Human Error In Aviation

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I. Introduction

Human error in aviation is somewhat of a sensitive topic due to the recent tragic events of September 11, 2001. The goal of this research is to understand human error in aviation, in order to understand how designing better computer systems can assist in making the aviation industry safer for pilots and passengers, by reducing human error. This paper does not attempt to address accidents caused by cowardly acts of terrorism.

Many people do not know that on February 20, 1981 a modern Argentine jet airliner, with 58 people on board, almost crashed into the upper floors of the 110-story World Trade Center in New York (Grayson, 1988). The Argentine jet was put on a holding pattern in the New York area. The ceilings were low, with heavy fog, and the sky was mostly obscured. Because of a communication error between the pilot and the air traffic controller, the Argentine flight maneuvered the airplane down to 1,500 feet, straight toward the north tower. The controller had actually said 2,700 feet. The World Trade Center was 1,749 feet high! The pilot did ask for confirmation of the altitude, and possibly due to radio interference, did not receive an answer. Unfortunately, the pilot did not pursue his request for confirmation. An alarm sounded at the radar tracking station warning air traffic controllers of the low altitude. The controller immediately instructed the pilot to turn right immediately and climb to 3,000 feet. Apologies were shared, and the error was noted. When the controller was asked if there was any language problem in the communication with the Argentine pilot, he answered, “Yes, on a scale of one to ten of understanding – least to best – the level was about four.”

To err is human, that is how the saying goes. It is a fact of life. People are not precision machinery designed for accuracy. In fact, we humans are a different kind of device entirely. Creativity, adaptability, and flexibility are our strengths. Continual alertness and precision in action or memory are our weaknesses. We are amazingly error tolerant. We are extremely flexible, robust, and creative, superb at finding explanations and meanings from partial and noisy evidence. The same properties that lead to such robustness and creativity also produce errors. The natural tendency to interpret partial information -- although often our prime virtue -- can cause operators to misinterpret system behavior in such a plausible way that the misinterpretation can be difficult to discover.

Errors are an inevitable part of flying. No matter how good a pilot’s training is, we can never hope to eliminate all errors. Nowhere in life can we ever muster enough brainpower and diligence to make mistakes impossible. Even at our very best, we see a shadow cast by our own brilliance. This paper will discuss human error in a general sense, human error specific to aviation, maintaining situational awareness in aviation and human error reduction techniques. The goal is to become educated in human error in order to determine how to reduce, if not eliminate, human error in aviation.

II. Human Error

Many of the causal factors that contribute to accidents can be viewed as different "types" of human error. Human error can be defined as inappropriate human behavior that lowers levels of system effectiveness or safety, which may or may not result in an accident or injury (Wickens, Gordan, Liu, 1998). Technically, the term human error could include mistakes made by humans operating a system, humans who designed the equipment, humans who supervise the worker, and humans who trained or advised the worker. However, the term is usually used to describe operator error, the inappropriate behavior of the person directly working with the system. There are numerous ways to classify and categorize human error. We have a tendency to want to view error at the operator level. First, we tend to blame the individual; second we try to identify any other factors. Shealey (1979) suggests several reasons for why this narrow perspective is taken:

- It is human nature to apportion blame at someone else.
- Our legal system is geared to apportioning blame.
- It is easier for management to blame the worker than other aspects.
- It is in the interests of the company to blame the worker rather than admit deficiencies in their procedures product or system.

Operator error is a very common cause of accidents. However, studies of accidents (Shanders & Shaw, 1988) revealed that in no case was human error the only factor. They proposed a model of *contributing factors in accident causation* – CFAC. The factors are broad & encompass most factors found in other models. Their model includes and emphasizes management, social and psychological factors. Also, human factors variables are recognized in the categories: Physical environment, Equipment design, and Work itself.

Operator errors can occur for many reasons, including inattentiveness, poor work habits, lack of training, poor decision-making, personality traits, social pressures and so forth. There have been several attempts to classify the types of errors that people make during task performance. These classifications are then used to try to improve human performance. Currently, errors can be categorized into four widely used, general classifications:

1) Slips – When the wrong action is performed.

2) Lapses – When an action is omitted or a memory failure occurs.

3) Rule-Based Mistakes – When the wrong rule is selected for an action.

4) Knowledge-Based Mistakes – When the wrong plan is generated for the given situation.

