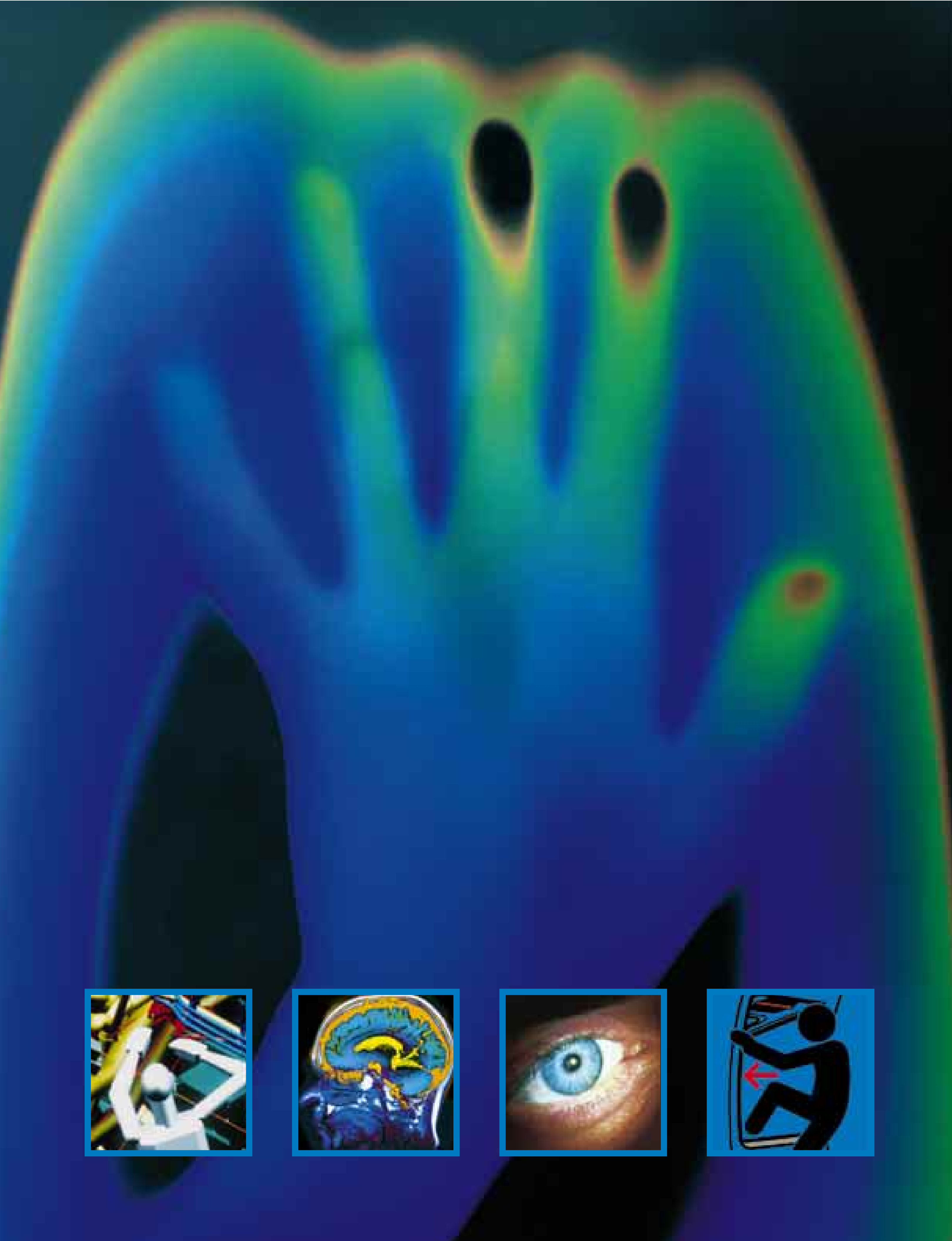


THE ROLE OF HUMAN FACTORS IN IMPROVING AVIATION SAFETY

Human error has been documented as a primary contributor to more than 70 percent of commercial airplane hull-loss accidents. While typically associated with flight operations, human error has also recently become a major concern in maintenance practices and air traffic management. Boeing human factors professionals work with engineers, pilots, and mechanics to apply the latest knowledge about the interface between human performance and commercial airplanes to help operators improve safety and efficiency in their daily operations.

