Enhancing Human Performance

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Improvements in aviation safety and efficiency are dependent on the development of a national aviation system that is not only technically sophisticated, but also human centered. One of the lessons learned by the Federal Aviation Administration is that ignoring human factors can be costly both in the need for reengineering and in schedule delays. Thus the agency's human factors specialists are helping to develop procedural changes that can be used in combination with new equipment to enhance human performance, and thereby improve the safety and efficiency of the air transportation system.

A variety of projects have been undertaken to improve the performance of pilots, crews, air traffic controllers, and system maintainers. The focus of these efforts is on baselining human performance, improving and standardizing methods for performance measurement, gaining better insight into the impact of the environment on performance, and translating the knowledge gained into procedures and guidelines. This work is being conducted in collaboration with the National Aeronautics and Space Administration, the Department of Defense, The MITRE Corporation, the Volpe National Transportation Systems Center, aviation professionals, industry, and universities.

The FAA's *National Plan for Civil Aviation Human Factors: An Initiative for Research and Application*, published in 1995, provides the framework for these collaborative efforts. This plan incorporates five basic research thrusts: information management and display, human-centered automation, selection and training, human performance assessment, and bioaeronautics.

To improve air transportation safety and efficiency, procedural changes designed to enhance human performance are being developed with the help of Federal Aviation Administration human factors specialists.

Information Management and Display

In the near future, flight crews and air traffic controllers will exchange information over high-speed digital data links. A steady stream of information will flow from numerous digital computers on board the aircraft. The cockpit will be information rich, with pilots operating their aircraft under conditions of "free flight." Free flight represents a shift from today's centralized command-and-control air traffic control system. Whenever practical, pilots will determine their route, speed, and altitude to achieve the most economical and efficient flight plan. Controllers will play more of a traffic management role and may in some circumstances share with pilots responsibility for individual aircraft separation assurance.

The free flight environment will depend heavily on the enhanced exchange of information between people and between people and systems. Human factors specialists are working to identify the most efficient and reliable ways of displaying and exchanging information, and to develop system designs that will reduce the frequency of information transfer errors and misinterpretations and minimize the impact of those errors that do occur. The results of this research will ensure that the changes accompanying the increased automation needed to implement free flight do not introduce new problems for the users and operators of the global air transportation system.

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Because most maintenance documentation is produced today in electronic form, aircraft inspectors and maintainers have easy access to a wealth of essential information.

Concurrent with the free flight initiative are research ventures being conducted by the FAA and the airlines to enhance aviation safety. One such effort resulted in an automated performance measurement system, the backbone of the Flight Operations Quality Assurance Program, which has been prototyped and field-tested with several airlines. This system gathers data regarding multiple aircraft parameters in a single data recorder on board an aircraft and analyzes those data to provide information about the performance of the cockpit crew throughout all phases of flight.

In a joint project with NASA, the FAA is also conducting research on the air-ground system integration issues associated with the implementation of advanced communications, navigation, and surveillance technologies. This work is focused on identifying current operational problems that could be eliminated by improved system designs. Analysis of the data collected will result in the development of equipment design principles for advanced flight deck information management systems to facilitate the integration of new information.

Pilots and controllers are not the only aviation professionals affected by the information age. In the days of the DC-3, for example, maintenance communication was rather straightforward. There were relatively few airplanes, and their maintenance requirements were, by today's standards, decidedly low-tech. This situation has changed dramatically. By 1988 the Boeing Commercial Airplane Company alone was producing 1,126 active maintenance manuals for 5,300 airplanes and 425 worldwide operators.

Today most major airframe manufacturers produce their maintenance documentation in electronic form, making a massive amount of information readily available. Yet aircraft inspectors and maintainers must know how to access and apply that information. To this end, the FAA is evaluating computer systems that allow rapid access to stored information such as regulations, airworthiness directives, repair procedures, and parts lists. These computers also have on-screen written input capabilities that permit the user to file reports, fill out forms, and provide input to local and national computer databases, reducing the significant amount of time inspectors and technicians currently spend on paperwork.

