automation complacency).

Conditions that contribute to design-induced flight crew errors:

- ☐ Inadequate primary aircraft control/display arrangement;
- ☐ Inadequate primary display data or data format;
- ☐ Incompatible flight deck control/display activation, or aircraft-response mapping;
- ☐ Inadequate hazard advisory or warning display;
- ☐ Inadequate flight deck design (controls or displays outside crew vision or reach);
- ☐ Inadequate human-computer-display interface/usability (error-prone design);
- ☐ Inadequate system instructions/documentation;
- ☐ Inadequate aviation-system support or facilities (navigation aids, airport, air traffic control);
- ☐ Nonstandard flight deck layouts (conducive to negative habit transfer); and,
- ☐ Inappropriate type or level of automation, or excessive mode complexity.

## 8. Supervisory and Organizational

- ☐ Inappropriate scheduling/crew assignment.
- ☐ Failure to monitor crew rest/duty requirements.
- ☐ Failure to establish adequate standards.
- ☐ Failure to monitor compliance with standards.
- ☐ Failure to monitor crew training/qualifications.
- ☐ Failure to identify/remove a known high-risk pilot.
- ☐ Failure to establish/monitor quality standards.
- ☐ Intentional violation of a standard or regulation.
- ☐ Failure to perceive or to assess correctly mission risks, with respect to:
    - ☐ Environmental hazards/operating conditions;
    - ☐ Mission tasking and flight crew skill level; and/or,
    - ☐ Aircraft and equipment limitations.

Conditions leading to supervisory failures:

- ☐ Excessive operations tempo/organizational workload (imposed by the organization or imposed by organizational chain);
- ☐ Inadequate organizational safety culture;

☐ Inattention to safety management (inadequate safety supervision);
☐ Inadequate work standards/low performance expectations;
☐ Inadequate/bad example set by supervisors;
☐ Inadequate safety commitment/emphasis by supervisors;
☐ Organization lacked an adequate system for monitoring and correcting hazardous conditions;
☐ Supervisors did not promote and reward safe behavior or quickly correct unsafe behaviors;
☐ Organization did not have adequate policies and procedures to ensure high-quality work performance;
☐ Organization had inadequate job-qualification standards or training program;
☐ Organization had inadequate internal communication;
☐ Organization had no system or an inadequate system for management of high-risk pilots;
☐ Organization had inadequate process or procedures for operational risk management;
☐ Organization did not provide adequate aeromedical/human factors training;
☐ Organization did not ensure sufficient involvement of medical and occupational health specialists; and,
☐ Organization did not establish or enforce acceptable medical/health standards.

[This checklist was developed by Anthony P. Ciavarelli, Ed.D., associate provost for instruction at the Naval Postgraduate School, Monterey, California, U.S.]

## Notes

1. The *black-hole effect* typically occurs during a visual approach conducted on a moonless or overcast night, over water or over dark and featureless terrain where the only visual stimuli are lights on and/or near the airport. The absence of visual references in the pilot's near vision affects depth perception and causes the illusion that the airport is closer than it actually is and, thus, that the aircraft is too high. The pilot may respond to this illusion by conducting an approach below the correct flight path (i.e., a low approach).

2. *Flicker vertigo* is a sensory disturbance caused by light and shadow alternating at specific frequencies, such as when sunlight is viewed through slowly rotating propeller blades or rotor blades. Reactions include distraction, disorientation, nausea and unconsciousness.

3. A *lapse* is an error of omission in which an item previously known is forgotten. Lapses are unintended and often are caused by inattention or inadequate association at the time the item was learned.

4. A *slip* is an error of commission in which the action does not proceed as planned. Slips are unintended and often are caused by inattention at the time of action.

5. A *knowledge-based error* is an error of commission in which the action proceeds as planned but the plan is inappropriate for the situation. Knowledge-based errors arise from incomplete or incorrect knowledge.

6. A *skill-based error* is an error of commission or an error of omission. Skill-based errors typically arise when an unintended action occurs during the execution of a well-practiced and familiar task, or when a required step is omitted during execution of an operational task sequence.

7. A *rule-based error* is an error of commission in accordance with a rule that is inappropriate for the situation. A rule-based error typically occurs when misclassification of a situation leads to application of an inappropriate rule or to incorrect memory of procedures.

Suite 300, 601 Madison Street • Alexandria, VA 22314-1756 U.S. • Telephone: +1 (703) 739-6700, Fax: +1 (703) 739-6708
www.flightsafety.org

# Human Factors Analysis and Classification System

***HFACS was developed as a framework for safety research to support the design of new investigative methods and accident/incident databases to systematically examine human error in aviation safety.***

*Scott A. Shappell*
*Douglas A. Wiegmann*

Since the late 1950s, the drive to reduce the accident rate has yielded increased levels of safety to where it is now safer to fly in a commercial airliner than to drive a car or even walk across a busy city street. While the aviation accident rate has declined since the first flights nearly a century ago, the cost of aviation accidents in lives and dollars has risen steadily. As a result, the effort to reduce the accident rate further has taken on new meaning within military and civilian aviation.

Even with all the innovations and improvements realized in the last several decades, one fundamental question remains generally unanswered: "Why do aircraft crash?" The answer may not be as straightforward as one might think. In the early years of aviation, it could reasonably be said that, more often than not, the aircraft killed the pilot. That is, the aircraft were intrinsically unforgiving and, relative to their modern counterparts, mechanically unsafe. Nevertheless, the modern era of aviation has witnessed an ironic reversal of sorts. It now appears to some that the pilots themselves are more deadly than the aircraft they fly (Mason, 1993; cited in Murray, 1997). Estimates in the literature indicate that between 70 percent and 80 percent of aviation accidents can be attributed, at least in part, to human error (Shappell and Wiegmann, 1996). To off-handedly attribute accidents solely to pilot error is like telling patients they are "sick" without examining the underlying causes or further defining the illness.

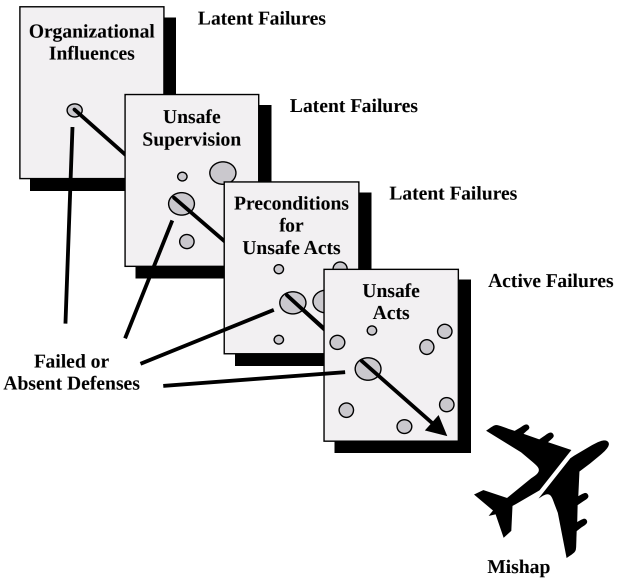
So, what really constitutes that 70 percent to 80 percent of human error repeatedly referred to in the literature? Some would have us believe that human error and pilot error are synonymous. Yet, writing off aviation accidents to pilot error is an overly simplistic, if not naive, approach to accident causation. After all, it is well established that accidents cannot be attributed to a single cause or, in most instances, even a single individual (Heinrich, Petersen and Roos, 1980). Even the identification of a primary cause is fraught with problems. Rather, aviation accidents are the end result of a number of causes, only the last of which are the unsafe acts of the pilots (Reason, 1990; Shappell and Wiegmann, 1997a; Heinrich, Peterson and Roos, 1980; Bird, 1974).

The challenge for accident investigators and analysts is how best to identify and mitigate the causal sequence of events, in particular that 70 percent to 80 percent associated with human error. Armed with this challenge, those interested in accident causation are left with a growing list of investigative schemes to choose from. There are nearly as many approaches to accident causation as there are those involved in the process (Senders and Moray, 1991). Nevertheless, a comprehensive framework for identifying and analyzing human error continues to elude safety professionals and theorists. Consequently, interventions cannot be accurately targeted at specific human causal factors, nor can their effectiveness be objectively measured and assessed. Instead, safety professionals are left with the status quo. That is, they are left with interest/fad-driven research resulting in intervention strategies that peck around the edges of accident causation, but do little to reduce the overall accident rate. A framework is needed around which a data-driven safety program can be developed (Wiegmann and Shappell, 1997).

## Reason's "Swiss Cheese" Model of Human Error

One approach to the genesis of human error is the one proposed by James Reason (1990). Generally referred to as the "Swiss cheese" model of human error, Reason describes four levels of human failure, each influencing the next (Figure 1). Working backwards in time from the accident, the first level depicts those *unsafe acts* of operators that ultimately led to the accident.[1] More commonly referred to in aviation as pilot error, this level is where most accident investigations have focused their efforts and, consequently, where most causal factors are uncovered.

**James Reason's "Swiss Cheese" Model of Human Error Causation**



Source: U.S. Federal Aviation Administration

Figure 1

After all, it is typically the actions or inactions of pilots that are directly linked to the accident. For instance, failing to properly scan the aircraft's instruments while in instrument meteorological conditions (IMC) or penetrating IMC when authorized only for visual meteorological conditions (VMC) may yield relatively immediate and lethal consequences. Represented as holes in the cheese, these active failures are typically the last unsafe acts committed by pilots.

What makes the Swiss cheese model particularly useful in accident investigation is that it forces investigators to address latent failures within the causal sequence of events as well. Latent failures, unlike their active counterparts, may lie dormant or undetected for hours, days, weeks or even longer, until they adversely affect the unsuspecting pilots. Consequently, latent failures may be overlooked by investigators.

Within this concept of latent failures, Reason described three more levels of human failure. The first involves the condition of the flight crew as it affects performance. Referred to as *preconditions for unsafe acts*, this level involves conditions such as mental fatigue and poor communication and coordination practices, often referred to as crew resource management (CRM). Not surprising, if fatigued pilots fail to communicate and coordinate their activities with others on the flight deck or individuals external to the aircraft (e.g., air traffic controllers, maintenance technicians), poor decisions are made and errors often result.

But exactly why did communication and coordination break down in the first place? This is perhaps where Reason's work departed from more traditional approaches to human error. In many instances, the breakdown in good CRM practices can be traced back to instances of *unsafe supervision*, the third level of human failure. If, for example, two inexperienced (and perhaps even below-average) pilots are paired with each other and sent on a flight into known adverse weather at night, is anyone really surprised by a tragic outcome? To make matters worse, if this practice is coupled with the lack of quality CRM training, the potential for miscommunication and, ultimately, pilot error, is magnified. In a sense then, the crew was "set up" for failure as crew coordination and ultimately performance would be compromised. This is not to lessen the role played by the pilots, only that intervention and mitigation strategies might lie higher within the system.

Reason's model did not stop at the supervisory level; the organization can influence performance at all levels. For example, in times of fiscal austerity, funding is often cut and, as a result, training and flight time may be curtailed. In the absence of good CRM training, communication and coordination failures will begin to appear, as will other preconditions, all of which will affect performance and elicit pilot error. Therefore, it makes sense that, if the accident rate is going to be reduced below current levels, investigators and analysts must examine the accident sequence in its entirety and expand it beyond the flight deck. Ultimately, causal factors at all levels within the organization must be addressed if any accident investigation and prevention system is going to succeed.

In many ways, Reason's Swiss cheese model of accident causation has revolutionized common views of accident causation. Unfortunately, however, it is simply a theory with few details on how to apply it in a real-world setting. In other words, the theory never defines what the holes in the cheese really are, at least within the context of everyday operations. Ultimately, one needs to know what these system failures (holes) are, so that they can be identified during accident investigations or, better yet, detected and corrected before an accident occurs.

Rather than attempt to define the holes using esoteric theories with little or no practical applicability, the original framework (*Taxonomy of Unsafe Operations*) was developed using more than 300 naval aviation accidents obtained from the U.S. Naval Safety Center (Shappell and Wiegmann, 1997a). The original taxonomy has since been refined using input and data from other military (U.S. Army Safety Center and U.S. Air Force Safety Center) and civilian organizations (U.S. National Transportation Safety Board [NTSB] and U.S. Federal Aviation Administration [FAA]). The result was the development of the Human Factors Analysis and Classification System (HFACS).

## Human Factors Analysis and Classification System

Drawing upon Reason's (1990) concept of latent failures and active failures, HFACS describes four levels of failure: unsafe acts, preconditions for unsafe acts, unsafe supervision and organizational influences. A brief description of the major components and causal categories follows, beginning with the level most closely tied to the accident, i.e., unsafe acts.