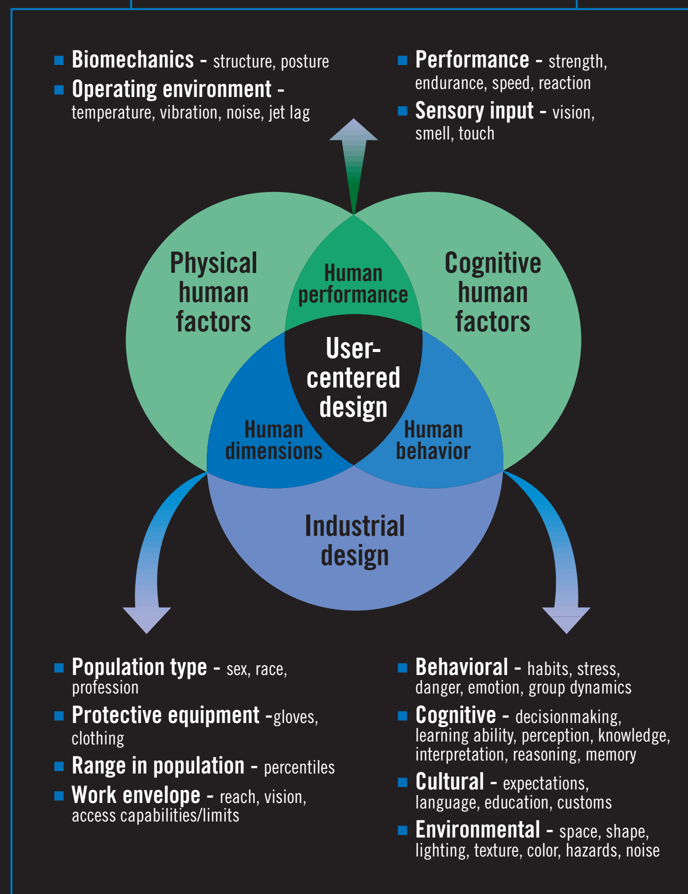
SAFETY

CURT GRAEBER
CHIEF ENGINEER
HUMAN FACTORS ENGINEERING
BOEING COMMERCIAL AIRPLANES GROUP

The term "human factors" has grown increasingly popular as the commercial aviation industry has realized that human error, rather than mechanical failure, underlies most aviation accidents and incidents. If interpreted narrowly, human factors is often considered synonymous with crew resource management (CRM) or maintenance resource management (MRM). However, it is much broader in both its knowledge base and scope. Human factors involves gathering information about human abilities, limitations, and other characteristics and applying it to tools, machines, systems, tasks, jobs, and environments to produce safe, comfortable, and effective human use. In aviation, human factors is dedicated to better understanding how humans can most safely and efficiently be integrated with the technology. That understanding is then translated into design, training, policies, or procedures to help humans perform better.

Despite rapid gains in technology, humans are ultimately responsible for ensuring the success and safety of the aviation industry. They must continue to be knowledgeable, flexible, dedicated, and efficient while exercising good judgment. Meanwhile, the industry continues to make major investments in training, equipment, and systems that have long-term implications.

Because technology continues to evolve faster than the ability to predict how humans will interact with it, the industry can no longer depend as much on experience and intuition to guide decisions related to human performance.



Instead, a sound scientific basis is necessary for assessing human performance implications in design, training, and procedures, just as developing a new wing requires sound aerodynamic engineering.

Boeing has addressed this issue by employing human factors specialists, many of whom are also pilots or mechanics, since the 1960s. Initially focused on flight deck design, this group of about 30 experts now considers a much broader range of elements (see graphic), such as cognitive psychology, human performance, physiology, visual perception, ergonomics, and human-computer interface design. Applied collectively, their knowledge contributes to the design of Boeing airplanes and support products that help humans perform to the best of their capability while compensating for their natural limitations.