In 1971, one of the first theories of human error, the four Types of Failures (Meister, 1971) was introduced. These types of failures are based on where the error originates:

1) Operating errors

2) Design Errors

3) Manufacturing Errors

4) Installation and Maintenance Errors

Rasmussen's SRK model (skill, rule, knowledge) describes three different levels of cognitive control that might potentially be used by a person during task performance (Wickens et al, 1998). If people are extremely experienced with the task, they will process the information at the skill-based level of performance, reacting to the raw perceptual elements at an automatic, subconscious level. When people are familiar with the task but do not have extensive experience, they will process the information and perform at the rule-based level. When the situation is novel, decision makers will not have any rules stored from previous experience to call on. They will therefore have to operate at the knowledge-based level, which is essentially analytical processing using conceptual information. Errors are sometimes categorized according to Rasmussen's SRK model.

One scheme that is frequently used is a simple dichotomy between errors of omission and errors of commission (Wickens et al, 1998). Errors of omission are instances where the operator fails to perform one or more procedural step that is necessary for the particular circumstances they are facing. Errors of commission refer to errors in which the operator performs extra steps that are incorrect or performs a step incorrectly. Swain and Guttman (1983) proposed four Human Error Categories, expanding on errors of omission and commission:

1) Error of Omission

2) Error of Commission

3) Sequential Error – Performed actions out of the correct order.

4) Time Error – Performed actions too slow, too fast or too late.

Norman (1981) differentiated between slips and mistakes: slips are errors in execution and include errors resulting from inattention, misperceptions, losing track of one's place, and so on. For example, if someone misses a step going down a ladder, this is a slip. People don't usually intend to miss a step when this happens. Mistakes on the other hand, are errors in planning an action, i.e. having an inappropriate intention and carrying it out. For example, if a person intentionally turns onto a one-way street going the wrong way, this is a mistake.

Error rates have also been studied at great length. In multiple contexts, and many scenarios humans have a general error rate of 0.5% to 1.0%. Generally, humans make a mistake up to 1% of the time when performing any given task. A study done by Chedru & Geschwind, (1972) found that when writing, humans would make a grammatical error 1.1% of the time. A study by Potter (1995) revealed something a bit more shocking. The error rate for pilots when making entries into an aircraft flight management system, per keystroke is 10%. It is even higher if there is a heavy workload. For this reason alone, human error in aviation, with regard to system design should be studied at great length.

Swain & Guttman (1980) introduced eight "Human-Machine and Error Analysis Steps" in order to probabilistically determine whether errors will occur:

1) Describe system goals and functions
2) Describe situation
3) Describe tasks and jobs
4) Analyze tasks for where errors are likely
5) Estimate probability of each error
6) Estimate probability error is not corrected
7) Devise means to increase reliability
8) Repeat steps 4 - 7in light of changes

III. Human Error in Aviation

The number of pilots is far smaller than the number of drivers, and aircraft crashes are much less frequent than auto accidents. Statistically the chances of death while riding in a motor vehicle are 30-50 times greater than while riding in a commercial aircraft. However, the number of people who fly as passengers in aircrafts is large enough, and the cost of a single air crash is sufficiently greater than that of a single car crash that the human factors issues of airline safety are as important as those involved with ground transportation. The competing tasks that pilots must perform involve maintaining situation awareness for hazards in the surrounding airspace, navigating to three-dimensional points in the sky, following procedures related to aircraft and airspace operations, and communicating with air traffic control and other personnel on the flight deck (Wickens et al, 1998). Much of the competition for resources is visual, but a great deal more involves more general competition for perceptual, cognitive and response-related resources. Depending on many factors, from the aircraft type to weather conditions, the pilot’s workload can range from under load to extreme overload.