### Unsafe Acts

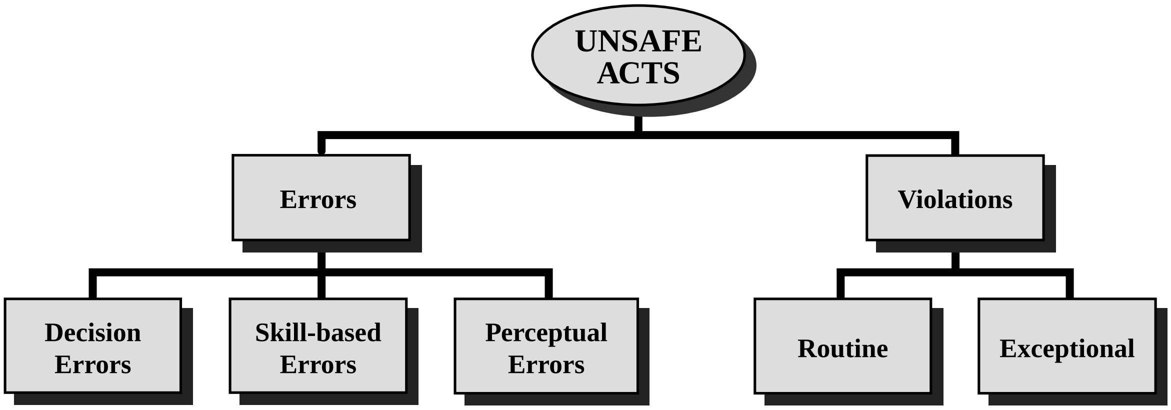
The unsafe acts of pilots can be classified loosely into two categories: errors and violations (Reason, 1990). In general, errors represent the mental activities or physical activities of individuals that fail to achieve their intended outcome. Not surprising, given the fact that human beings make errors, these unsafe acts dominate most accident databases. Violations, on the other hand, refer to the willful disregard for the rules and regulations that govern the safety of flight. The bane of many organizations, the prediction and prevention of these preventable unsafe acts continue to elude managers and researchers.

Distinguishing between errors and violations does not provide the level of granularity required of most accident investigations. Therefore, the categories of errors and violations were expanded here (Figure 2), as elsewhere (Reason, 1990; Rasmussen, 1982), to include three basic error types (skill-based, decision and perceptual) and two forms of violations (routine and exceptional).

### Errors

**Skill-based errors.** Skill-based behavior within the context of aviation is best described as "stick-and-rudder" and other

Categories of Unsafe Acts Committed by Pilots



Source: U.S. Federal Aviation Administration

Figure 2

basic flight skills that occur without significant conscious thought. As a result, these skill-based actions are particularly vulnerable to failures of attention and/or memory. Attention failures have been linked to many skill-based errors, such as the breakdown in visual scan patterns, task fixation, the inadvertent activation of controls and the misordering of steps in a procedure (Table 1). A classic example is a flight crew that becomes so fixated on troubleshooting a non-fuctioning warning light that they do not notice their descent into the terrain. Consider the person who locks himself out of the car or misses his highway exit because he was either distracted, hurried or daydreaming. These are examples of attention failures that commonly occur during highly automatized behavior.

In contrast to attention failures, memory failures often appear as omitted items in a checklist, place-losing or forgotten intentions. For example, most of us have experienced going to the refrigerator only to forget what we went for. Likewise, it is not difficult to imagine that when under stress during in-flight emergencies, critical steps in emergency procedures can be missed. Nevertheless, even when not particularly stressed, individuals have forgotten to set the flaps on approach or lower the landing gear.

The third, and final, type of skill-based error involves technique errors. Regardless of one's training, experience and educational background, the manner in which one carries out a specific sequence of events may vary greatly. That is, two pilots with identical training, flight grades and experience may differ significantly in the manner in which they maneuver their aircraft. While one pilot may fly smoothly with the grace of a soaring eagle, others may fly with the darting, rough transitions of a sparrow. Nevertheless, while both may be safe and equally adept at flying, the techniques they employ could set them up for specific failure modes. Such techniques are as much a factor of innate ability and aptitude as they are an overt expression of one's personality, making efforts at the prevention and mitigation of technique errors difficult.

**Decision errors.** The second error form represents intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts represent the actions or inactions of individuals whose "hearts are in the right place," but they either did not have the appropriate knowledge or simply chose poorly.

Perhaps the most heavily investigated of all error forms, decision errors can be grouped into three general categories: procedural errors, poor choices and problem-solving errors (Table 1). Procedural decision errors (Orasanu, 1993), or rule-based mistakes, as described by Rasmussen (1982), occur during highly structured tasks of the sort, if X, then do Y. Aviation, particularly within the military and commercial sectors, is highly structured, and much of pilot decision making is procedural. There are explicit procedures to be performed at virtually all phases of flight. Errors can, and often do, occur when a situation is not recognized or misdiagnosed and the incorrect procedure is applied. This is particularly true when pilots are placed in highly time-critical emergencies, such as an engine malfunction on takeoff.

Not all situations have corresponding procedures to deal with them. Therefore, many situations require a choice to be made among multiple response options. Consider the pilot who unexpectedly confronts a line of thunderstorms directly in his path while flying home after a long week away from the family. He can choose to fly around the weather, divert to an alternate

## Table 1
## Selected Examples of Unsafe Acts of Pilots

**Errors**

**Skill-based Errors**
- Breakdown in visual scan
- Failed to prioritize attention
- Inadvertent use of flight controls
- Omitted step in procedure
- Omitted checklist item
- Poor technique
- Over-controlled the aircraft

**Decision Errors**
- Improper procedure
- Misdiagnosed emergency
- Incorrect response to emergency
- Exceeded ability
- Inappropriate maneuver
- Poor decision

**Perceptual Errors (due to)**
- Misjudged distance/altitude/airspeed
- Spatial disorientation
- Visual illusion

**Violations**

- Failed to adhere to briefing
- Failed to use the radio altimeter
- Flew an unauthorized approach
- Violated training rules
- Flew an overaggressive maneuver
- Failed to properly prepare for the flight
- Briefed unauthorized flight
- Not current/qualified for the mission
- Intentionally exceeded the limits of the aircraft
- Continued low-altitude flight in VMC
- Unauthorized low-altitude flight

Note: This is not a complete listing.
VMC = Visual meteorological conditions

Source: U.S. Federal Aviation Administration airport until the weather passes or penetrate the weather, hoping to quickly transition through it. Confronted with situations such as this, choice-decision errors (Orasanu, 1993), or knowledge-based mistakes as they are otherwise known (Rasmussen, 1986), may occur. This is particularly true when there is insufficient experience, insufficient time or other outside pressures that may preclude correct decisions. Stated simply, sometimes we chose well, and sometimes we do not.

Finally, there are occasions when a problem is not well understood and formal procedures and response options are not available. It is during these ill-defined situations that the invention of a novel solution is required. Individuals find themselves where no one has been before. Individuals placed in this situation must resort to slow and effortful reasoning processes, and time is a luxury rarely afforded. Not surprisingly, while this type of decision making is more infrequent than other forms, the relative proportion of problem-solving errors committed is markedly higher.

**Perceptual errors.** Not unexpectedly, when one's perception of the world differs from reality, errors can, and often do, occur. Typically, perceptual errors occur when sensory input is degraded or unusual, as is the case with visual illusions and spatial disorientation, or when pilots misjudge the aircraft's altitude, attitude or airspeed (Table 1). Visual illusions, for example, occur when the brain tries to "fill in the gaps" with what it feels belongs in a visually impoverished environment, such as that seen at night or when flying in adverse weather. Likewise, spatial disorientation occurs when the vestibular system cannot resolve one's orientation in space and therefore makes a "best guess" — typically when visual (horizon) cues are absent at night or when flying in adverse weather. In either event, the unsuspecting individual often must make a decision that is based on faulty information and the potential for committing an error is increased.

It is important to note, however, that it is not the illusion or disorientation that is classified as a perceptual error. Rather, it is the pilot's erroneous response to the illusion or disorientation. For example, many unsuspecting pilots have experienced "black-hole" approaches and have flown perfectly good aircraft into terrain or water. This continues to occur, even though it is well known that flying at night over dark, featureless terrain (e.g., a lake or field devoid of trees), will produce the illusion that the aircraft is actually higher than it is. Pilots are taught to rely on their primary instruments, rather than the outside world, particularly during the approach phase of flight.

## Violations

By definition, errors occur within the rules and regulations espoused by an organization, typically dominating most accident databases. In contrast, violations represent a willful disregard for the rules and regulations that govern safe flight. Violations occur much less frequently than errors (Shappell et al., 1999b).

While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their etiology, that will help the safety professional when identifying accident causal factors. The first, routine violations, tends to be habitual by nature and often tolerated by governing authority (Reason, 1990). Consider, for example, the individual who drives consistently 5–10 miles per hour (mph) faster than allowed by law or someone who routinely flies in marginal weather when authorized only for VMC. Furthermore, individuals who drive 64 mph in a 55-mph zone, almost always drive 64 mph in a 55-mph zone. That is, they routinely violate the speed limit. The same typically can be said of the pilot who routinely flies in marginal weather.

These violations (commonly referred to as "bending" the rules) are tolerated often and, in effect, sanctioned by supervisory authority (i.e., you are not likely to receive a traffic citation until you exceed the posted speed limit by more than 10 mph). If, however, the local authorities began handing out traffic citations for exceeding the speed limit on the highway by nine mph or less (as is often done on military installations), then it is less likely that individuals would violate the rules. Therefore, by definition, if a routine violation is identified, one must look further up the supervisory chain to identify those individuals in authority who are not enforcing the rules.

On the other hand, unlike routine violations, exceptional violations appear as isolated departures from authority, not necessarily indicative of an individual's typical behavior pattern nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55-mph zone is considered an exceptional violation. Likewise, flying under a bridge or engaging in other prohibited maneuvers, such as low-level canyon running, would constitute an exceptional violation. However, it is important to note that, while most exceptional violations are appalling, they are not considered exceptional because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority. What makes exceptional violations particularly difficult for any organization to deal with is that they are not indicative of an individual's behavioral repertoire and, as such, are particularly difficult to predict. When individuals are confronted with evidence of their behavior and asked to explain it, they often provide little explanation. Indeed, those individuals who survived such excursions from the norm clearly knew that, if caught, dire consequences would follow.

## Preconditions for Unsafe Acts

Arguably, the unsafe acts of pilots can be linked directly to nearly 80 percent of all aviation accidents. Simply focusing on unsafe acts is like focusing on a fever without understanding the underlying disease causing it. Thus, investigators must dig deeper into why the unsafe acts took place. As a first step, two major subdivisions of unsafe pilot conditions were developed: substandard conditions of operators and the substandard practices they commit (Figure 3).

## Substandard Conditions of Operators

**Adverse mental states.** This category was created to account for mental conditions that affect performance (Table 2, page 21). Principal among these are the loss of situational awareness, task fixation, distraction and mental fatigue caused by sleep loss or other stressors. Also included in this category are personality traits and pernicious attitudes such as overconfidence, complacency and misplaced motivation.

If an individual is mentally fatigued, the likelihood increases that an error will occur. Similarly, overconfidence and other pernicious attitudes such as arrogance and impulsivity will influence the likelihood that a violation will be committed. Clearly then, any framework of human error must account for preexisting adverse mental states in the causal chain of events.

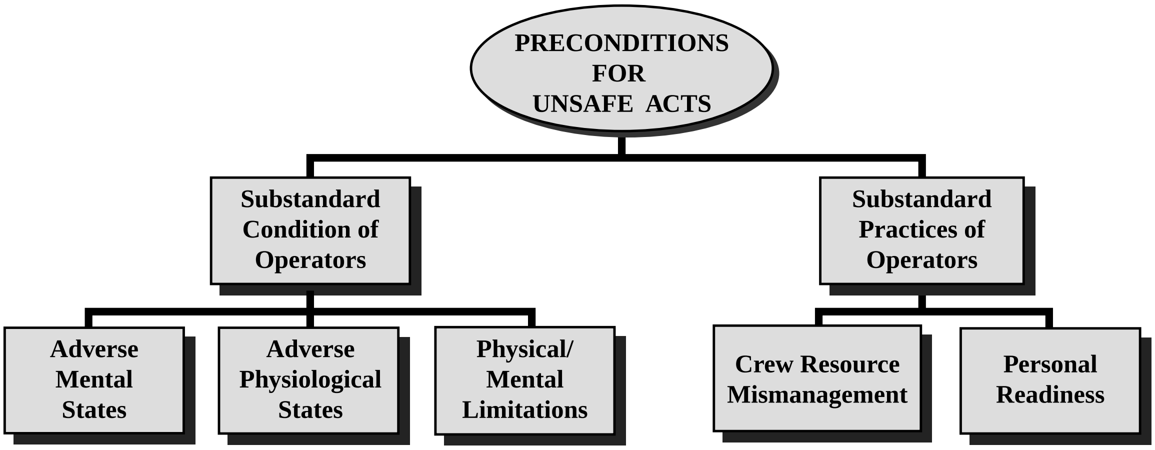
**Adverse physiological states.** This category refers to those medical conditions or physiological conditions that preclude safe operations (Table 2). Particularly important to aviation are such conditions as visual illusions and spatial disorientation, as well as physical fatigue and pharmacological and medical abnormalities known to affect performance.

The effects of visual illusions and spatial disorientation are well known to most aviators. Less well known to pilots, and often overlooked, are the effects of simply being ill. Nearly all of us have gone to work ill, dosed with over-the-counter medications, and have generally performed well. Consider, however, the pilot suffering from the common head cold. Some pilots view a head cold as a minor inconvenience that can be remedied easily using over-the-counter antihistamines, acetaminophen and other non-prescription pharmaceuticals. When confronted with a stuffy nose, pilots typically are concerned only with the effects of a painful sinus block as cabin altitude changes. Then again, it is not the overt symptoms that flight surgeons are concerned with. Rather, it is the accompanying inner-ear infection and the increased likelihood of spatial disorientation when entering IMC that is alarming — not to mention the side effects of antihistamines, fatigue and sleep loss on pilot decision making. These sometimes subtle medical conditions must be recognized within the causal chain of events.