Because improving human performance can help the industry reduce the commercial aviation accident rate, much of the focus is on designing human-airplane interfaces and developing procedures for both flight crews and maintenance technicians. Boeing also continues to examine human performance throughout the airplane to improve usability, maintainability, reliability, and comfort. In addition, human factors specialists participate in analyzing operational safety and developing methods and tools to help operators better manage human error. These responsibilities require the specialists to work closely with engineers, safety experts, test and training pilots, mechanics, and cabin crews to properly integrate human factors into the design of all Boeing airplanes. Their areas of responsibility include addressing human factors in

1. Flight deck design.
2. Design for maintainability and in-service support.
3. Error management.
4. Passenger cabin design.

1 FLIGHT DECK DESIGN

Over the past several decades, safer and more reliable designs have been responsible for much of the progress made in reducing the accident rate and increasing efficiency. Improvements in engines, systems, and structures have all contributed to this achievement. Additionally, design has always been recognized as a factor in preventing and mitigating human error. When Boeing initiates a new design activity, past operational experience, operational objectives, and scientific knowledge define human factors design requirements. Analytical methods such as mockup or simulator evaluations are used to assess how well various design solutions meet these requirements. Underlying this effort is a human-centered design philosophy that has been validated by millions of flights and decades of experience. This approach produces a design that applies technology in the best way to satisfy validated requirements:

- Customer input.
- Appropriate degree of automation.
- Crew interaction capability.
- Communication, Navigation and Surveillance/Air Traffic Management improvements.

Customer input.

Boeing involves potential customers in defining top-level design requirements for new designs or major derivatives and in applying human factors principles. A good example is the high level of airline involvement in designing the 777. From the beginning, operators' flight crews and mechanics worked side by side with Boeing design teams on all airplane systems. Eleven of the initial operators also participated in dedicated flight deck design reviews early in the design process. An independent external team of senior human factors scientists also participated in a parallel set of reviews. In the final review, flight crews and other representatives from each operator spent time in the 777 engineering flight simulator to evaluate the design in a variety of normal and nonnormal situations. These activities ensured that operator requirements were considered from the beginning, and validated that the implementation included a sound pilot–flight deck interface.

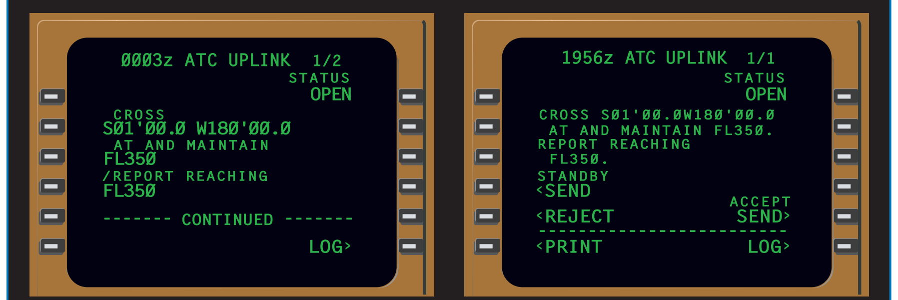
Appropriate degree of automation.

Boeing flight decks are designed to provide automation to assist, but not replace, the flight crew member responsible for safe operation of the airplane. Flight crew errors typically occur when the crew does not perceive a problem and fails to correct the error in time to prevent the situation from deteriorating. Consequently, Boeing flight decks incorporate intuitive, easy-to-use systems. These systems support instrument displays with visual and tactile motion cues to minimize potential confusion about what functions are automated. In the fly-by-wire 777, visual and tactile motion cues are provided by backdriven controls. These controls reinforce situational awareness and help keep the flight crew fully aware of changes occurring to the airplane's status and flight path during all phases of automated and manual flight.

Crew interaction capability.

Flight crew communication relies on the use of audio, visual, and tactile methods. All these methods must be used appropriately in the communication that takes place during flight. This includes crewmember-to-airplane, crewmember-to-crewmember, and airplane-to-crewmember communication. Consequently, the duplicated flight controls of all Boeing airplanes are also interconnected. Both control wheels turn together

Figure 1 UPLINK MESSAGE FORMAT



when either is moved so that the control inputs of each flight crew member are immediately obvious to the other. The same is true for column movements. The tactile and visual feedback provided by interlinkage is much more immediate than verbal coordination and better enables pilots to help each other in time-critical emergencies.