The introduction of new technology also is changing the way certification specialists do business. With the advent of the Global Positioning System (GPS), it has become necessary to refine certification requirements for stand-alone GPS receivers. The FAA Certification Human Factors and Operations Checklist for Standalone GPS Receivers provides a systematic means of determining whether the operational characteristics and controls of GPS receivers satisfy minimum requirements for capability and ease of use. This checklist has also alleviated the uncertainty among manufacturers regarding certification criteria, reduced the need to provide special training for certification specialists, promoted standardization of certification procedures, and given certification specialists a clear understanding of the criteria to be used in evaluating the human factors aspects of receiver displays and controls.

In addition, the FAA is working to develop and validate job performance aids for use by its Airway Facilities organization, which manages and maintains all systems and equipment supporting air traffic operations. The recently published *Human Factors Design Guide (HFDG) for Commercial-off-the-Shelf, Non-Developmental Items, and Developmental Systems* is a comprehensive reference tool designed to help project engineers consider human performance during the development, procurement, and evaluation phases of equipment and system acquisitions. And the handbook *Human Factors in the Design and Evaluation of Air Traffic Control Systems* introduces air traffic controllers and airway maintenance specialists to the field of human factors.

Human-Centered Automation

As advanced automated technologies are introduced, it is essential to understand how users will react to the new equipment. The interaction between aviation system operators and computers

is turning out to be more complex than anyone anticipated. Indeed, the study of human–computer interaction in aviation is becoming a highly specialized subfield within the discipline of human factors research.

The emerging role and impacts of advanced automation in air traffic control are explored in two recent reports of the National Research Council. The first, *Flight to the Future: Human Factors in Air Traffic Control* (1), establishes a baseline of knowledge about human performance and limitations with regard to today's automation systems. The second, *The Future of Air Traffic Control: Human Operators and Automation* (2), explores alternative future automation concepts and the role of the controller in ensuring the safety and efficiency of the air traffic control system. The human factors perspective embodied in this report recognizes that the design of advanced automation and decision support tools needs to be balanced by a concern with how this technology may affect controller workload and controllers' inherent performance limitations.

Decision support systems will be an essential element of the new automation that will help controllers work smarter, not harder. These systems will provide computer assistance in anticipating future conflicts between aircraft and other aircraft, restricted military airspace, or adverse weather, and will help identify trajectories that can be used to maneuver aircraft safely around such problems. Other decision aids will expedite the efficient arrival of aircraft during rush periods at busy airports. These aids will assign aircraft to land on particular runways and determine the sequence in which they should land, enabling controllers to manage arrivals so as to maximize runway utilization. Decision support tools will also enable controllers to accommodate the preferred routing of pilots under free flight by extrapolating a preferred route, probing for conflicts, and generating and prioritizing alternative routings to resolve any conflicts predicted.

To aid in understanding how general aviation pilots will operate in a more automated, information-rich environment, human factors engineers have helped design a reconfigurable advanced general aviation flight deck simulator. This simulator can readily be reconfigured as a Piper Malibu or Cessna Skyhawk II or as a "glass" cockpit for examination of advanced displays. [In a glass cockpit, displays such as cathode ray tube (CRT) screens and flat panels are used to present flight control and aircraft status information.] The architecture is also flexible enough that it may, with the addition of hardware and software, be reconfigured to simulate a multiengine turboprop/turbojet aircraft.

The simulator depicts the complex interactions among the environment, hardware, communications, crew resource management, and situational and risk variables. It has a high-fidelity visual system with a 150-degree-wide field of view, capable of both day- and nighttime views. This system permits variations in runway lighting, airport and terrain characteristics, and atmospheric conditions, all of which can influence the pilot's decision making and flight performance. Cockpit panels and consoles can be reconfigured to support human factors studies on aircraft displays, and the simulator's data collection system has the capacity to collect data on a broad range of pilot/crew performance measures. The simulator is currently being used to evaluate display and control systems in support of aircraft certification.

Selection and Training

In addition to issues related to the human performance–technology interface, the introduction of new technologies brings the need to ensure that aircraft flight crews are properly trained to use the technology and to react properly should problems arise. The Advanced Qualification Program (AQP) encourages the use of innovative proficiency-based training. Carriers develop their own

New automated decision support systems will help air traffic controllers anticipate and resolve conflicts between aircraft and restricted military space, adverse weather conditions, or other aircraft.

proficiency objectives, which address the range of conditions and contingencies faced by pilots working within that carrier's operational domain. These objectives define the skills and tasks a pilot must master to be proficient on a given aircraft type. Each airline's AQP must be approved by the FAA. Currently at least 15 air carriers are participating in the program.