**Physical/Mental Limitations.** The third, and final, substandard condition involves individual physical/mental limitations (Table 2). This category refers to those instances when mission requirements exceed the capabilities of the individual at the controls. For example, the human visual system is severely limited at night; yet, like driving a car, drivers do not necessarily slow down or take additional precautions. In aviation, while slowing down is not always an option, giving additional attention to basic flight instruments and increasing one's vigilance often will increase safety. When precautions are not taken, the result can be catastrophic, as pilots often will fail to see other aircraft, obstacles or power lines because of the size or the contrast of the object in the visual field.

Similarly, there are occasions when the time required to complete a task or a maneuver exceeds an individual's capacity. Individuals vary widely in their ability to process and respond to information. Nevertheless, good pilots are noted typically for their ability to respond quickly and accurately. It is well documented, however, that if individuals are required to respond quickly (i.e., less time is available to consider all the possibilities or choices thoroughly), the probability of making an error increases. Consequently, it should be no surprise that

**Categories of Preconditions for Unsafe Acts**



Source: U.S. Federal Aviation Administration

Figure 3

### Table 2
### Selected Examples of Unsafe Conditions

**Substandard Conditions of Operators**

**Adverse Mental States**
- Channelized attention
- Complacency
- Distraction
- Mental fatigue
- Get-home-itis
- Haste
- Loss of situational awareness
- Misplaced motivation
- Task saturation

**Adverse Physiological States**
- Impaired physiological state
- Medical illness
- Physiological incapacitation
- Physical fatigue

**Physical/Mental Limitations**
- Insufficient reaction time
- Visual limitation
- Incompatible intelligence/aptitude
- Incompatible physical capability

**Substandard Practices of Operators**

**Crew Resource Management**
- Failed to back up
- Failed to communicate/coordinate
- Failed to conduct adequate briefing
- Failed to use all available resources
- Failure of leadership
- Misinterpretation of traffic calls

**Personal Readiness**
- Excessive physical training
- Self-medication
- Violation of crew rest requirement
- Violation of bottle-to-throttle requirement

Note: This is not a complete listing.

Source: U.S. Federal Aviation Administration

when faced with the need for rapid processing and reaction times, as is the case in most aviation emergencies, all forms of error could be exacerbated.

In addition to the basic sensory and information-processing limitations described above, there are at least two additional examples of physical/mental limitations that must be addressed, although they often are overlooked by most safety professionals. These limitations involve individuals who are not compatible with aviation, because they are either unsuited physically or do not possess the aptitude to fly. For example, some individuals do not have the physical strength to operate in the potentially high-G environment of military aviation or, for anthropometric reasons, have difficulty reaching the controls. In other words, flight decks traditionally have not been designed with all shapes, sizes and physical abilities in mind. Likewise, not everyone has the mental ability or aptitude for flying aircraft. Just as not all of us can be concert pianists or football linebackers, not everyone has the innate ability to pilot an aircraft, a vocation that requires the ability to take decisions quickly and to respond accurately in life-threatening situations. The difficult task for the safety investigator is identifying whether aptitude might have contributed to the accident causal sequence.

## Substandard Practices of Operators

Clearly then, numerous substandard conditions of operators can, and do, lead to the commission of unsafe acts. Nevertheless, there are a number of things that we do to ourselves that set up these substandard conditions. Generally speaking, the substandard practices of operators can be summed up in two categories: crew resource mismanagement and personal readiness.

**Crew Resource Mismanagement.** Good communication skills and team coordination have been the mantra of industrial/organizational/personnel psychology for decades. Not surprising then, CRM has been a cornerstone of aviation for the last few decades (Helmreich and Foushee, 1993). The category, *crew resource mismanagement*, was created to account for occurrences of poor coordination among personnel. Within the context of aviation, this includes coordination between pilots and between pilots and air traffic controllers and maintenance technicians, as well as with facility personnel and other support personnel. But coordination does not stop in flight; it also includes coordination before and after the flight.

It is not difficult to envision a scenario where the lack of crew coordination has led to confusion and poor decision making, resulting in an accident. Aviation accident databases are replete with examples of poor coordination among pilots. For example, on Dec. 29, 1972, the flight crew of a Lockheed L-1011 diverted from an approach to Miami (Florida, U.S.) International Airport to determine whether the nose landing gear was extended (NTSB, 1972). The aircraft struck terrain in the Florida Everglades seven miles (13 kilometers) from the airport. Of the 163 occupants, 96 passengers and five crewmembers were killed. NTSB, in its final report, said that the probable cause of the accident was “the failure of the flight crew to monitor the flight instruments during the final four minutes of flight and to detect an unexpected descent soon enough to prevent impact with the ground. Preoccupation with a malfunction of the nose-landing-gear position-indicating system distracted the crew’s attention from the instruments and allowed the descent to go unnoticed.”

**Personal Readiness.** In aviation or, for that matter, in any occupational setting, individuals are expected to show up for work ready to perform at optimal levels. Nevertheless, in aviation, as in other professions, personal readiness failures occur when individuals fail to prepare physically or mentally for duty. For example, violations of crew rest requirements, bottle-to-brief rules and self-medication affect performance on the job and are particularly detrimental in the aircraft. It is not difficult to imagine that when individuals violate crew rest requirements, they run the risk of mental fatigue and other adverse mental states, which ultimately lead to errors and accidents. Note, however, that violations that affect personal readiness are not considered "unsafe act, violation" because they typically do not happen on the flight deck, nor are they necessarily active failures with direct and immediate consequences.

Not all personal readiness failures occur as a result of violations of governing rules or regulations. For example, running 10 miles before piloting an aircraft may not be against any existing regulations, yet it may impair the physical capabilities and mental capabilities of the individual enough to degrade performance and elicit unsafe acts. Likewise, the traditional "candy bar and coke" lunch of the modern businessman may sound good but may not be sufficient to sustain performance in the rigorous environment of aviation. While there may be no rules governing such behavior, pilots must use good judgment when deciding whether they are fit to fly an aircraft.

## Unsafe Supervision

In addition to those causal factors associated with the pilot/operator, Reason (1990) traced the causal chain of events through the supervisory chain of command. As such, we have identified four categories of unsafe supervision: inadequate supervision, planned inappropriate operations, failure to correct a known problem and supervisory violations (Figure 4). Each is described briefly below.

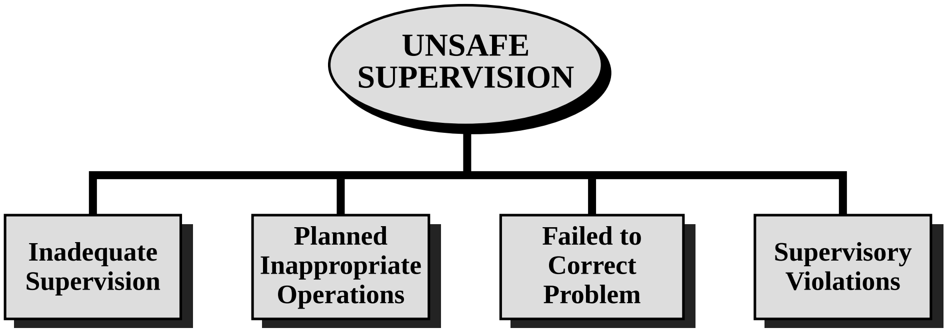
**Inadequate Supervision**. The role of any supervisor is to provide the opportunity to succeed. To do this, the supervisor, no matter at what level of operation, must provide guidance, training opportunities, leadership and motivation, as well as the proper role model to be emulated. Unfortunately, this is not always the case. For example, it is not difficult to identify a situation in which adequate CRM training either was not provided or the opportunity to attend such training was not afforded to a particular pilot. Conceivably, flight crew coordination skills would be compromised; if the aircraft were put into an adverse situation (an emergency), the risk of an error being committed would be increased and the potential for an accident would increase.

Similarly, sound professional guidance and oversight are essential ingredients of any successful organization. While empowering individuals to take decisions and function independently is certainly essential, this does not divorce the supervisor from accountability. The lack of guidance and oversight has proven to be the breeding ground for many violations. Thorough investigation of accident causal factors must consider the role supervision plays (i.e., whether the supervision was inappropriate or did not occur at all) in the genesis of human error (Table 3, page 23).

**Planned Inappropriate Operations**. Occasionally, the operational tempo and/or the scheduling of pilots is such that individuals are put at unacceptable risk, crew rest is jeopardized and performance is affected adversely. Such operations, though arguably unavoidable during emergencies, are unacceptable during normal operations. Therefore, the second category of unsafe supervision, *planned inappropriate operations*, was created to account for these failures (Table 3).

Consider the issue of improper crew pairing. It is well known that when very senior, dictatorial captains are paired with very junior, weak first officers, communication and coordination problems are likely to occur. For example, on Jan. 13, 1982, the first officer of a Boeing 737 told the captain four times

**Categories of Unsafe Supervision**



Source: U.S. Federal Aviation Administration

**Figure 4**

## Table 3
## Selected Examples of Unsafe Supervision

**Inadequate Supervision**
- Failed to provide guidance
- Failed to provide operational doctrine
- Failed to provide oversight
- Failed to provide training
- Failed to track qualifications
- Failed to track performance

**Planned Inappropriate Operations**
- Failed to provide correct data
- Failed to provide adequate brief time
- Improper manning
- Mission not in accordance with rules/regulations
- Provided inadequate opportunity for crew rest

**Failed to Correct a Known Problem**
- Failed to correct document in error
- Failed to identify an at-risk pilot
- Failed to initiate corrective action
- Failed to report unsafe tendencies

**Supervisory Violations**
- Authorized unnecessary hazard
- Failed to enforce rules and regulations
- Authorized unqualified crew for flight

Note: This is not a complete listing.

Source: U.S. Federal Aviation Administration

that something was "not right" during their departure from Washington (D.C., U.S.) National Airport; nevertheless, the captain did not reject the takeoff (NTSB, 1982). Of the 79 occupants, 74 occupants were killed when the aircraft struck a bridge and came to rest in water. NTSB said, in its final report, that the probable cause of the accident was "the flight crew's failure to use engine anti-ice during ground operation and takeoff, their decision to take off with snow/ice on the airfoil surfaces of the aircraft and the captain's failure to reject the takeoff during the early stage when his attention was called to anomalous engine-instrument readings."

**Failure to Correct a Known Problem.** This category of known unsafe supervision refers to those instances in which deficiencies among individuals, equipment, training or other related safety areas are known to the supervisor, yet are allowed to continue (Table 3). For example, it is not uncommon for accident investigators to interview the pilot's friends, colleagues and supervisors after a fatal accident only to find out that they "knew it would happen to him some day." If the supervisor knew that a pilot was incapable of flying safely and allowed the flight anyway, the supervisor clearly did the pilot no favors. The failure to correct the behavior, either through remedial training or, if necessary, removal from flight status, essentially signed the pilot's death warrant — not to mention that of others who may have been on board.

Likewise, the failure to consistently correct or discipline inappropriate behavior fosters an unsafe atmosphere that promotes the violation of rules. Aviation history is rich with reports by pilots who tell hair-raising stories of their exploits and barnstorming low-level flights (the infamous "been there, done that"). While entertaining to some, they often serve to promulgate a perception of tolerance and one-upmanship until one day someone ties the low-altitude flight record of ground level. Indeed, the failure to report these unsafe tendencies and initiate corrective actions is yet another example of the failure to correct known problems.

**Supervisory Violations.** *Supervisory violations,* on the other hand, are reserved for those instances in which existing rules and regulations are willfully disregarded by supervisors (Table 3). Although arguably rare, supervisors have been known occasionally to violate the rules and doctrine when managing their assets. For example, there have been occasions when individuals were permitted to operate an aircraft without current qualifications or a license. Likewise, it can be argued that failing to enforce existing rules and regulations or flaunting authority also are violations at the supervisory level. While rare and possibly difficult to identify, such practices are a flagrant violation of the rules.

## Organizational Influences

As noted previously, fallible decisions of upper-level management directly affect supervisory practices, as well as the conditions and actions of operators. Unfortunately, these organizational errors often go unnoticed by safety professionals because of the lack of a clear framework from which to investigate them. Generally speaking, the most elusive of latent failures revolve around issues related to resource management, organizational climate and operational processes, as shown in Figure 5.

**Resource Management.** This category encompasses the realm of corporate-level decision making regarding the allocation

**Organizational Factors Influencing Accidents**

Source: U.S. Federal Aviation Administration

**Figure 5**

and maintenance of organizational assets such as human resources (personnel), monetary assets and equipment/facilities (Table 4). Generally, corporate decisions about how such resources should be managed center on two distinct objectives — the goal of safety and the goal of on-time, cost-effective operations. In times of prosperity, both objectives can be balanced easily and satisfied fully. As mentioned earlier, there also may be times of fiscal austerity that demand some give-and-take between the two. Unfortunately, history tells us that safety can be the loser in such battles; safety and training are often the first to be cut in organizations having financial difficulties. If cutbacks in such areas are too severe, flight proficiency may suffer and the best pilots may leave the organization.