Communication, Navigation and Surveillance/Air Traffic Management interface.

In the future, flight crews will be expected to assume much larger roles in route planning and metering for approaches. Cognitive engineering has already assumed an important role as the industry considers the effects of new technology on the skills, workload, and coordination with other airplanes required of both flight crews and air traffic controllers. For example, cooperation among human factors specialists, data link communications engineers, and end users has resulted in significant changes in the design of the interfaces that flight crews and controllers have with the computers that support their tasks and in the operational use of data link messages. The changes enhance user comprehension, reduce error rates, and result in decreased training requirements.

Perhaps the simplest example is the progression from an aircraft communication addressing and reporting system interface to a future air navigation system (FANS) interface for data link. Boeing initially studied the effects of uplink message formats on pilot comprehension in 747-400 operational trials (fig. 1). Lessons learned were used when designing the data link interface in the Pegasus flight management system incorporated into current-production 757 and 767 airplanes. These same changes are being applied retroactively to the 747-400. Another example is the 777 communications management interface, which uses multifunction displays and cursor controls to simplify management of data-linked communications and can be customized by operators.

2 DESIGN FOR MAINTAINABILITY AND IN-SERVICE SUPPORT

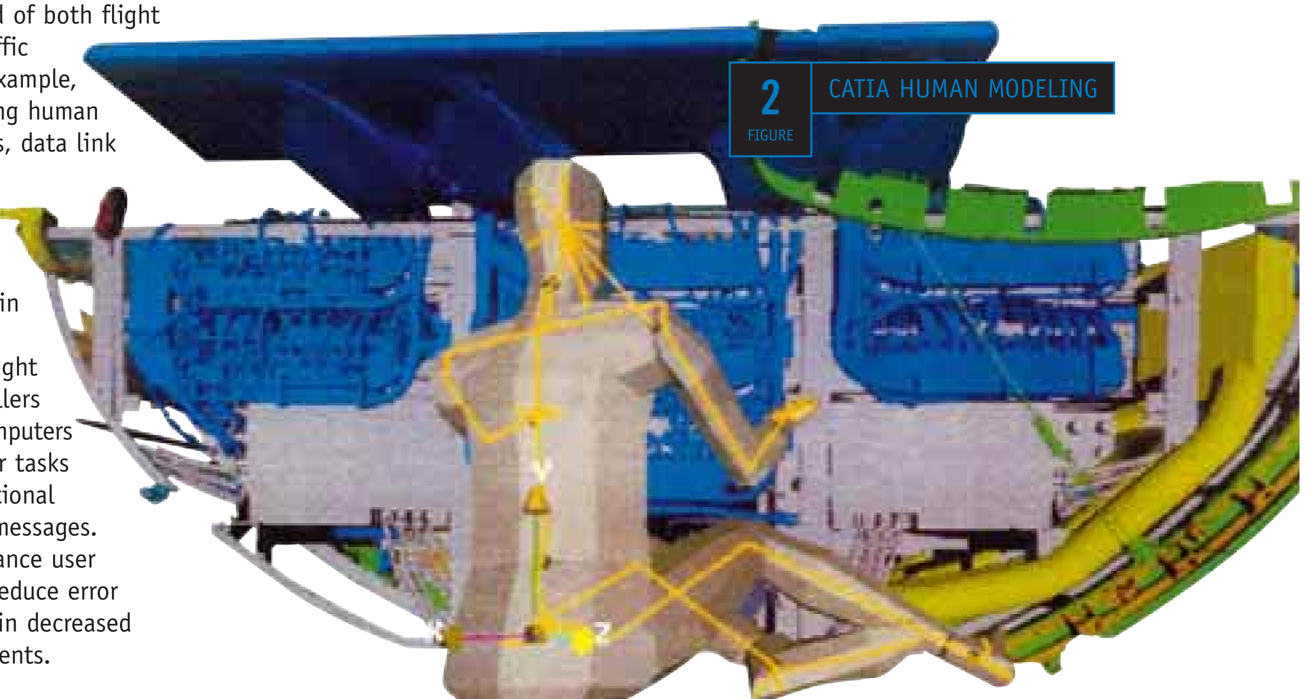
Over the past several years, airplane maintenance has benefited from an increased focus on how human factors can contribute to safety and operational efficiency. In maintenance, as in flight deck design, Boeing employs a variety of sources to address human factors issues, including

- Chief mechanic participation.
- Computer-based maintainability design tools.
- Fault information team.
- Customer support processes.