In an effort to accelerate the use of AQPs and make them more accessible to regional airlines, a model AQP was designed. A computer software tool ensures that training programs meet each carrier's specific requirements in the most efficient way possible. The software provides an analytical framework that allows individual carriers to integrate crew resource management into their pilot training programs, helping them improve flight crew performance and reduce the adverse effects of errors in the cockpit.

The model AQP for the regional airlines focuses on scenario-based training, whereby pilots are provided specific information and must use that knowledge to solve in-flight problems. For example, a training event might include a specific maneuver or procedures for dealing with an engine loss. A particular flight condition, such as bad weather or a malfunctioning aircraft system, might also be presented. To handle an event successfully, the crew must quickly and accurately assess the situation, plan how to manage the event, and apply appropriate technical and crew resource management skills.

For the past 18 months, the FAA has worked closely with Washington, D.C.–based Atlantic Coast Airlines to design a program that will improve performance and enhance air carrier safety by leading to the development of procedures for crew resource management. As a result, the airline has rewritten its checklists and pilot's quick-reference handbook to include crew coordination and planning items. A new preparation and planning section of the airline's written procedures, for example, assists the pilot in making nonroutine decisions in response to an abnormal or emergency situation. Furthermore, briefings such as those for approach and landing have been restructured to ensure better crew coordination and planning. Results of Atlantic Coast Airlines' Advanced Crew Resource Management (ACRM) operational implementation indicate that a combination of appropriately designed ACRM procedures and training and incorporation of ACRM into fleet standard operating procedures is effective in improving crew performance.

Research on improving the selection and training of air traffic controllers has focused on a PC-based pretraining screening instrument. Testing has verified that this instrument is free of any racial, gender, or cultural bias in evaluating job applicants.

Finally, in response to aviation safety concerns raised by the International Civil Aviation Organization, Congress mandated research to investigate proficiency in the English language among international air traffic controllers and pilots. Data from studies conducted in Venezuela and Honduras involving more than 100 controllers from tower, approach control, and en route facilities are currently being analyzed. Results from research in Latin America and Europe will be used by an international study group in forming a multilateral consensus standard for English language proficiency, as well as an associated training curriculum.

Human Performance Assessment

Programs such as AQP require performance data. New technology currently being tested and deployed will make air traffic controller performance data available for training purposes. The Systematic Air Traffic Operations Research Initiative (SATORI) is a computer system that recreates the air traffic control representation of radar, map, and weather data routinely recorded at air route traffic control centers. With this system, air traffic controllers and managers will be able to recreate air traffic control operations graphically in a format much like that originally displayed to the controller.

SATORI will support a variety of training efforts, such as investigation of operational errors and deviations, investigation of aircraft accidents, review of local operating procedures, review of local traffic management strategies, facility-wide briefings on incidents, and review of airspace design. A terminal radar approach control version of SATORI is being deployed at Dulles International Airport in Washington, D.C.; the en route SATORI system is being deployed nationally at 20 air route traffic control centers.

In another program aimed at improving human performance, FAA, NASA, and DOD scientists have teamed up to assess the impacts of fatigue on air transportation system operators and to develop appropriate countermeasures. A video entitled "Fatigue Busters" is being used at safety seminars to help general aviation pilots recognize and deal with fatigue. In addition, an extensive survey of regional airline operations is being analyzed to determine the causes of fatigue.

Two other major fatigue-related projects are under way—one examining air traffic controller shiftwork schedules and the other exploring napping on the midnight shift as a possible fatigue

countermeasure. Related projects involve the evaluation of sleep, fatigue, jet lag, and performance changes associated with the work schedules of flight crews and the evaluation of a drowsiness detection system. Coordination of these research efforts will ensure applicability of the results to both civilian and military workforces.

An important research program on human performance concerns the changing roles and workload of air traffic controllers under free flight. With free flight, not only will pilots have more flexibility to fly directly to their destination, but it will also be possible to dynamically restructure the controller's airspace to expedite the flow of air traffic through and around congested airspace. Although automation may simplify the controller's job, controllers must be able to maintain their situation awareness—their mental picture of the air traffic situation. In a multiyear research effort, controller performance, workload, and sector team operations will be studied in relation to the incremental introduction of these advanced technologies.