### Table 4
### Selected Examples of Organizational Influences

**Resource/Acquisition Management**
- Human resources
  - Selection
  - Staffing/manning
  - Training
- Monetary/budget resources
  - Excessive cost cutting
  - Lack of funding
- Equipment/facility resources
  - Poor design
  - Purchase of unsuitable equipment

**Organizational Climate**
- Structure
  - Chain-of-command
  - Delegation of authority
  - Communication
  - Formal accountability for actions
- Policies
  - Hiring and firing
  - Promotion
  - Drugs and alcohol
- Culture
  - Norms and rules
  - Values and beliefs
  - Organizational justice

**Organizational Process**
- Operations
  - Tempo
  - Time pressure
  - Production quotas
  - Incentives
  - Measurement/appraisal
  - Schedules
  - Deficient planning
- Procedures
  - Standards
  - Clearly defined objectives
  - Documentation
  - Instructions
- Oversight
  - Risk management
  - Safety programs

Note: This is not a complete listing.

Source: U.S. Federal Aviation Administration

Excessive cost-cutting also could result in reduced funding for new equipment or the purchase of equipment that is designed inadequately for the type of operations conducted by the company. Other trickle-down effects include poorly maintained equipment and workspaces, and the failure to correct known flaws in existing equipment. The result is a scenario involving unseasoned, less-skilled pilots flying old and poorly maintained aircraft under the least desirable conditions and schedules.

**Organizational Climate.** This category refers to a broad class of organizational variables that influence worker performance. Formally, it was defined as the “situationally based consistencies in the organization’s treatment of individuals” (Jones, 1988). In general, however, organizational climate can be viewed as the working atmosphere within the organization. One telltale sign of an organization’s climate is its structure, as reflected in the chain-of-command, delegation of authority and responsibility, communication channels and formal accountability for actions (Table 4). As on the flight deck, communication and coordination are vital within an organization. If management and staff are not communicating, or if no one knows who is in charge, organizational safety clearly suffers and accidents occur (Muchinsky, 1997).

An organization’s policies and culture also are good indicators of its climate. Policies are official guidelines that direct management’s decisions about such things as hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, and the use of safety equipment. Culture, on the other hand, refers to the unofficial or unspoken rules, values, attitudes, beliefs and customs of an organization. Culture is “the way things really get done around here.”

When policies are ill-defined, adversarial or conflicting, or when they are supplanted by unofficial rules and values, confusion occurs within the organization. Indeed, there are some corporate managers who are quick to give “lip service” to official safety policies while in a public forum, but then overlook such policies when operating behind the scenes. Safety is bound to suffer under such conditions.

**Organizational Process.** This category refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standardized operating procedures and formal methods for maintaining checks and balances (oversight) between the work force and management. For example, such factors as tempo, time pressures, incentive systems and work schedules are factors that can adversely affect safety (Table 4). As stated earlier, there may be instances when those within the upper echelon of an organization determine that it is necessary to increase the tempo to a point that overextends a supervisor's staffing capabilities. Therefore, a supervisor may resort to inadequate scheduling procedures that jeopardize crew rest and produce inadequate crew pairings, putting pilots at increased risk. Organizations should have procedures in place to address such contingencies, as well as oversight programs to monitor such risks.

Not all organizations have these procedures, nor do they engage in an active process of monitoring pilot errors and human factors problems via anonymous reporting systems and safety audits. As such, supervisors and managers often are unaware of the problems before an accident occurs. Indeed, it has been said that "an accident is one incident too many" (Reinhart, 1996). It is incumbent upon any organization to fervently seek out the holes in the cheese and plug them up, before an accident occurs.

## Conclusion

The HFACS framework bridges the gap between theory and practice by providing investigators with a comprehensive, user-friendly tool for identifying and classifying the human causes of aviation accidents. The system, which is based upon Reason's (1990) model of latent failures and active failures (Shappell and Wiegmann, 1997a), encompasses all aspects of human error, including the conditions of operators and organizational failure. Nevertheless, HFACS only contributes to an already burgeoning list of human error taxonomies if it does not prove useful in the operational setting. HFACS recently has been employed by the U.S. military for use in aviation accident investigation and analysis. To date, HFACS has been applied to the analysis of human factors data from approximately 1,000 military aviation accidents. Throughout this process, the reliability and content validity of HFACS has been tested repeatedly and demonstrated (Shappell and Wiegmann, 1997c).

Given that accident databases can be analyzed reliably using HFACS, the next logical question is whether anything unique will be identified. Early indications within the military suggest that the HFACS framework has been instrumental in the identification and analysis of global human factors safety issues (e.g., trends in pilot proficiency; Shappell et al. 1999), specific accident types (e.g., controlled flight into terrain [CFIT][2]; Shappell and Wiegmann, 1997b) and human factors problems such as CRM failures (Wiegmann and Shappell, 1999). Consequently, the systematic application of HFACS to the analysis of human factors accident data has afforded the U.S. Navy and the U.S. Marine Corps (for which the original taxonomy was developed) the ability to develop objective, data-driven intervention strategies. In a sense, HFACS has illuminated those areas ripe for intervention rather than relying on individual research interests not necessarily tied to saving lives or preventing aircraft losses.

Additionally, the HFACS framework and the insights gleaned from database analyses have been used to develop innovative accident investigation methods that have enhanced both the quantity and quality of the human factors information gathered during accident investigations. Not only are safety investigators better suited to examine human error in the field but, using HFACS, they can now track those areas (the holes in the cheese) responsible for the accidents, as well. Only now is it possible to track the success or failure of specific intervention programs designed to reduce specific types of human error and subsequent aviation accidents. In so doing, research investments and safety programs can be readjusted or reinforced to meet the changing needs of aviation safety.

Recently, these accident analysis and investigative techniques, developed and proven in the military, have been applied to the analysis and investigation of U.S. civil aviation accidents (Shappell and Wiegmann, 1999). Specifically, the HFACS framework is currently being used to systematically analyze both commercial and general aviation accident data to explore the underlying human factors problems associated with these events. The framework also is being employed to develop improved methods and techniques for investigating human factors issues during actual civil aviation accident investigations by FAA and NTSB. Initial results of this project have begun to highlight human factors areas in need of further safety research. In addition, it is anticipated that HFACS will provide the fundamental information and tools needed to develop a more effective and accessible human factors accident database for civil aviation.

In summary, the development of the HFACS framework has proven to be a valuable first step in the establishment of a larger military and civil aviation safety program. The ultimate goal of this, and any other, safety program is to reduce the aviation accident rate through systematic, data-driven investment.♦

[FSF editorial note: To ensure wider distribution in the interest of aviation safety, this report has been reprinted from the U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine's *The Human Factors Analysis and Classification System — HFACS*, DOT/FAA/AM–007/7, February 2000. Some editorial changes were made by FSF staff for clarity and for style. Scott A. Shappell, Ph.D., is manager of the Human Factors Research Laboratory at the FAA Civil Aeromedical Institute. Douglas A. Wiegmann, Ph.D., is an assistant professor at the University of Illinois at Urbana-Champaign.]

## Notes

1. Reason's original work involved operators of a nuclear power plant. For the purposes of this manuscript, *operators* here refers to pilots, maintainers, supervisors and other humans involved in aviation.

2. 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 phases, which typically comprise about 16 percent of the average flight duration of a large commercial jet.

## References

Bird, F. (1974). *Management Guide to Loss Control*. Atlanta, GA: Institute Press.

Heinrich, H.W., Petersen, D., and Roos, N. (1980). *Industrial accident prevention: A safety management approach* (5th ed.). New York: McGraw-Hill.

Helmreich, R.L., and Foushee, H.C. (1993). Why crew resource management? Empirical and theoretical bases of human factors training in aviation. In E.L. Wiener, B.G. Kanki and R.L. Helmreich (Eds.), *Cockpit resource management* (pp. 3–45). San Diego, CA: Academic Press.

Jones, A.P. (1988). Climate and measurement of consensus: A discussion of "organizational climate." In S.G. Cole, R.G. Demaree and W. Curtis, (Eds.), *Applications of Interactionist Psychology: Essays in Honor of Saul B. Sells* (pp. 283–90). Hillsdale, NJ: Earlbaum.

Murray, S.R. (1997). Deliberate decision making by aircraft pilots: A simple reminder to avoid decision making under panic. *The International Journal of Aviation Psychology*, 7, 83–100.

Muchinsky, P.M. (1997). *Psychology applied to work* (5th ed.). Pacific Grove, CA: Brooks/Cole Publishing Co.

U.S. National Transportation Safety Board (NTSB) (1972). *Eastern Air Lines, Inc. L-1011, N310EA, Miami, Florida, December 19, 1972 (Tech. Report NTSB-AAR-73-14).*

NTSB. (1982). *Air Florida, Inc., Boeing 737-222, N62AF, Collision with 14th Street Bridge, Near Washington National Airport, Washington, D.C., January 13, 1982* (Tech. Report NTSB-AAR-82-8).

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents*, 4, 311–33.

Reason, J. (1990). *Human Error*. New York: Cambridge University Press.

Reinhart, R.O. (1996). *Basic Flight Physiology* (2nd ed.). New York: McGraw-Hill.

Senders, J.W., and Moray, N.P. (1991). *Human error: Cause, prediction and reduction.* Hillsdale, NJ: Earlbaum.

Shappell, S.A., and Wiegmann, D.A. (1996). U.S. naval aviation mishaps 1977–92: Differences between single- and dual-piloted aircraft. *Aviation, Space, and Environmental Medicine*, 67, 65–9.

Shappell, S.A., and Wiegmann D.A. (1997a). A human error approach to accident investigation: The taxonomy of unsafe operations. *The International Journal of Aviation Psychology*, 7, 269–91.

Shappell, S.A., and Wiegmann, D.A. (1997b). Why would an experienced aviator fly a perfectly good aircraft into the ground? In *Proceedings of the Ninth International Symposium on Aviation Psychology*, (pp. 26–32). Columbus, OH: The Ohio State University.

Shappell, S.A., and Wiegmann, D.A. (1997). A reliability analysis of the Taxonomy of Unsafe Operations. *Aviation, Space, and Environmental Medicine*, 68, 620.

Shappell, S.A., and Wiegmann, D.A. (1999a). Human error in commercial and corporate aviation: An analysis of FAR Part 121 and 135 mishaps using HFACS. *Aviation, Space, and Environmental Medicine*, 70, 407.

Shappell, S., Wiegmann, D., Fraser, J., Gregory, G., Kinsey, P., and Squier, H (1999b). Beyond mishap rates: A human factors analysis of U.S. Navy/ Marine Corps TACAIR and rotary wing mishaps using HFACS. *Aviation, Space, and Environmental Medicine*, 70, 416–17.

Wiegmann, D.A., and Shappell, S.A. (1997). Human factors analysis of post-accident data: Applying theoretical taxonomies of human error. *The International Journal of Aviation Psychology*, 7, 67–81.

Wiegmann, D.A., and Shappell, S.A. (1999). Human error and crew resource management failures in Naval aviation mishaps: A review of U.S. Naval Safety Center data, 1990–96. *Aviation, Space, and Environmental Medicine*, 70, 1147–51.

## Further Reading From FSF Publications

Hobbs, Alan; Williamson, Ann. "Survey Assesses Safety Attitudes of Aviation Maintenance Personnel in Australia." *Aviation Mechanics Bulletin* Volume 48 (November–December 2000).

FSF Editorial Staff. "Embraer Bandeirante Strikes Mountain Ridge During Trans-island Flight in Fiji." *Accident Prevention* Volume 57 (November 2000).

FSF Editorial Staff. "Noncompliance With Departure Procedures Sets Course for Impact With Mountain." *Accident Prevention* Volume 57 (August 2000).

FSF Editorial Staff. "Low Engine Oil Pressure, Severe Vibration Prompt Pilatus PC-12 Forced Landing." *Accident Prevention* Volume 57 (June 2000).

U.S. National Transportation Safety Board. "Controlled Flight Into Terrain; Korean Air Flight 801; Boeing 757-300, HL7568; Nimitz Hill, Guam; August 6, 1997." *Flight Safety Digest* Volume 19 (May–July 2000).

FSF Editorial Staff. "Floatplane Strikes Ridge During Sightseeing Flight." *Accident Prevention* Volume 57 (April 2000).

FSF Editorial Staff. "Use of Standard Phraseology by Flight Crews and Air Traffic Controllers Clarifies Aircraft Emergencies." *Airport Operations* Volume 26 (March–April 2000).

FSF Editorial Staff. "Fuel Imbalance Cited in Learjet 35A Control Loss." *Accident Prevention* Volume 57 (February 2000).

FSF Editorial Staff. "Cargo Airplane Strikes Building During Rejected Takeoff." *Accident Prevention* Volume 57 (January 2000).

Sallee, G.P.; Gibbons, D.M. "Propulsion System Malfunction Plus Inappropriate Crew Response (PSM+ICR)." *Flight Safety Digest* Volume 18 (November–December 1999).

Wilson, Dale R. "Darkness Increases Risks of Flight." *Human Factors and Aviation Medicine* Volume 46 (November–December 1999).