Chief mechanic participation.

Modeled on the role of chief pilot, a chief mechanic was appointed to the 777 program and to all subsequent airplane programs (717, 737-600/-700/-800/-900, 757-300, and 767-400 Extended Range [ER]). As with the chief pilot, the mechanic acts as an advocate for operator or repair station counterparts. The appointment of a chief mechanic grew out of the recognition that the maintenance community contributes significantly to the success of airline operations in both safety and on-time performance. Drawing on the experience of airline and production mechanics, reliability and maintainability engineers, and human factors specialists, the chief mechanic oversees the implementation of all maintenance-related features.

Figure 2 CATIA HUMAN MODELING



Computer-based maintainability design tools.

Beginning with the 777 program, Boeing stopped building full-scale airplane mockups, which in the past helped determine whether a mechanic could reach an airplane part for removal and reinstallation. Now, using a computer-aided three-dimensional interactive application (CATIA), Boeing makes this type of determination using a human model. During design of the 737-600/-700/-800/-900, Boeing used human modeling analysis to determine that the electrical/electronic bay needed to be redesigned to allow a mechanic to access all wire bundles for the expanded set of avionics associated with the updated flight deck concept (fig. 2). In addition to ensuring access and visibility, human factors specialists conduct ergonomic analyses to assess the human capability to perform maintenance procedures under different circumstances. For example, when a mechanic needs to turn a valve from an awkward position, it is important that the force required to turn the valve must be within the mechanic's capability in that posture. For another example, when a maintenance operation must be accomplished in poor weather at night, secure footing and appropriate handling forces are necessary to protect the mechanic from a fall or from dropping a piece of equipment.

Fault information team (FIT).

Human factors considerations in maintenance also led to the formation of the FIT. During development of the 737-600/-700/-800/-900, Boeing chartered the FIT to promote effective presentation of maintenance-related information, including built-in test equipment (BITE) and maintenance documentation. The FIT charter has since expanded to promote consistency in maintenance processes and design across all systems and models. The goal is to enable mechanics to maintain all Boeing commercial airplanes as efficiently and accurately as possible. This cross-functional team has representatives from maintenance, engineering, human factors, and operators.

One of the team's primary functions is to administer and update standards that promote uniformity among Boeing airplane maintenance displays. For the text of these displays, Boeing has created templates that provide for common fault menus for all systems. The interface should look the same to the mechanic regardless of the vendor or engineering organization that designs the component. Engineers responsible for airplane system design coordinate their BITE and maintenance design efforts with the FIT. The FIT reviews all information used by the mechanic, including placards, manuals, training, and size, location, and layout of controls and indicators, and works with the engineers to develop effective, consistent displays. The team also provides input and updates to Boeing design standards and requirements.

Customer support processes.

In the early 1990s, Boeing formed a maintenance human factors group. One of the group's major objectives was to help operators implement the Maintenance Error Decision Aid (MEDA) process.

The group also helps maintenance engineers improve their maintenance products, including Aircraft Maintenance Manuals, fault isolation manuals, and service bulletins. As maintenance support becomes more electronically based, human factors considerations have become an integral part of the Boeing design process for tools such as the Portable Maintenance Aid. In addition, the group is developing a human factors awareness training program for Boeing maintenance engineers to help them benefit from human factors principles and applications in their customer support work.

3 ERROR MANAGEMENT

Failure to follow procedures is not uncommon in incidents and accidents related to both flight operations and maintenance procedures. However, the industry lacks insight into why such errors occur. To date, the industry has not had a systematic and consistent tool for investigating such incidents. To improve this situation, Boeing has developed human factors tools to help understand why the errors occur and develop suggestions for systematic improvements.