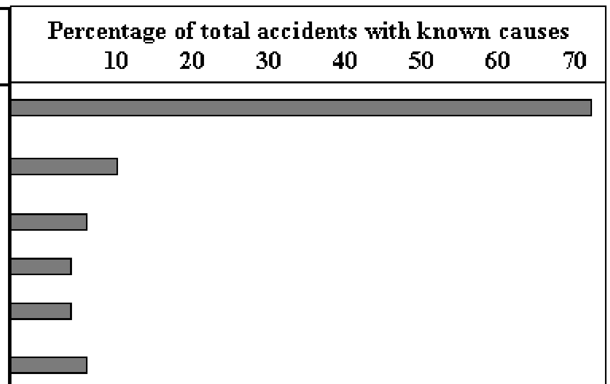
Aviation psychology is the field of study concerned with the development and operation of safe, effective aviation systems from the standpoint of the human operators who are responsible for 70 percent of aircraft accidents. Psychology applied to aviation is an integrative field involving knowledge of just about all areas in psychology, including perception and attention, cognition, physiological, experimental, industrial/organizational, clinical, and educational (Pereira Lima, 2000). In addition to having knowledge in the field of psychology, someone who is interested in studying psychology applied to aviation must know about the aviation field including the pilot's tasks, memory and decision making skills, pilot selection, cockpit designs, human-computer interaction, human factors design, training systems development, program management and human performance research. An aviation psychologist is concerned with pilot performance and reducing flight crew error. Someone interested in this field will be challenged with the goal of inventing the most efficient way of allowing information to reach the pilot. Important to the pilot is the clarity and speed of information about weather and hazards coming from the air traffic controller, and the rest of his/her team members including copilot, flight engineers, and cabin attendants (Busse, 1999). The Aviation Psychologist works to prioritize information coming in to the pilot, so that the more crucial information is salient. Because the field of aviation psychology is integrative, one may hold different titles depending on their area of emphasis. For example, those with an experimental emphasis would be Aerospace Experimental Psychologists, those with an engineering emphasis would be Aerospace Engineering Psychologist, and those with a human factors emphasis would be Human Factor Specialists in aviation.

The history of human factors in aviation goes back to World War II, when pilots could not control an airplane due to the poorly designed displays and controllers and were killed. Today, after all these years and after the great influence of automation and computers on new aircraft designs, we still hear about the major aircraft accidents in the news. Aircraft components, along with most other items of equipment, have become both more sophisticated and more reliable over these past three decades. On the other side, there is a growing appreciation that designers, manufacturers, corporate decision makers, and maintenance managers can make mistakes, which, in turn, create the conditions promoting errors on a flight (Reason, 1990). The combination of these two trends has resulted in more and more reports of human errors rather than component-related failures. The following figure shows the Boeing statistical summary of all the world transportation aircraft accidents for the last ten years (Boeing, 1997).

Primary Cause Factors – Hull Loss Accidents

Worldwide Commercial Jet Fleet (Boeing Statistical Summary, 1997)

Primary factor	Number of accidents in last 10 years
Cockpit crew	104
Airplane	13
Maintenance	9
Weather	6
Airport/ATC	5
Miscellaneous/other	8
Total with known Causes	145
Unknown or awaiting reports	60
Total	205



Although airplanes are built from thousands of parts, components, and small complex systems, most aircraft accidents are not caused by system failures. Boeing's statistical summary (1997) of worldwide commercial jet airplane accidents shows that 71.7% of the hull loss accidents, in the last 10 years (1987-1996), were due to cockpit crew rather than maintenance, weather, etc. These statistics show explicitly how important the direct role of human and consequently human error is in aviation. Even, other factors like maintenance or airport traffic control (ATC) that contribute to more than 10% of the accidents are not completely independent of human error. Many of those ATC and maintenance problems are caused by operators' lack of attention or in another word human error. Human errors in aviation can easily lead to public disasters, whereas in an area like manufacturing the consequence would rarely be this tragic.

Researchers have done quite a large amount of studies on pilot error. The Aviation Psychology department at the Naval Postgraduate School, School of Aviation Safety in Monterey, CA (1998) developed an error checklist for airplane accidents to categorize different error factors. The eight different factor categories are:

1) Sensory-Perceptual Factors

2) Medical and Physiological Factors

3) Knowledge or Skill Factors

4) Personality and Safety Attitude

5) Risk Judgment/Decision Factors

6) Communications/Crew Coordination Factors

7) Design/System Factors

8) Supervisory Factors

Sensory-Perceptual Factors include:

- Misjudged distance, clearance, altitude, speed, etc.
- False perception due to Visual Illusion
- False Perception due to Vestibular Illusion
- Spatial Disorientation/Vertigo
- Experienced an Attention Failure
- **Loss of Situation Awareness**

Medical and Physiological Factors include:

- Self-medicated (without or against medical advice)
- Flew under influence of drugs/alcohol
- Flew with cold or flu (or other known illness)
- Flew while under excess personal Stress or Fatigue
- Flew without adequate nutrition (skipped meals)
- Experienced G-loc or G-excess on flight
- Experienced Hypoxia during flight

Knowledge or Skill Factors

- Showed inadequate knowledge of systems, procedures, etc
- Poor flight control/airmanship (Skill-based error)
- Misuse of procedures (performance of cockpit tasks)

Personality and Safety Attitude

- Showed pattern of Overconfidence
- Showed pattern of Excess Motivation
- Was "Hot Dogging" on mishap flight
- Exhibited anger/frustration
- Too assertive or non-assertive for situation
- Lacked confidence to perform tasks/mission(s)
- Yielded to social pressure (command or peers)

Risk Judgment / Decision Factors

- Knowingly accepted a high risk situation
- Misjudged actual risks of mission (complacency)
- Did not monitor flight progress/conditions (complacency)
- Used incorrect task priorities
- Knowingly deviated from safe procedure (imprudence)
- Intentionally violated Safety Standard or Regulation
- Willfully ignored warning input
- Knowingly exceeded personal limits
- Knowingly exceeded published aircraft limits
- Knowingly exceeded prescribed mission profile/parameters
- Yielded to social pressure (command or peers)

Communications/Crew Coordination Factors

- Inadequate Mission Plan/Brief or Preflight
- Failed to communicate plan/intentions
- Failed to use standard/accepted language
- Misunderstood or unacknowledged communication
- Inadequate crew challenge or crosscheck
- Crewmember intentionally withheld vital safety data
- Pilot in Command failed to lead and/or delegate
- Pilot in Command failed to use all available resources
- Interpersonal conflict/crew argument

Design/System Factors

- Used wrong switch/lever or control
- Misread or misinterpreted instrument reading
- Could not reach or see control
- Could not see or read instrument or indicator
- Failed to respond to warning signal
- Selected/Used wrong system operating mode
- Over-reliance on automated system (automation complacency)

Supervisory Factors

- Inappropriate schedule/crew assignment
- Failed to monitor Crew Rest/Duty Allowance
- Failed to establish adequate standards
- Failed to monitor compliance to standards
- Failed to monitor crew training/qualifications
- Failed to screen/remove High-Risk Aviator
- Failed to establish/monitor Quality Standards
- Intentionally violated or directed other(s) to violate a standard, rule or regulation

IV. Situational Awareness

Successfully operating complex systems depends upon knowing not only what tasks to perform and how to perform them, but also when to do so. To become proficient, an operator of a complex system must know several types of knowledge: declarative knowledge (what to do), procedural knowledge (how to do it), and operational skill (when to do it) (Bass et al, 1996). Consequently, training for such an environment should focus on declarative knowledge and procedural skill, as well as on the integration of that knowledge into operational skills. Operational skills are critical in a dynamic environment where the operator has to make decisions about what to do and when to do it. In order to make these types of decisions in dynamic and risky domains, operators must acquire and maintain situation awareness.

The definition of Situation Awareness that has been agreed upon by the Enhanced Safety through Situation Awareness Integration (ESSAI) consortium: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future".

Piloting takes place in a very dynamic environment. To a far greater extent than driving, much of the information that is relevant for safety is not directly visible in its intuitive “special” form. Rather, the pilot must depend on an understanding or awareness of the location and future implications of hazards, relative to the current aspect of the aircraft; that is, the pilot must achieve an awareness of the situation (Wickens et al, 1998). Historically, a significant number of accidents in complex systems have been attributed to a lack of situation awareness (SA). Despite increased use of automation and improvements in display design to improve SA, re-design is unable to completely eliminate accidents of these types. One viable option is to train operators to acquire and to maintain situation awareness.

Although the impact of situation awareness on operators in complex systems has been recognized, no single accepted theory for situation awareness has emerged. Situation awareness is a state of knowledge, which directly relates the elements of a dynamic environment to the operator's target goals. Although separate from the processes of decision-making and performance, situation awareness is intricately associated with them. Achieving situation awareness is a difficult and often imprecise process for the human operators of complex systems. Acquiring and maintaining situational awareness is enhanced by operators' internal long-term memory structures that enable processing of large amounts of information required in complex situations.