Wiener, Earl L.; Chute, Rebecca D.; Moses, John H. "Transition to Glass: Pilot Training for High-technology Transport Aircraft." *Flight Safety Digest* Volume 18 (June–August 1999): 1–136.

Australian Bureau of Air Safety Investigation. "Advanced-technology Aircraft Safety Survey Report." *Flight Safety Digest* Volume 18 (June–August 1999): 137–216.

FSF Editorial Staff. "Learjet Strikes Terrain When Crew Tracks False Glideslope Indication and Continues Descent Below Published Decision Height." *Accident Prevention* Volume 56 (June 1999).

FSF Icarus Committee. "Aviation Grapples with Human-factors Accidents." *Flight Safety Digest* Volume 18 (May 1999).

FSF Editorial Staff. "B-757 Damaged by Ground Strike During Late Go-around from Visual Approach." *Accident Prevention* Volume 56 (May 1999).

Caldwell, J. Lynn. "Managing Sleep for Night Shifts Requires Personal Strategies." *Human Factors and Aviation Medicine* Volume 46 (March–April 1999).

Veillette, Patrick R. "Crew Error Cited as Major Cause of U.S. Aerial Fire Fighting Accidents." *Flight Safety Digest* Volume 18 (April 1999).

Sumwalt, Robert L. III. "Enhancing Flight-crew Monitoring Skills Can Increase Flight Safety." *Flight Safety Digest* Volume 18 (March 1999).

FSF Editorial Staff. "Ice Ingestion Causes Both Engines to Flame Out During Air-taxi Turboprop's Final Approach." *Accident Prevention* Volume 56 (February 1999).

FSF ALAR Task Force. "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999).

FSF Editorial Staff. "MD-83 Crew Continues Flight Operations with Suspected Engine Malfunction." *Accident Prevention* Volume 55 (October 1998).

FSF Editorial Staff. "Overcoming Effects of Stress Offers Greatest Opportunity to Sleep Well." *Human Factors and Aviation Medicine* Volume 45 (July–August 1998).

Simmon, David A. "Boeing 757 CFIT Accident at Cali, Colombia, Becomes Focus of Lessons Learned." *Flight Safety Digest* Volume 17 (May–June 1998).

Pope, John A. "Mixed-crew Operations Require Special Consideration in Company Flight Manuals." *Flight Safety Digest* Volume 17 (April 1998).

FSF Editorial Staff. "Boeing 737 Pilot Flying Selects Incorrect Altitude in Holding Pattern, Causes Dangerous Loss of Separation with MD-81." *Accident Prevention* Volume 55 (April 1998).

Mohler, Stanley R. "Continued Caution Urged for Pilot Use of Alcohol." *Human Factors and Aviation Medicine* Volume 45 (March–April 1998).

FSF Editorial Staff. "Boeing 767 Descends Below Glide Path, Strikes Tail on Landing." *Accident Prevention* Volume 55 (February 1998).

Mohler, Stanley R. "Pilot Fatigue Manageable, But Remains Insidious Threat." *Human Factors and Aviation Medicine* Volume 45 (January–February 1998).

FSF Editorial Staff. “Studies Investigate the Role of Memory in the Interaction Between Pilots and Air Traffic Controllers.” *Airport Operations* Volume 24 (January–February 1998).

FSF Editorial Staff. “MD-88 Strikes Approach Light Structure in Nonfatal Accident.” *Accident Prevention* Volume 54 (December 1997).

FSF Editorial Staff. “Inadequate Visual References in Flight Pose Threat of Spatial Disorientation.” *Human Factors and Aviation Medicine* Volume 44 (November–December 1997).

FSF Editorial Staff. “Collision with Antenna Guy Wire Severs Jet’s Wing During Nonprecision Approach.” *Accident Prevention* Volume 54 (October 1997).

Uplinger, Shannon. “English-language Training for Air Traffic Controllers Must Go Beyond Basic ATC Vocabulary.” *Airport Operations* Volume 23 (September–October 1997).

FSF Editorial Staff. “Preparing for Last-minute Runway Change, Boeing 757 Flight Crew Loses Situational Awareness, Resulting in Collision with Terrain.” *Accident Prevention* Volume 54 (July–August 1997).

FSF Editorial Staff. “Flight Crew’s Failure to Perform Landing Checklist Results in DC-9 Wheels-up Landing.” *Accident Prevention* Volume 54 (May 1997).

FSF Editorial Staff. “Captain Rejects Takeoff as Boeing 757 Veers off Slippery Runway.” *Accident Prevention* Volume 54 (March 1997).

FSF Fatigue Countermeasures Task Force. “Final Report: Principles and Guidelines for Duty and Rest Scheduling in Corporate and Business Aviation.” *Flight Safety Digest* Volume 16 (February 1997).

Koenig, Robert L. “FAA Identifies CRM-related Issues and Training Needs in Flight-inspection Missions.” *Human Factors and Aviation Medicine* Volume 44 (January–February 1997).

Koenig, Robert L. “Excess Words, Partial Readbacks Score High in Analysis of Pilot-ATC Communication Errors.” *Airport Operations* Volume 23 (January–February 1997).

FSF Editorial Staff. “Learjet MEDEVAC Flight Ends in Controlled-flight-into-terrain (CFIT) Accident.” *Accident Prevention* Volume 54 (January 1997).

FSF Icarus Committee. “Aviation Safety: Airline Management Self-audit.” *Flight Safety Digest* Volume 15 (November 1996).

FSF Editorial Staff. “After Loud Bang, Captain Rejects Takeoff; DC-10 Runs Off End of Runway.” *Accident Prevention* Volume 53 (October 1996).

U.S. Federal Aviation Administration Human Factors Team. “The Interfaces Between Flightcrews and Modern Flight Deck Systems.” *Flight Safety Digest* Volume 15 (September–October 1996).

Mohler, Stanley R. “Routine Lifestyle Choices Can Reduce Performance and Increase Susceptibility to Diseases.” *Human Factors and Aviation Medicine* Volume 43 (September–October 1996).

FSF Editorial Staff. “Flight Crew of DC-10 Encounters Microburst During Unstabilized Approach, Ending in Runway Accident.” *Accident Prevention* Volume 53 (August 1996).

FSF Editorial Staff. “During Three-engine Takeoff in DC-8, Captain Makes Premature Liftoff, Resulting in Stall and Collision With Terrain.” *Accident Prevention* Volume 53 (May 1996).

FSF Editorial Staff. “Commuter Captain Fails to Follow Emergency Procedures After Suspected Engine Failure, Loses Control of the Aircraft During Instrument Approach.” *Accident Prevention* Volume 53 (April 1996).

# Data Show 421 Fatal Accidents Involving Large Jets and Turboprops in 1990s

***A study by the U.K. Civil Aviation Authority shows that the number of accidents each year during the period ranged from a low of 37 in 1998 to a high of 48 in 1995.***

*FSF Editorial Staff*

The annual number of fatal accidents worldwide involving large jet airplanes and turboprop airplanes (those weighing more than 5,700 kilograms/12,500 pounds) remained relatively stable from 1990 through 1999, the U.K. Civil Aviation Authority Accident Analysis Group (AAG) said.

Data compiled by AAG show that 421 accidents occurred during the 10-year period (Figure 1, page 30). (The data exclude accidents caused by terrorism or sabotage and those that occurred during test operations or military-type operations.) Fewer accidents — 37 — occurred in 1998 than in any other year during the period; the highest number of accidents was 48 in 1995.

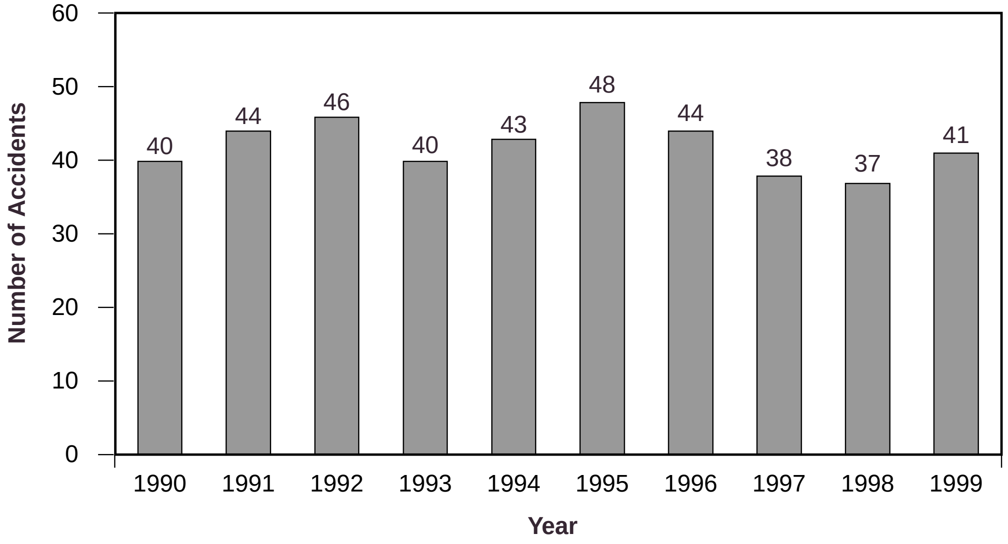
The fatal accidents resulted in 11,793 fatalities during the 10-year period (Figure 2, page 30). The lowest number of fatalities was 604 in 1990; the highest number of fatalities was 2,100 in 1996.

AAG said that, of the 421 fatal accidents, 356 accidents (85 percent) involved air carrier aircraft; the remaining 15 percent of fatal accidents involved business jets. The following findings are based on data available from the 356 air carrier aircraft accidents:

- Figure 3 (page 31) shows the five most common primary causal factors (the most dominant causal factors, as determined by AAG) and the number of fatal accidents in each class of aircraft in which those primary causal factors were determined to have been involved. About 60 percent of the accidents were associated with one of the five primary causal factors; the remaining accidents were not included in this figure. The most common primary causal factor was “lack of positional awareness in the air.” For three classes of aircraft — Western-built turboprops, Eastern-built jets and Eastern-built turboprops — lack of positional awareness in the air was the most common primary causal factor in fatal accidents (although Eastern-built jets were associated with an equal percentage of fatal accidents in which the primary causal factor was determined to be “omission of action/inappropriate action”). Western-built jets most frequently were involved in fatal accidents in which the primary causal factor was omission of action/inappropriate action;

- Figure 4 (page 31) shows the total number of causal factors associated with the accidents. The number of

**Large* Jet Aircraft and Turboprop Aircraft Fatal Accidents Worldwide, 1990–1999**

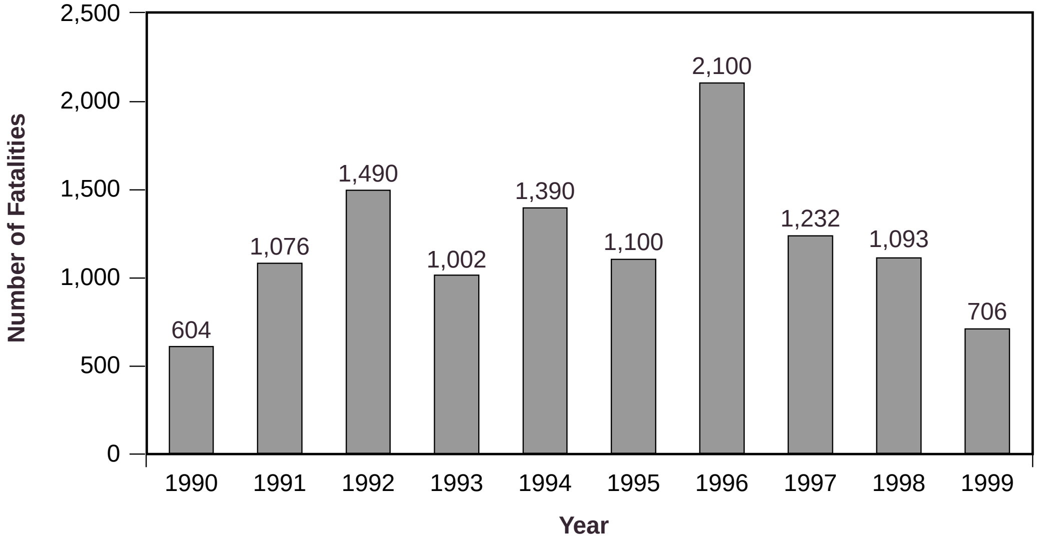


* Gross weight greater than 5,700 kilograms/12,500 pounds.

Source: U.K. Civil Aviation Authority

Figure 1

**Fatalities Resulting From Large* Jet Aircraft and Turboprop Aircraft Accidents Worldwide, 1990–1999**



* Gross weight greater than 5,700 kilograms/12,500 pounds.

