Chapter 6

The Human Factor in Commercial Aviation

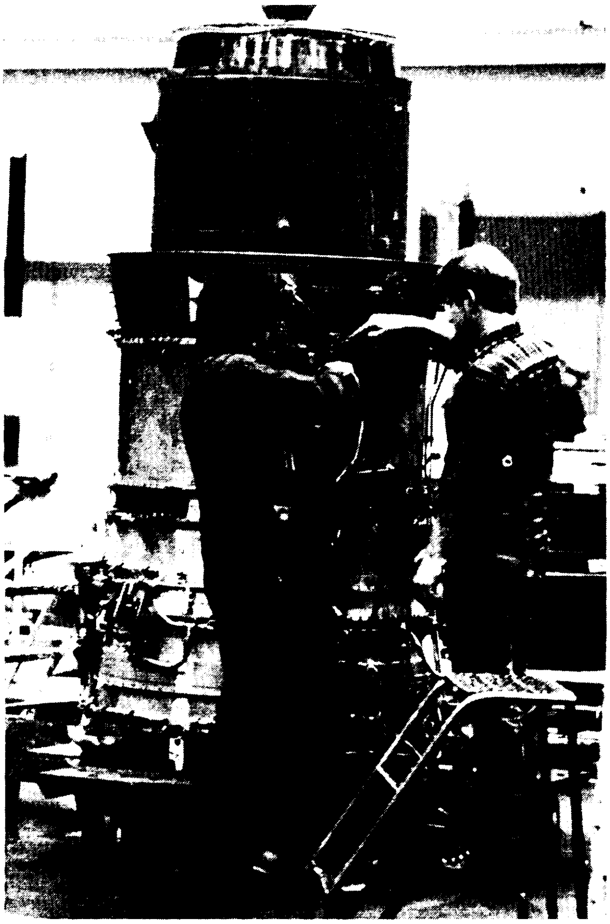


Photo credit: United Airlines

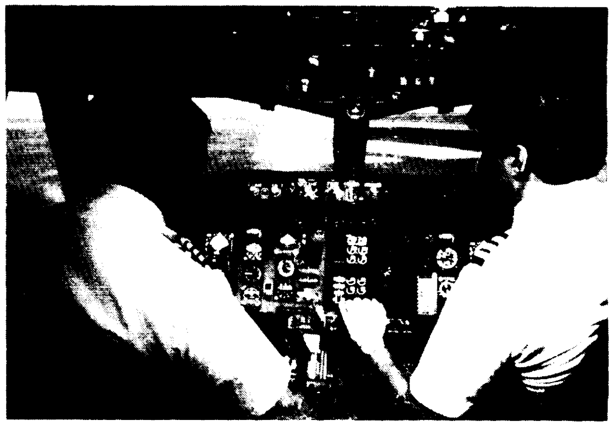


Photo credit: The Singer Co.

Photo credit: Federal Aviation Administration

People are central to aviation safety,

CONTENTS

Box

Figure

Table

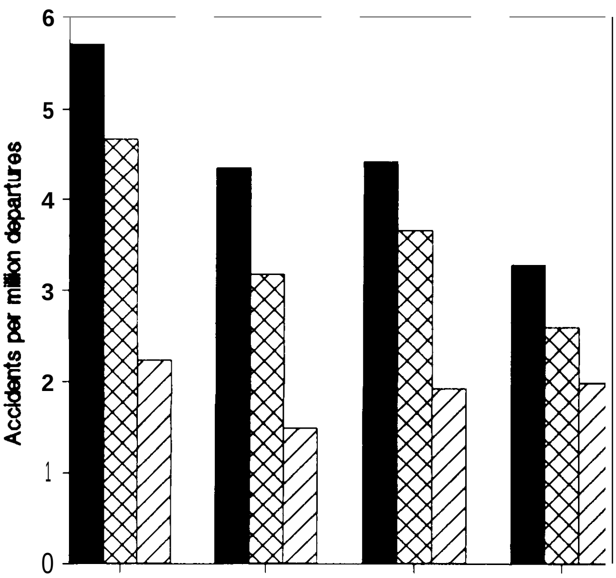
The Human Factor in Commercial Aviation

The people who operate and support the U.S. aviation system are crucial to its safety; the resourcefulness and skills of crewmembers, air traffic controllers, and mechanics help prevent countless mishaps each day. However, despite the fact that the total accident rate for large jets declined over the past decade, the National Transportation Safety Board data show that the rate of accidents involving pilot error did not change (see figure 6-l). Policy, procedures, or technology designed to reduce human error would substantially influence safety, as human error is a factor in over 65 percent of commercial aviation accidents.