In a collaborative effort between the FAA and the NASA Ames Research Center, an air–ground integration experiment is being conducted to investigate how the interactions between controllers and flight crews may change under different free flight regimes. This research will help identify further requirements for decision support tools to resolve operational issues.

An additional aspect of the interaction between free flight and advanced technology involves more efficient communications between the controller and the cockpit crew. The proposed Controller–Pilot Data Link Communication system will allow controllers and pilots to communicate with one another using a digital link rather than voice. In today's operations, communications are a key workload factor for controllers, especially during busy traffic periods. Some airlines already use data link between aircraft and the airline's operations control center to feed flight plan information to the aircraft's flight management system. Data link will enable controllers to compose and uplink messages containing instructions and advisories, and will allow pilots to compose and downlink requests for changes in their flight plans.

Bioaeronautics

Bioaeronautics addresses issues of bioengineering, biomedicine, and biochemistry associated with aviation performance and safety. For example, in the area of biodynamics, researchers are studying ways to reduce the potential for injury and death in civil aviation accidents. Engineers are conducting tests of aircraft seats and restraint systems to measure their performance in a simulated crash environment. The tests involve a wide variety of restraining systems, including pilot seats for small airplanes, passenger seats for large transport aircraft, flight attendant seats, child restraints, and other special types of seats. The testing incorporates many new technologies, such as sophisticated anthropomorphic crash dummies, electronic sensors, new measurement devices, and high-speed data acquisition and photography equipment.

This research recently resulted in an FAA rule prohibiting certain types of child restraints on aircraft. Tests revealed that booster seats elevate

Automation will simplify the air traffic controller's job in the future, but the controller will still have to maintain a mental picture of the air traffic situation.

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Engineers use anthropomorphic dummies to test the performance of aircraft seats and restraint systems in simulated crash environments.

children without providing a side or back protective shell, and in some cases provide no integral belts to help restrain the child. Vest and harness restraints do not attach to a rigid shell or platform and leave the child free to come in contact with injurious objects. As a result, the FAA now recommends that children under 20 pounds be restrained in approved rear-facing child restraint systems, that children weighing 20 to 40 pounds use approved forward-facing restraints, and that children weighing more than 40 pounds use the standard lap belt attached to all airline seats.

The FAA also is developing new biomedical technologies as part of its accident investigation efforts. Medical certification of pilots does not permit the use of most pharmaceuticals, and pilots' compliance must be assessed. The capability now exists to perform state-of-the-art toxicology tests on the blood, urine, and tissue of pilots involved in fatal accidents to determine the levels of both licit and illicit drugs. Computer software and database programs have been developed to facilitate the handling of large amounts of these data. For example, an hour of one person's time is now required to gather the information that once took six people a full month to obtain.

Conclusion

Great strides in advanced technology and automation have created the need for more attention to human factors, not less. The FAA's ongoing human factors research program has a broad range of beneficiaries in both government and industry. Within government, specialists in flight standards and certification are gaining a better knowledge of how features of the aircraft flight deck and cabin design, as well as training and operational procedures, affect human performance and safety. Aviation security personnel are incorporating human performance criteria in airport security systems and staffing, airway facilities experts are acquiring the information required to procure and operate efficient error-resistant systems, and air traffic controllers are being provided with decision support systems that will improve safety and increase throughput to accommodate the higher traffic levels projected for the future.

Manufacturers have gained the knowledge and information required to develop systems that will operate effectively within the global air transportation system. Air carriers are achieving the ability to apply more effective personnel selection and training programs. And general aviation is receiving guidance on equipment and procedures that will enhance safe operation while reducing costs.

Research into aviation human factors is already paying large dividends through heightened awareness of the importance of human performance to flight safety. These payoffs will continue as new systems, tools, and technology are implemented for regular use throughout the aviation community.

For additional information on the FAA's human factors program, visit these Web sites:
http://www.hf.faa.gov;
www.tc.faa.gov/hum_fac.html; or
www.CAMI.JCCBI.GOV/resources/.

References

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