Two of the tools operate on the philosophy that when airline personnel (either flight crews or mechanics) make errors, contributing factors in the work environment are part of the causal chain. To prevent such errors in the future, those contributing factors must be identified and, where possible, eliminated or mitigated. The tools are

- Procedural Event Analysis Tool.
- Maintenance Error Decision Aid.

Procedural Event Analysis Tool (PEAT).

This tool, for which training began in mid-1999, is an analytic tool created to help the airline industry effectively manage the risks associated with flight crew procedural deviations. PEAT assumes that there are reasons why the flight crew member failed to follow a procedure or made an error and that the error was not intentional. Based on this assumption, a trained investigator interviews the flight crew to collect detailed information about the procedural deviation and the contributing factors associated with it. This detailed information is then entered into a database for further analysis. PEAT is the first industry tool to focus on procedurally related incident investigations in a consistent and structured manner so that effective remedies can be developed (see p. 31).

Maintenance Error Decision Aid (MEDA). This tool began as an effort to collect more information about maintenance errors. It developed into a project to provide maintenance organizations with a standardized process for analyzing contributing factors to errors and developing possible corrective actions (see "Boeing Introduces MEDA" in *Airliner* magazine, April–June 1996, and "Human Factors Process for Reducing Maintenance Errors" in *Aero* no. 3, October 1998). MEDA is intended to help airlines shift from blaming maintenance personnel for making errors to systematically investigating and understanding contributing causes. As with PEAT, MEDA is based on the philosophy that errors result from a series of related factors. In maintenance practices, those factors typically include misleading or incorrect information, design issues, inadequate communication, and time pressure. Boeing maintenance human factors experts worked with industry maintenance personnel to develop the MEDA process. Once developed, the process was tested with eight operators under a contract with the U.S. Federal Aviation Administration.

Since the inception of MEDA in 1996, the Boeing maintenance human factors group has provided on-site implementation support to more than 100 organizations around the world. A variety of operators have witnessed substantial safety improvements, and some have also experienced significant economic benefits because of reduced maintenance errors.

Three other tools that assist in managing error are

- Crew information requirements analysis.
- Training aids.
- Improved use of automation.

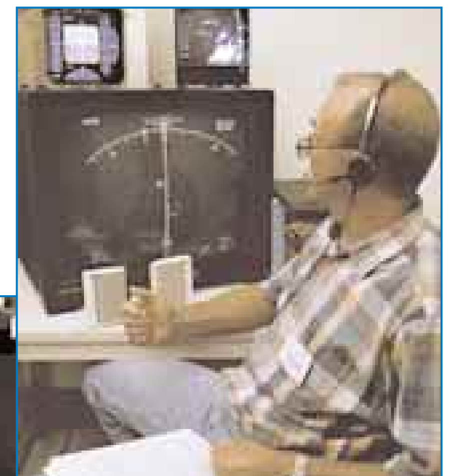
Crew information requirements analysis (CIRA). Boeing developed the CIRA process to better understand how flight crews use the data and cues they are given. It provides a way to analyze how crews acquire, interpret, and integrate data into information upon which to base their actions. CIRA helps Boeing understand how the crew arrived at or failed to arrive at an understanding of events. Since it was developed in the mid-1990s, CIRA has been applied internally in safety analyses supporting airplane design, accident and incident analyses, and research.

Training aids. Boeing has applied its human factors expertise to help develop training aids to improve flight safety. An example is the company's participation with the aviation industry on a takeoff safety training aid to address rejected takeoff runway accidents and incidents. Boeing proposed and led a training tool effort with participation from line pilots in the industry. The team designed and conducted scientifically based simulator studies to determine whether the proposed training aid would be effective in helping crews cope with this safety issue. Similarly, the controlled flight into terrain training aid resulted from a joint effort by flight crew training instructor pilots, human factors engineering, and aerodynamics engineering.