The reasons for not recognizing an impending situational awareness problem typically fall into three general categories: 1) system data problems, 2) human limitations, and 3) time-related problems (Bass et al, 1996).

1) System data problems

In modern complex systems, system data problems arise despite the careful design and development of computer-human interfaces that include new technologies to help reduce these problems. Types of system data problems include:

- Data pertinent to the deteriorating situation are obscured by other system data.
- Data are sometimes hidden within automated functions.
- Data are sometimes spread across many displays, leaving the operator to integrate the data into usable information.
- Data are presented at a level of detail that is inappropriate for the tasks being accomplished, leaving the human to abstract useful information from a glut of system data.

2) Human limitations

Unfortunately, it is not possible to engineer solutions for all situation awareness related problems. Even when system data are complete and available, human limitations may lead to missing the signs that a dangerous situation is developing. Some reasons that operators have trouble performing situation assessment relate to features of the work environment, such as high workload and interruptions. Others reasons relate to characteristics of human behavior. Such behaviors include the tendency to fixate on the task at hand to the exclusion of others and poor passive system monitoring.

3) Time-related problems

Another element of the situation assessment problem in complex systems is dynamic state data. This behavior adds to the difficulty of detecting potentially dangerous system states because it requires that data monitoring and interpretation be exercised repeatedly over time, further reducing the likelihood of it being done properly. The need to monitor particular data among all the system states during that period compounds this problem

V. Human Error Reduction

In order to reduce human error, one of the first things needed is a change in attitude. The behavior we call human error is just as predictable as system noise, perhaps more so: therefore, instead of blaming the human who happens to be involved, it would be better to try to identify the system characteristics that led to the incident and then to modify the design, either to eliminate the situation or at least to minimize the impact for future events. One major step would be to remove the term "human error" from our vocabulary and to re-evaluate the need to blame individuals. A second major step would be to develop design specifications that consider the functionality of the human with the same degree of care that has been given to the rest of the system (Norman, 1990).

Human error and their negative consequences are decreased in one of three ways (Wickens et al, 1998):

1) System design
2) Training
3) Personnel selection

For system design, errors can be reduced by: making it impossible for a person to commit an error, making it difficult to commit an error, or making the system error tolerant so that when errors occur, the negative consequences are avoided. Error tolerance can be achieved by methods such as feedback to the operator about current consequences, feedback about future consequences, and monitoring actions for possible errors. Design features can be included so that erroneous actions can be reversed, if they are noticed, before they have serious consequences on system performance. Human Factors principles should be applied to design. The goal is to reduce, if not eliminate, risk through design. An important thing to remember is that reliability goes down as complexity goes up.

When system design or information support cannot be used, then selection and training methods should be designed to minimize operator error. Training and Personnel Selection are important factors; however because mistakes are unavoidable in human performance even the most experienced, and best trained pilots will make errors. The notion of “error management" has developed in the past two decades in order to help solve this problem. While we must accept the inevitability of error, we must nevertheless maintain performance standards. Error management demands that we distinguish between an individual being reckless or showing a disregard for the rules, and mistakes that are simply the product of human limitations (Ragman, 1999). "Error management" represents a fundamental shift in aviation philosophy from “excellent airmen commit no errors” to “excellent airmen commit, recognize and resolve errors.”

The first and most basic premise of error management is that human error is universal and inevitable. Error management views human performance as a two-sided coin -- human performance and human error. The coin's two sides are inextricably linked. We cannot have one without the other. Error is universal. Error is inevitable. One cannot engage in human performance of any form without human error. A second, and equally critical, premise of error management is that error does not, has not, and will not cause an incident, an accident, or a fatality. Consequences cause incidents, accidents, and fatalities. While error is universal and inevitable, consequences are not universal or inevitable. The logic of this premise is beyond dispute. Errors happen all the time. Incidents, accidents, and fatalities do not. Error management targets the gap between the errors and their consequences. Error management holds the view that any attempt to address flight safety, which does not acknowledge universal and inevitable human error will fall short of the mark. The acknowledgement removes the stigma associated with error. It depersonalizes error. Error is no longer a reflection upon the crewmember. Just as the sun will rise in the east and set in the west, errors will occur. Error management also assumes technical proficiency. Technically proficient crewmembers commit errors. Incompetent crewmembers shouldn't be flying airplanes.