Source: U.K. Civil Aviation Authority

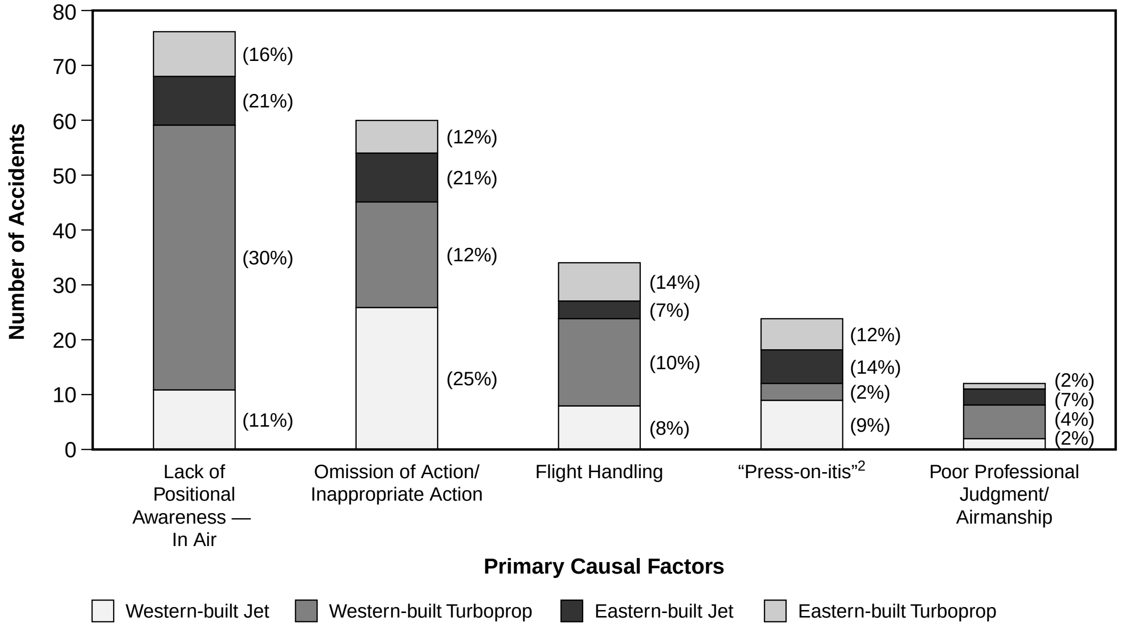
Figure 2

causal factors most frequently associated with a single accident was three; the highest number of factors was 11 in the Dec. 20, 1995, accident involving an American Airlines Boeing 757 that struck mountainous terrain near Cali, Colombia. Of the 163 passengers and crew, four passengers survived.[1] (Nine percent of fatal accidents were recorded as having no causal factors because of a lack of information about those accidents.);

- Figure 5 (page 32) shows the five most common circumstantial factors (factors that contributed to the

*continued on page 32.*

**Primary Causal Factors of Large[1] Air Carrier Jet Aircraft and Turboprop Aircraft Fatal Accidents Worldwide, 1990–1999**



Note: Percentages for each aircraft category do not total 100 because accidents associated with other primary risk factors are not included.

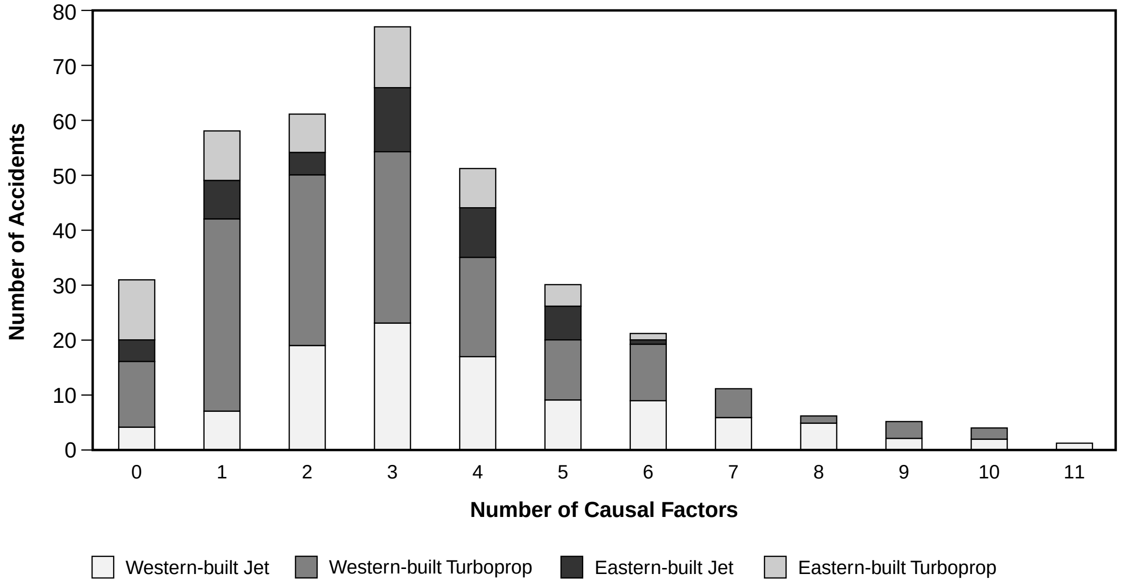
[1] Gross weight greater than 5,700 kilograms/12,500 pounds.

[2] "Press-on-itis" has been defined as continuing toward the destination despite a lack of readiness of the airplane or flight crew.

Source: U.K. Civil Aviation Authority

Figure 3

**Number of Causal Factors Allocated in Large* Air Carrier Jet Aircraft and Turboprop Aircraft Fatal Accidents Worldwide, 1990–1999**



* Gross weight greater than 5,700 kilograms/12,500 pounds.

Source: U.K. Civil Aviation Authority

Figure 4

outcome but were not considered instrumental to the accident). More than 90 percent of the accidents involved at least one of the five circumstantial factors;

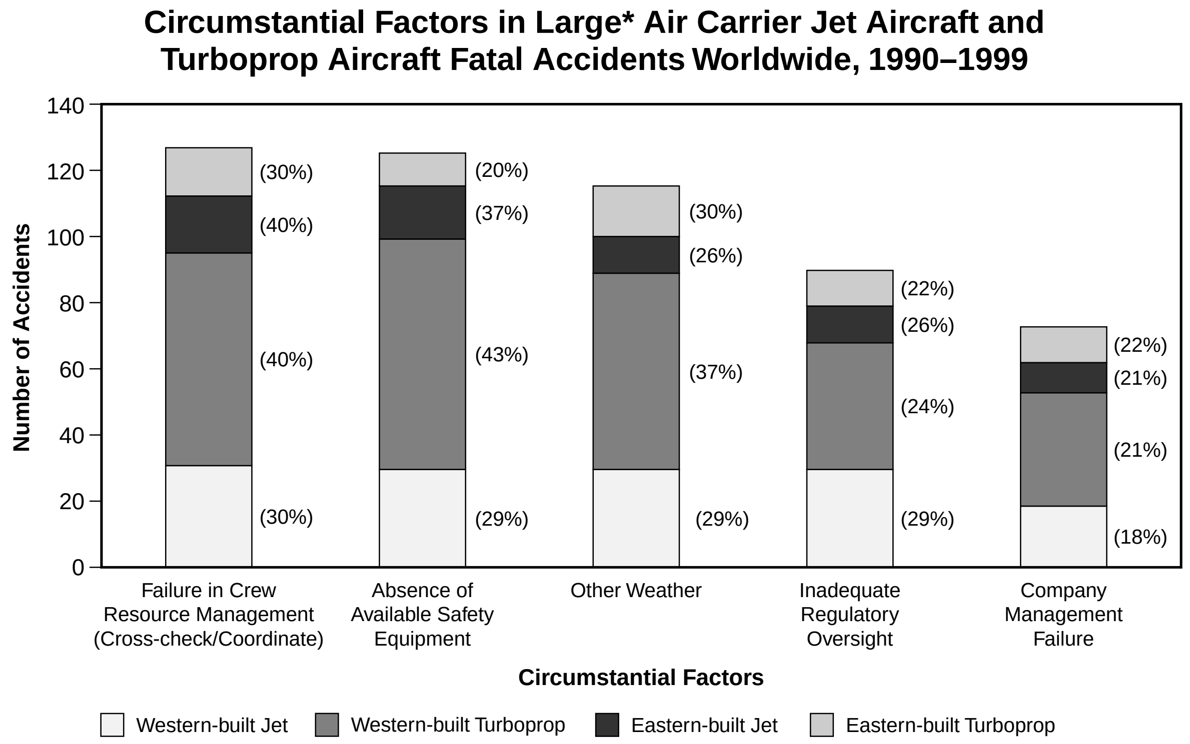
- Figure 6 (page 33) shows the five most common consequences. Of the five, “collision with terrain/water/obstacle” was associated most frequently with an accident; and,

- Figure 7 (page 33) shows the most common combinations of primary causal factors and consequences. AAG said that the five combinations were associated with 47 percent of the accidents. The most common combination was “lack of positional awareness in the air,” resulting in controlled flight into terrain;[2] the combination was present in 21 percent of the fatal accidents.♦

## Notes

1. In its final report on the accident, the Aeronáutica Civil of the Republic of Colombia said that the probable causes of the accident were “the flight crew’s failure to adequately plan and execute the approach to Runway 19 at SKCL [Cali’s Alfonso Bonilla Aragon International Airport], and their inadequate use of automation; failure of the flight crew to discontinue the approach into Cali, despite numerous cues alerting them of the inadvisability of continuing the approach; the lack of situational awareness of the flight crew regarding vertical navigation, proximity to terrain and the relative location of critical radio aids; [and] failure of the flight crew to revert to basic radio navigation at the time when the FMS [flight management system]-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight.”

2. 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 phases, which typically comprise about 16 percent of the average flight duration of a large commercial jet.

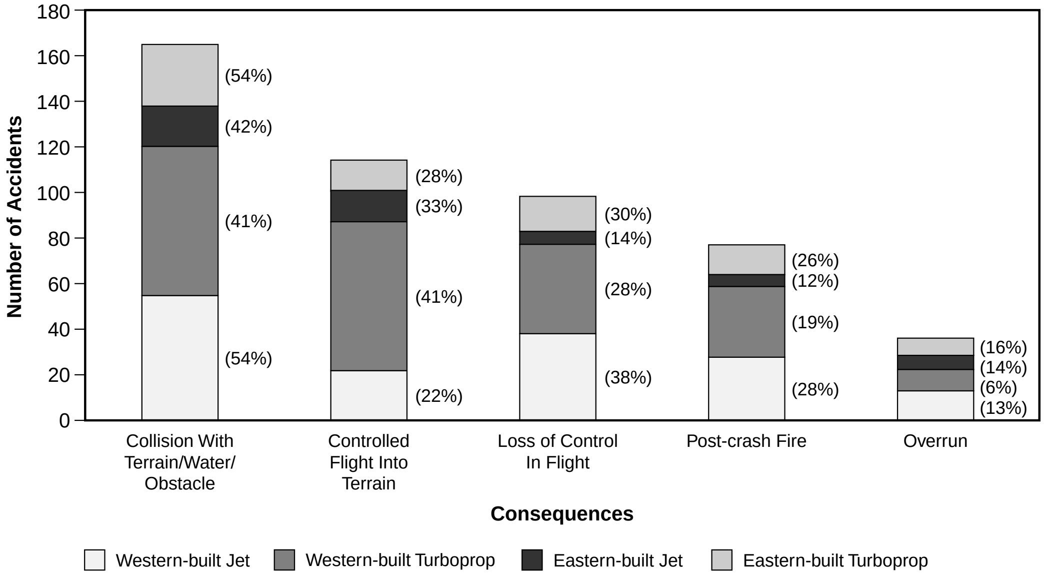


Note: Percentages for each aircraft category do not total 100 because many accidents were associated with more than one circumstantial factor.

* Gross weight greater than 5,700 kilograms/12,500 pounds.

Source: U.K. Civil Aviation Authority

**Figure 5**



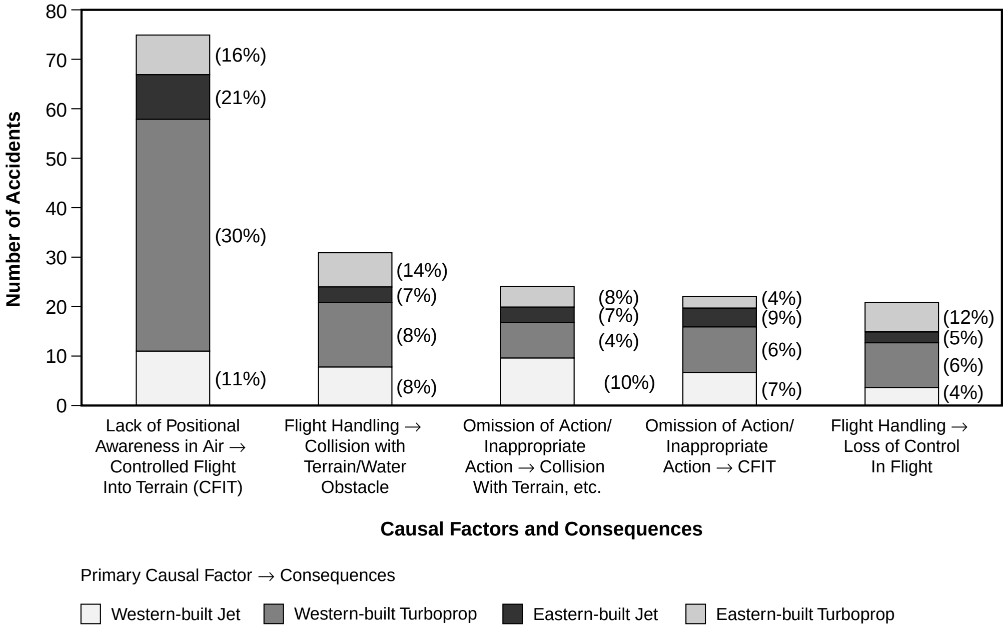
**Consequences of Large* Air Carrier Jet Aircraft And Turboprop Aircraft Accidents Worldwide, 1990–1999**

Note: Percentages for each aircraft category do not total 100 because many accidents were associated with more than one consequence.