Improved use of automation. Both human factors scientists and flight crews have reported that flight crews can become confused about the state of advanced automation, such as the autopilot, autothrottle, and flight management computer. This condition is often referred to as decreased mode awareness. It is a fact not only in aviation but also in today's computerized offices, where personal computers sometimes respond to a human input in an unexpected manner. The Boeing Human Factors organization is involved in a number of activities to further reduce or eliminate automation surprises and to ensure more complete mode awareness by flight crews. The primary approach is to better communicate the automated system principles, better understand flight crew use of automated systems, and systematically document skilled flight crew strategies for using automation. Boeing is conducting these activities in cooperation with scientists from the U.S. National Aeronautics and Space Administration (fig. 3). When complete, Boeing will use the results to improve future designs of the crewmember-automation interface and to make flight crew training more effective and efficient.

3 FIGURE FLIGHT CREW HUMAN FACTORS STUDY

Human factors specialists use an eyetracker to study pilot mode awareness in the 747-400 flight deck.



4 PASSENGER CABIN DESIGN

The passenger cabin represents a significant human factors challenge related to both passengers and cabin crews. Human factors principles usually associated with the flight deck are now being applied to examine human performance functions and ensure that cabin crews and passengers are able to do what they need or want to do. Some recent examples illustrate how the passenger cabin can benefit from human factors expertise applied during design. These include

- Automatic overwing exit.
- Other cabin applications.

Automatic overwing exit. The 737-600/-700/-800/-900 is equipped with an improved version of the overwing emergency exit (fig. 4), which opens automatically when activated by a passenger or cabin or flight crew member. Human performance and ergonomics methods played important roles in both its design and testing. Computer analyses using human models ensured that both large and small people would be able to operate the exit door without injury. The handle was redesigned and tested to ensure that anyone could operate the door using either single or double handgrips. Then, approximately 200 people who were unfamiliar with the design and who had never operated an overwing exit participated in tests to verify that the average adult can operate the exit in an emergency. The exit tests revealed a significantly improved capability to evacuate the airplane. This major benefit was found to be unique to the 737 configuration. The human factors methodology applied during test design and data analysis contributed significantly to refining the door mechanism design for optimal performance.

Other cabin applications. Working with payloads designers, human factors specialists also evaluate cabin crew and passenger reach capability, placard comprehension, emergency lighting adequacy, and other human performance issues. Because of the focus on human capabilities and limitations, the analyses and design recommendations are effective in reducing potential errors and in increasing usability and satisfaction with Boeing products.

More general issues of human usability have also been addressed. For instance, human factors specialists collaborated with engineers in various studies during 767-400ER program design. The reach and visibility of the passenger service units components were reviewed so cabin crews could use them more easily and effectively. The glare ratio on the sidewalls was analyzed and improved for increased passenger comfort. In addition, the cabin crew panel for controlling the in-flight entertainment system was modified for easier operation and maintainability.

4 FIGURE 737-600/-700/-800/-900 OVERWING EMERGENCY EXIT

The overwing exit and the exit placard were redesigned using human factors methodology.

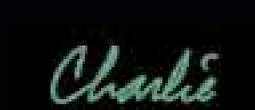
SUMMARY

A chief goal of the Boeing design philosophy is to build airplanes that can be flown safely while offering operational efficiency. An essential part of this philosophy is continuous improvement in designs and flight crew training and procedures. Integral to this effort is an ongoing attempt to better address human performance concerns as they relate to design, usability, maintainability, and reliability. By continuously studying the interface between human performance and commercial airplanes, Boeing continues to help operators apply the latest human factors knowledge for increased flight safety.

BOEING POSITION ON NONPUNITIVE REPORTING

Improving the safety of flight operations depends on understanding the lessons learned from operational events. Success depends on having sufficient data to do so. Today the industry's data scope is limited because the only data guaranteed to be collected is that related to accidents and major incidents. A more proactive approach is needed if we are to move forward.

Unfortunately, it is difficult to obtain insightful data in an aviation system that focuses on accountability. Flight and maintenance crews are often unduly exposed to blame because they are the last line of defense when unsafe conditions arise. We must overcome this "blame" culture and encourage all members of our operations to be forthcoming after any incident. We must be careful not to limit data collection to any one segment of the safety chain. Boeing believes that if we, the aviation community, hope to further reduce the overall accident rate, we must continue to promote and implement proactive, nonpunitive safety reporting programs designed to collect and analyze aviation safety information.