It is undeniable however that the training for pilots should be more inclusive. Robert Cohn is a pilot. In his book, *They Called It Pilot Error*, he said, "In retrospect, I was short-changed. When I thought more about it, I realized that I had never been taught or even made aware of many of the things that are crucial to the safe and proper use of an airplane. I had to learn those the hard way." He had never had any training on most physiological, mental and purely human factors that can seriously detract from or mentally contribute to safe flying. In order to provide better pilot training, procedural checklists should always be provided to pilots. Also, incentive programs can be used to reward pilots for error recovery.

VI. Conclusion

This paper has discussed human error, human error in aviation, situational awareness and error reduction. The goal was to become educated in human error in order to determine how to reduce if not eliminate human error in aviation.

Human error can be categorized in many different ways, from Meister's Types of Failures to Swain & Guttman's probabilities of error. Human error is impossible to eliminate since all humans make mistakes. Instead of placing blame on the operator, research should be done to determine why the operator made the error.

Errors are an inevitable part of flying as well, documented as far back as World War II. The aviation industry was one of the first to embrace human factors research in order to reduce pilot error. What has been discovered is no matter how good a pilot’s training is we can never hope to eliminate all errors. Yet, it is crucial that pilot’s do not make any errors. This is hardly possible.

One of the most common errors for pilots is a loss of situational awareness. Situational awareness is defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. Situational awareness problems can be categorized into system data problems, human limitation problems, or time related problems.

Nowhere in life can mistakes be made impossible. Human error and their negative consequences are decreased in three ways, system design, training, and personnel selection. Although personnel selection and training are extremely important factors, it is known that even the best-trained pilot will still make mistakes. Focusing training on error recovery, rather than error prevention will make a more successful pilot. Since it is known that all pilots, all humans, will make mistakes it is the job of the human-computer interaction professional to design systems that help eliminate or reduce the potential for errors. Design features can be included so that erroneous actions can be reversed, if they are noticed, before they have serious consequences on system performance. Human Factors principles should be applied to design. The goal is to reduce, if not eliminate, risk and errors through design.

References

Bass, Ellen J., Zenyuh, John P., Small, Ronald L., Fortin, Samuel T. (1996). A Context-based Approach to Training Situation Awareness. In Proceedings of HICS '96 - Third Annual Symposium on Human Interaction with Complex Systems, Los Alamitos, CA: IEEE Computer Society, pp. 89-95.

Burchell, Bill (2000). Human Factors: Still Trying to Catch On Despite ample evidence supporting the value of human factors training and awareness, the aviation industry has been slow to embrace the concept. *Overhaul & Maintenance,* VI, 10, 21.

Busse, Daniela (1999). On Human Error and Accident Causation. *Interact*.

Cohn, Robert L. (1994). *They Called It Pilot Error: True Stories Behind General Aviation Accidents*. TAB Books, New York, New York.

Gero, David (1999). *Military Aviation Disasters*. Haynes Publishing, Newbury Park, California..

Grayson, David (1988). *Terror In The Skies*. Citadel Press, Secaucus, New Jersey.

Heerkens, Hans (2001). Safety by design. *Interavia,* 56, 656, 45-47.

Nader, Ralph and Smith, Wesley J. (1994). *Collision Course: The Truth About Airline Safety*. TAB Books, Blue Ridge Summit, Pennsylvania.

Naval Postgraduate School (1998). Human Factors Checklist. *Aviation Psychology*, School of Aviation Safety, Summer.

Norman, Donald A. (1990). Commentary: Human error and the design of computer systems. *Communications of the ACM,* 1990, *33*, 4-7.

Pereira Lima, Edvaldo (2000). Paradigm shift in the cockpit. *Air Transport World*, 37, 11, 85-89.

Phillips, Edward H. (1999). Accidents Raise Issue Of Pilot Psychological Testing. *Aviation Week & Space Technology,* 151, 21, 43.

Ragman, J.T. (1999). Error management. *Flying Safety,* 55, 8, 12-15.

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

Tullo, Frank J. (2001). Responses To Mistakes Reveal More Than Perfect Rides. *Aviation Week & Space Technology*, 154, 21, 106.

Wickens, Christopher D., Gordon, Sallie E., and Liu, Yili (1998). *An Introduction to Human Factors Engineering.* Addison-Wesley Educational Publishers Inc., New York, New York.