* Gross weight greater than 5,700 kilograms/12,500 pounds.

Source: U.K. Civil Aviation Authority

Figure 6



**Most Common Combinations of Primary Causal Factors and Consequences in Large* Air Carrier Jet Aircraft and Turboprop Aircraft Fatal Accidents Worldwide, 1990–1999**

Note: Percentages for each aircraft category do not total 100 because accidents associated with other combinations are not included.

* Gross weight greater than 5,700 kilograms/12,500 pounds.

Source: U.K. Civil Aviation Authority

Figure 7

## Publications Received at FSF
## Jerry Lederer Aviation Safety Library

# FAA Publishes Guidelines for Use of Barometric Vertical Navigation Equipment For Instrument Approaches

***The advisory circular describes the types of equipment that FAA considers acceptable.***

*FSF Library Staff*

## Advisory Circulars

***Use of Barometric Vertical Navigation (VNAV) for Instrument Approach Operations Using Decision Altitude***. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 90-97. Oct. 19, 2000. 6 pp. Available through GPO.*

This document identifies the types of aircraft equipment that FAA has determined meet U.S. Federal Aviation Regulations Part 97 requirements for use in barometric VNAV approach operations. Approved VNAV capability allows for guided and stabilized descent paths during instrument approach procedures that otherwise have no vertical guidance. The aircraft eligibility and approval processes described in the AC support the goals of the FAA Safer Skies Initiative and the U.S. Secretary of Transportation Safety Summit to eliminate controlled-flight-into-terrain (CFIT) accidents.

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 phases, which typically comprise about 16 percent of the average flight duration of a large commercial jet.

***Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns***. U.S. Federal Aviation Administration Advisory Circular (AC) 150/5220-22. Oct. 6, 2000. 2 pp. Available through GPO.*

The AC contains standards for planning, design and installation of EMAS materials in runway safety areas to improve safety during runway overruns. EMAS refers to high-energy-absorbing engineered materials that are selected for strength and reliability and that will "reliably and predictably crush under the weight of an aircraft," the AC says.

The principal change in the standards applies to areas that are longer than required for stopping an aircraft that exits the runway at 70 knots. The AC says that, in such situations, the EMAS should be installed "as far from the runway end as practicable."

"Such placement decreases the possibility of damage to the system from short overruns or undershoots, and results in a more economical system by considering the deceleration capabilities of the existing runway system," the AC says.

***Taxi, Takeoff and Landing Roll Design Loads***. U.S. Federal Aviation Administration Advisory Circular (AC) 25.491-1. Oct. 30, 2000. 13 pp. Tables. Available through GPO.*

This AC provides guidance information for complying with U.S. Federal Aviation Regulations Part 25.491 requirements for ground loads during taxi, takeoff and landing roll. The AC includes a profile of one runway at San Francisco (California, U.S.) International Airport and describes acceptable commercial airplane operations on paved runways and taxiways.

## Reports

***Major Management Challenges and Program Risks: Department of Transportation***. U.S. General Accounting Office (GAO). January 2001. GAO-01-253. 62 pp. Figures, tables. Available through GAO.**

The GAO, which conducts research for the U.S. Congress, reviewed major performance and accountability challenges facing the U.S. Department of Transportation (DOT). This report includes brief summaries of actions that have been taken or currently are under way and additional actions recommended by the GAO. Summaries include goals for aviation safety and security, a U.S. Federal Aviation Administration cost-accounting system, and deregulation of the airline industry. The report says that DOT failed to meet its 1999 performance goals in four aviation safety program areas: reduction of the fatal accident rate in commercial aviation, reduction of the number of runway incursions, reduction of the rate of errors in maintaining safe separation between aircraft, and reduction of the frequency at which aircraft enter airspace without prior coordination.

***The Computerized Analysis of ATC Tracking Data for an Operational Evaluation of CDTI/ADS-B Technology***. Mills, S.H. U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. DOT/FAA/AM-00/30. September 2000. 9 pp. Figures. Available through NTIS.***

The Cargo Airlines Association and FAA evaluated the effectiveness of two new high-technology systems for cockpit operations and air traffic control (ATC) operations — cockpit display of traffic information (CDTI) and automatic dependent surveillance–broadcast (ADS–B). Thirteen aircraft types were flown in multiple traffic patterns for two parallel runways at an airport in Wilmington, Ohio, U.S. Human factors observers recorded data from the flight decks and control tower. ATC data also were recorded by the participating ATC facilities. To quantify and confirm the benefits of the new technologies, techniques were developed for computerized analysis of the data. This report describes the development of the assessment procedures and analysis tools, and the results of the analysis.

***The Effects of Performance Feedback on Air Traffic Control Team Coordination: A Simulation Study***. Bailey, L.L.; Thompson, R.C. U.S. Federal Aviation Administration Office of Aviation Medicine. DOT/FAA/AM-00/25. July 2000. 10 pp. Figures, tables. Available through NTIS.***

Crew resource management (CRM) generally refers to the effective coordination of efforts by individual flight crewmembers as they perform their individual and collective missions. The concept has been expanded to include aircraft dispatchers, flight attendants, maintenance personnel and air traffic control specialists (ATCS). CRM is being applied by ATCS to help manage individual sectors and to influence interactions with other ATCS. In this study, researchers employed video playback as a CRM skill-based training tool. A total of 240 participants in teams of four performed simulated radar-based air traffic control tasks, observed their own performances and identified factors that influenced crew coordination. Researchers examined the effectiveness of ATCS following video playback of their performances and concluded that such a technique is beneficial. ATCS were able to coordinate individual efforts and build team cohesion after viewing and evaluating their performances. Nevertheless, as aircraft density increased in the simulations, improvements in team coordination diminished. This result was identified as a topic for future study.♦

## Sources

* Superintendent of Documents
U.S. Government Printing Office (GPO)
Washington, D.C. 20402 U.S.
Internet: http://www.access.gpo.gov

** U.S. General Accounting Office (GAO)
P.O. Box 37050
Washington, D.C. 20013 U.S.
Internet: http://www.gao.gov

*** National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161 U.S.
Internet: http://www.ntis.org

## Accident/Incident Briefs

# Tire Leaves Wheel During Taxi for Takeoff

### *The incident followed separation of the inboard rim of the Boeing 747's wheel.*

*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**

## Fatigue Crack Cited in Wheel Assembly Failure

*Boeing 747. Minor damage. No injuries.*

While the airplane was being taxied for a night departure from an airport in England, the flight crew heard a bang and felt a bump. All anti-skid warning lights associated with the right-wing landing gear illuminated, and a passenger told the cabin crew that a tire had rolled from beneath the aircraft and across the grass next to the taxiway. Airport personnel inspected the airplane and found that the inboard rim of the no. 2 wheel (the front inboard wheel of the left-wing landing gear) had separated from the wheel, allowing the tire to roll off. The no. 1 wheel and the no. 2 wheel were replaced, and the airplane was towed to the gate to allow passengers to disembark. (Boeing 747 landing gear comprises a twin-wheel nose landing gear and a main landing gear configuration consisting of four four-wheel units — two body gear under the fuselage and two wing gear under the wings.)

Further inspection showed that fragments of the failed inboard rim had damaged the right-wing landing-gear door, the right-wing landing gear and the right-wing landing-gear folding door. A wiring conduit on the right-wing landing gear drag brace, which contained the anti-skid unit wiring, was severed in two places.

The inboard rim had fractured into three sections in the area where the inboard side joined the cylindrical section of the wheel hub. The accident report said that metallurgical inspection showed that all of the fracture surfaces "exhibited the characteristics of a single event overload … initiated by a high-cycle tension-fatigue crack in the bead radius of the rim, which had extended over a length [of] some four inches [10.2 centimeters]. The associated fracture characteristics suggested that this fatigue crack had initiated from a single point, possibly a surface defect."

The area had been shot-peened when the wheel was manufactured "to generate compressive stresses in the surface region of the radius," the report said. "After the wheel had been cleaned at the manufacturer's U.K. facility, it was readily apparent that the peening effect previously had been polished out over a length of some nine inches [22.9 centimeters] and that the fatigue-crack origin had been located within this polished band. The effect of this polishing had been to remove most of the compressive layer induced in the radius surface by the peening at manufacture."

Polishing also had removed the fatigue origin.

The wheel assembly (part no. 2603561) was an early version. When the incident occurred, the failed outboard half of the wheel had accumulated 7,174 cycles and 101 tire changes.

The wheel assembly was checked for cracks two months before the incident; no cracks were detected. The wheel assembly accumulated 84 cycles after the inspection and before the incident.

## Failed Bearing Prompts In-flight Engine Shutdown

*Boeing 727. No damage. No injuries.*

En route from England to Denmark on a night flight, the flight crew observed an "engine oil low" warning light illuminate for the no. 3 engine, as well as an increase in engine oil temperature and a decrease in oil pressure. The crew shut down the no. 3 engine and proceeded to the destination airport for a normal approach and landing.

An inspection by maintenance personnel showed that the in-flight loss of engine oil was caused by a failed bearing seal.

## Precautionary Landing Conducted After Fire in Galley Oven

*Airbus A340. Minor damage. No injuries.*

The airplane was in cruise flight at Flight Level 330 (33,000 feet) east of Japan when a flight attendant observed a small fire in the forward galley oven. The flight attendant used a Halon fire extinguisher to extinguish the fire and told the flight crew what had occurred.

The captain conducted a precautionary landing at an airport in Japan, where maintenance personnel examined the oven. The examination showed that the fire had been caused by grease that had ignited.

Air Taxi
Commuter

## Fire-warning Light Prompts Emergency Landing

*Fairchild SA227 Metro. No damage. No injuries.*

As the flight crew turned the airplane onto the downwind leg of the traffic pattern for landing at an airport in Australia, the left-engine fire-warning annunciator light illuminated. The engine was shut down, the annunciator light was extinguished, and the captain decided not to use the fire extinguisher. The flight crew conducted a single-engine landing.

The incident report said, "This was the third left-engine-fire indication the aircraft had experienced [in three months], the previous two having occurred over a two-week period. The [captain] was involved in all three events. During the first and second events, the fire-warning indications had remained illuminated following engine shutdown, and the [captain] had discharged the corresponding fire extinguisher into the engine fire zone on both those occasions. However, the [captain] chose not to discharge the fire extinguisher during the most recent event as the fire-warning indications had extinguished following the engine shutdown."

The operator's chief pilot supported the captain's decision.

The first event was caused by chafed insulation on a wire in the fire-warning system wiring harness. A maintenance inspection after the second event revealed "no fault that could have contributed to the activation of the fire-warning system," the report said. Nevertheless, the lower-turbine fire detector was repositioned because maintenance personnel believed that it might have been too close to the engine and might have caused a false fire indication. An investigation after the third event showed that a fire detector was operating at an incorrect temperature.

The report said that the decision not to use the fire extinguisher "was not in accordance with the requirements of the operator's approved phase-one emergency checklist procedures."

The report said, "As the [captain] had recently experienced two similar engine-fire indications in this aircraft, his response on this occasion may have been influenced by those recent events. However, the [captain's] decision not to activate the fire extinguisher placed heavy reliance on the extinguished fire-warning lights as an indicator that there was no longer a threat of fire. That decision … did not appear to take into account the possibility that a malfunction of the fire-warning system was masking a real fire.”

## Pilot Blames Inadvertent Flight Into Clouds for Accident

*Piper PA-31-350 Chieftain. Substantial damage. Two minor injuries.*

Day instrument meteorological conditions prevailed for the approach to an airport in the United States. The pilot said that he had been flying the aircraft at 1,700 feet and had begun a descent to traffic pattern altitude when he inadvertently flew into clouds or fog during a descending left turn. He said that he lost outside visual reference and that the airplane struck terrain at about 700 feet. The impact caused the left wing to separate from the airplane.

## Tail Wind Cited in Runway Overrun Accident

*Piper PA-32 Cherokee 260. Substantial damage. No injuries.*

In the hour before the airplane arrived at the private airstrip in New Zealand, the automatic weather-reporting system reported winds from the south-southeast at 16 knots to 18 knots, with a gust to 21 knots in the previous 20 minutes. The pilot told passengers that if conditions were not satisfactory, he would fly the airplane to an alternate airport.

The pilot entered downwind for a landing on Runway 27, a grass runway with an uphill slope. He estimated that winds were from the south-southeast at about 10 knots to 12 knots. The pilot described the final approach as normal “until short final, when increased tail wind was encountered,” the accident report said. “This was followed by a fast touchdown, further into the runway than he had intended.

“The pilot raised the flaps and attempted to brake on the uphill landing roll on the wet grass. He had to use reduced braking to correct for skidding, and the aircraft was traveling slowly but unable to be stopped as it reached the [end] of the runway.”