CHARLES R. HIGGINS
VICE PRESIDENT, AVIATION SAFETY AND AIRWORTHINESS
BOEING COMMERCIAL AIRPLANES GROUP

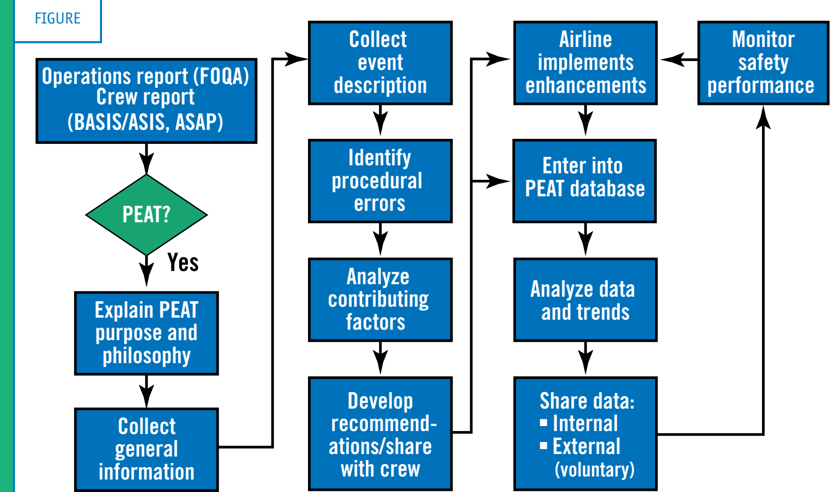
J. KENNETH HIGGINS
VICE PRESIDENT, AIRPLANE VALIDATION AND FLIGHT OPERATIONS
BOEING COMMERCIAL AIRPLANES GROUP

PROCEDURAL EVENT ANALYSIS TOOL

In mid-1999 Boeing began distributing the Procedural Event Analysis Tool (PEAT) to its operators. The company is offering this safety tool to help operators understand the reasons underlying incidents caused by flight crew deviation from established procedures.

PEAT is a structured analytic tool (fig. 1) that operators can use to investigate incidents and develop measures to prevent similar events in the future. It is available to operators free of charge and is the result of a cooperative development effort among airlines, pilot union representatives, and Boeing human factors specialists.

FIGURE 1 — THE PEAT PROCESS



PEAT originated from an extensive effort to identify the key underlying cognitive factors that contributed to procedural noncompliance in past accidents. In 1991 Boeing concluded a 10-year study that showed that flight crew deviation from established procedures contributed to nearly 50 percent of all hull-loss accidents. The aviation industry still lacks sufficient knowledge about the reasons for these deviations, however, and had no formal investigation tool to help identify them.

In addition to helping operators find these reasons, PEAT was designed to significantly change how incident investigations are conducted. When followed correctly, the PEAT process focuses on a cognitive approach (fig. 2) to understand how and why the event occurred, not who was responsible. Using PEAT successfully depends on acknowledging the philosophy that flight crews very rarely fail to intentionally comply with a procedure. In addition, operators must adopt an investigative approach that fosters cooperation between the flight crew and the safety officer conducting the investigation.

PEAT contains more than 200 analysis elements that enable the safety officer to conduct an in-depth investigation, summarize the findings, and integrate them across various events. PEAT also enables operators to track their progress in addressing the issues revealed by the analyses.

Operators can realize several benefits by using PEAT:

- A structured, systematic approach to investigations.
- Consistent application and results.
- Visibility of incident trends and risk areas.
- Reduction or elimination of procedural-related events.
- Improved operational safety.
- Improved economic efficiencies.
- A means for communicating and sharing relevant information between organizations, both internal and external to the airline.
- Compatibility with existing industry safety tools.

Operators must acquire hands-on training to effectively adopt and apply the PEAT process and software. Requests for training should be addressed to Mike Moodi in Boeing Flight Technical Services (fax 206-662-7812). More information is available on the Boeing PEAT web site:

http://www.boeing.com/news/techissues/peat/

FIGURE 2 — TAKING A COGNITIVE APPROACH