The airplane passed the end of the runway, traveled 18 meters (59 feet) downhill, collided with the boundary fence, struck a post, veered to the right and continued 26 meters (85 feet) before stopping. Winds 10 minutes after the accident were reported by the airstrip’s automatic weather-reporting system as south-southeast at 24 knots, with a gust to 29 knots in the previous 20 minutes. A passenger said that rain began as the airplane landed.

The report said that the accident occurred because of excessive tail wind on final approach and an increased tail wind on short-final approach. The report also said that the pilot’s failure to fly over the airstrip’s windsocks “probably led to his incorrect assessment of the tail wind component on the runway and to his decision to land there” and that the airplane’s tail-wind-component limitation “was defined in a way that provided the pilot with an opportunity to make an incorrect assessment.” The report said that reported wind direction may have been incorrect and that the aircraft flight manual’s performance chart did not provide the information to assess the uphill slope and maximum allowable tail wind at the airstrip.

Corporate Business

## Snow Blamed for Failure to Hold Short

*Israel Aircraft Industries 1125 Astra SPX. No damage. No injuries.*

*Saab-Fairchild 340A. No damage. No injuries.*

The flight crew of an Israel Aircraft Astra SPX, who were preparing for departure from an airport in Canada, were told by air traffic control to taxi to the runway and to hold short. The aircraft was taxied across the “hold short” line and toward the runway as a Saab-Fairchild 340A was about one nautical mile (1,853 meters) away on final approach to the same runway.

Both the tower controller and the ground controller were unable to contact the Astra crew; the tower controller instructed the crew of the 340A not to land. The crew of the Astra “almost immediately” contacted the tower controller and reported that their airplane was in position and ready for departure. The controller told the crew to vacate the runway to allow the crew of the 340A to land. After the 340A had landed, the crew of the Astra were cleared for takeoff.

The incident report said, “Information provided [to investigators] indicated that the [Astra] pilot missed the ‘hold short’ line because it was obscured by snow. Airport maintenance personnel inspected the runway … ‘hold short’ markings and reported that the ‘hold short’ line was a little faded, but the ‘hold short’ line and the ‘hold short’ warning signs adjacent to the taxiway were visible.”

## Aircraft Collide on Final Approach

*Beech King Air C90. Substantial damage. No injuries.*

*Gulfstream III. Minor damage. No injuries.*

Visual meteorological conditions prevailed as both aircraft were flown on final approaches to an airport in the United States. The King Air was being flown on a visual flight rules flight plan; the Gulfstream was being flown on an instrument flight rules flight plan.

When the flight crew of the King Air contacted the tower controller, they were told to fly a straight-in approach to Runway 16R.

"The [pilot said that the] approach was made by visual reference alone," the accident report said. "The weather was clear, visibility was unrestricted, and the sun angle was not a factor. When he was three [miles] to four miles out on final [approach] for 16R with airspeed of 120 [knots] to 125 knots, suddenly and unexpectedly, there was a shadow over his aircraft, and the nose of the Gulfstream became visible in the top of his windshield. Immediately, there was a loud 'bang,' his aircraft rocked violently, and he thinks it turned to the right."

The impact damaged the left wing and broke off the communications radio antenna. The flight crew slowed the airplane, lowered the landing gear and flaps, and landed after receiving a green light from the control tower.

The captain of the Gulfstream said that his airplane was established on the instrument landing system (ILS) approach to Runway 16R and was about 10 miles (19 kilometers) from the airport when approach control issued a traffic advisory about an aircraft that was "ahead, unverified at 2,900 feet (as I recall) and ATC [air traffic control] was not talking to them."

The Gulfstream crew continued the approach, received a second traffic advisory and slowed the airplane's rate of descent while they looked for the other aircraft. The captain said that he observed no warning from the traffic-alert and collision avoidance system.

"When they were about four miles [seven kilometers] north of the runway threshold, on the ILS at 140 [knots] to 145 knots, he [the captain] felt the aircraft roll," the accident report said. "He didn't know what had happened but knew it was not normal. He thought it might have been wake turbulence, but then he saw a King Air aircraft below them, on his left and very close."

The Gulfstream flight crew initiated a go-around and reported to the tower "that they had possibly had a midair collision." After a fly-by of the control tower to determine whether the landing gear and flaps appeared to be in the normal position, and after low passes to confirm that the landing gear was not damaged, they landed the airplane.

## Airplane Destroyed in Collision With Deer on Runway

*Learjet 60. Airplane destroyed. Two serious injuries.*

Visual meteorological conditions prevailed for the early afternoon landing at an airport in the United States. After touchdown, the airplane collided with two deer.

The airplane continued along the runway with the brakes on; near the end of the runway, the airplane veered to the right, crossed a taxiway and rolled into a ditch. Rescuers extricated the captain and first officer before the cockpit was engulfed in flames.

The pilot said that the thrust reversers had been activated but had failed to operate.

Other
General
Aviation

## Airplane Taxis Without Pilot

*Tipsy Nipper T.66 Series 2. Substantial damage. One minor injury.*

The airplane, with its brakes set, was being hand-propped to start the engine in a grassy area at an airport in England. After several unsuccessful attempts to start the engine, the pilot adjusted the throttle to a higher setting and tried again.

"This time, the engine started, and the aircraft [began] to move forwards," the occurrence report said. "The pilot attempted to reach the throttle to stop the aircraft but slipped and fell over. The aircraft traveled across a concrete area and stopped against a fabric-covered hangar."

## Airplane Strikes Wall After Takeoff in Gusty Crosswind

*Piper J-3C65 Cub. Substantial damage. One minor injury.*

Winds were from 320 degrees at 13 knots with gusts to 27 knots at the time of the midday takeoff on Runway 26 at an airport in Ireland. The pilot said that, after takeoff, a gust of wind lifted the airplane's right wing and, despite his "full control input," the airplane turned about 90 degrees to the left. The airplane flew about 80 meters (262 feet) across the grass perimeter, struck a stone wall and stopped — inverted — in a plowed field next to the airport.

The pilot said that, as part of his pre-takeoff check, he had moved the pitch-trim crank handle to the full-rear (tail-down) position and then forward to the appropriate setting. An investigation showed that, after the accident, the trim was in the tail-down position. The pilot said that the crank handle might have been moved by rescue personnel as they removed the passenger from the airplane. Investigators said that, because of impact damage, the crank handle could not be rotated and that the trim cable had lost tension and had separated from the activating pulley.

The flight manual said that the airplane's maximum demonstrated crosswind component was 10 knots.

Rotorcraft

## Mistakes in Measuring Fuel Quantity Cited in Engine Failure

*Kawasaki KH-4. Minor damage. No injuries.*

The pilot was flying the helicopter on one in a series of scenic charter flights in Australia and had been airborne for about 25 minutes when the engine failed. The helicopter was about 500 feet above ground level and about two nautical miles (3.7 kilometers) from the planned landing site.

The pilot began an autorotative descent and maneuvered to land in a lightly wooded area. During landing, the tail rotor struck the ground, and the helicopter tipped forward, then touched down in a slight nose-down attitude. The tail-rotor blades, main-rotor mast, right-front landing skid, very-high-frequency radio antenna and landing light were damaged.

The helicopter operator said that fuel exhaustion and the recent replacement of the calibrated dipstick used to measure the contents of the fuel tank may have contributed to the engine's power loss. The operator required that pilots carry enough fuel to complete their planned flights, plus a 20-minute reserve. About one-half liter (0.53 quart) of aviation gasoline was recovered from the fuel tanks after the accident.

The original dipstick was a hollow, calibrated, hard plastic tube supplied by the helicopter manufacturer. To measure fuel, the dipstick was inserted diagonally into the fuel tank and through a hole in the tank baffle; a finger was then placed over the hole at the top of the dip stick to trap fuel in the tube and allow for the tank contents to be read against a graduated scale. The replacement was a wooden dipstick calibrated to measure fuel quantity when the dipstick was inserted almost vertically into the tank.

The pilot — a part-time pilot who typically had worked one day a week during the three months preceding the accident — said that he had used the new wooden dipstick for the first time on the day of the accident, using the same technique he had used with the original dipstick.

"This technique could result in a significant over-estimation of tank contents," the accident report said.

The pilot said that he had not been instructed in the correct method of using the new dipstick, but he had used similar dipsticks on other helicopter models.

The accident report said that the helicopter fuel log contained "ambiguous entries" from the previous day, that there was a discrepancy between the last fuel-log entry and the dipstick reading taken before the first flight of the day, and that the operator had no policy for resolving discrepancies.

"The pilot's relatively low level of experience on this helicopter type and his employment status as a part-time relieving pilot had possibly contributed to his reliance on a dipstick reading that was not supported by a visual assessment of the fuel tank contents," the report said.

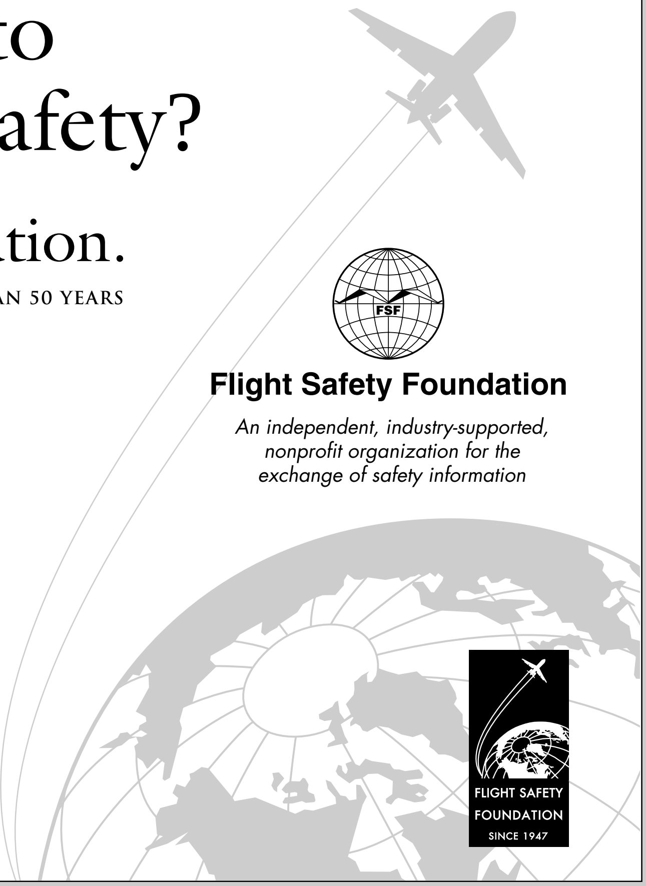
After the accident, the operator issued a notice informing company pilots of the correct technique for measuring fuel quantity and discontinued its policy of hiring part-time relieving pilots at bases staffed by one full-time pilot.

## Carburetor Ice Suspected In Power Loss

*Robinson R22. Substantial damage. No injuries.*

The pilot was completing an autorotation with a powered recovery in Italy. When power was applied, the engine did not respond. The pilot landed the helicopter in a tail-low attitude. The impact bent the tail boom upward, and the main rotor severed the tail boom, which fell about 60 feet (18.3 meters) from the helicopter.

The pilot said that he had not applied carburetor heat when he reduced power for the maneuver and that carburetor ice may have caused the power loss. The temperature at the time of the accident was 48 degrees Fahrenheit ([F] 9 degrees Celsius [C]), and the dew point was 42 degrees F (5.5 degrees C).♦



### We Encourage Reprints

Articles in this publication, in the interest of aviation safety, may be reprinted in whole or in part, but may not be offered for sale, used commercially or distributed electronically on the Internet or on any other electronic media without the express written permission of Flight Safety Foundation's director of publications. All uses must credit Flight Safety Foundation, *Flight Safety Digest*, the specific article(s) and the author(s). Please send two copies of the reprinted material to the director of publications. These reprint restrictions apply to all Flight Safety Foundation publications.

### What's Your Input?

In keeping with FSF's independent and nonpartisan mission to disseminate objective safety information, Foundation publications solicit credible contributions that foster thought-provoking discussion of aviation safety issues. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Flight Safety Digest*, please contact the director of publications. Reasonable care will be taken in handling a manuscript, but Flight Safety Foundation assumes no responsibility for material submitted. The publications staff reserves the right to edit all published submissions. The Foundation buys all rights to manuscripts and payment is made to authors upon publication. Contact the Publications Department for more information.

**Flight Safety Digest**

**Suggestions and opinions expressed in FSF publications belong to the author(s) and are not necessarily endorsed by Flight Safety Foundation. Content is not intended to take the place of information in company policy handbooks and equipment manuals, or to supersede government regulations.**

Staff: Roger Rozelle, director of publications; Mark Lacagnina, managing editor; Wayne Rosenkrans, senior editor; Linda Werfelman, senior editor; Karen K. Ehrlich, web and print production coordinator; Ann L. Mullikin, production designer; Susan D. Reed, production specialist; and Patricia Setze, librarian, Jerry Lederer Aviation Safety Library

Subscriptions: One year subscription for twelve issues includes postage and handling: US$480. Include old and new addresses when requesting address change. • Attention: Ahlam Wahdan, membership services coordinator, Flight Safety Foundation, Suite 300, 601 Madison Street, Alexandria, VA 22314 U.S. • Telephone: +1 (703) 739-6700 • Fax: +1 (703) 739-6708