An analysis of major accidents involving large, commercial transports, identified flight crew errors as the leading significant causal factors in these accidents,[1] For accidents having multiple causes (over 70 percent in this analysis), reducing the likelihood of one causal factor reduces substantially the overall probability of the accident occurring. As shown in table 6-1, flight crew causes predominate, although other human errors are elements of many

[1]Richard L. Sears, "A New Look At Accident Contributors and the Implications of Operational and Training Procedures," *Influence of Training, Operational and Maintenance Practices on Flight Safety,* Proceedings of the Flight Safety Foundation's 38th Annual International Air Safety Seminar, Nov. 4-7, 1985 (Arlington, VA: Flight Safety Institute, 1985).

Figure 6-1.— Part 121 Total and Human Error-Caused Accidents



SOURCE: Office of Technology Assessment based on National Transportation Safety Board data, 1975-85. Data from 1986 and 1987 are not yet available.

Table 6-1 .—Significant Jetliner Accident Causes in 93 Major Accidents[a] Worldwide, 1977.84

Causal factor	Percent of accidents
Flight crew causes:	
Pilot deviated from basic operational procedures	**33**
Inadequate crosscheck by 2nd crew member	**26**
Captain did not respond to crew inputs	10
Crews not conditioned for proper response during abnormal conditions	9
Pilot did not recognize the need for go-around	6
Deficiencies in accepted navigation procedures	4
Pilot incapacitation	4
inadequate piloting skills	4
Pilot used improper procedure during go-around	3
Crew errors during training flights	3
Pilot not trained to respond promptly to ground proximity warning system command	3
Pilot unable to execute safe landing or go-around when runway sighting is lost	3
Operational procedures did not require use of available approach aids	3
Captain inexperienced in aircraft type	3
All other causes:[b]	
Design faults	13
Maintenance and inspection deficiencies	12
Complete absence of approach guidance	10
Air traffic control failures or errors	9
Other	9
Weather information insufficient or in error	8
Runway hazards	7
Air traffic control/crew communication deficiencies	6
Weight or center-of-gravity in error	5

[a]A major accident involves either a fatality Or a hull loss.
[b]Includes other human errors, equipme-nt failures or problems, weather, maintenance, and airport facilities.

SOURCE: Office of Technology Assessment based on Richard L. Sears, Boeing Commercial Airplane Co., "'A New Look at Accident Contributors and the Implications of Operational and Training Procedures, " *Influence of Training, Operational and Maintenance Practices on Flight Safety,* Proceedings of the Flight Safety Foundation's 38th Annual International Air Safety Seminar (Arlington, VA: Flight Safety Foundation, Nov 4-7, 1965), pp. 29-51.

of the remaining causes. OTA analyses of accident data (see chapter 5) found that human errors initiate over half of U.S. jetliner accidents. Additionally, OTA found that most of the fatal accidents caused by aircraft component failure also involve human error.

Post-accident investigations usually uncover the details of what happened. In the case of mechanical failures, accident data analysis often leads logically to *why* the accident occurred. It is much more difficult to determine the precise reason for human errors. Without an understanding of human behavior factors in the operation of a system, preventive or corrective actions are impossible.

Human factors understanding is especially important to systems in which humans interact regularly with sophisticated machinery and in industries where human error-induced accidents can have catastrophic consequences. However, human factors is not treated as a "core" or "enabling" technology in commercial aviation. Technical decisions for aircraft design, regulation, production, and operation are based on "hard" sciences such as aerodynamics, propulsion, and structures. Human capabilities do not lend themselves readily to consistent, precise measurements, and human factors research requires much more time and cooperation than most other aeronautics research.[2] Data on human performance and reliability are regarded by many technical experts as "soft," and receive scant attention in some aviation system designs, testing, and certification. When data are used in designs, it is often after the fact. This chapter explores areas of aviation safety where human factors are especially important and evaluates Federal programs to address human factors in accident prevention.

[2]R. Curtis Graeber, National Aeronautics and Space Administration Ames Research Center, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings–OTA Workshop on Human Factors in Commercial Aviation Safety," unpublished typescript, May 28, 1987.

HUMAN ERROR

The role of the human in an aviation system is complex; thus the nature of human errors, from mental to physical, in aviation accidents varies widely. Mental or cognitive errors can include improper judgment or decisionmaking, while physical errors may stem from motor skill deficiencies or equipment design. A combination of physical and mental processes may influence other kinds of errors, such as those involving communication, perception, or alertness.

Many types of human error are systematic, following certain predictable patterns; once these patterns are identified, countermeasures can be developed. For example, accidents due to pilots' forgetting to extend landing gear have been virtually eliminated in commercial operations by the introduction of cockpit warning devices.

Much of the discussion in this chapter focuses on fundamental human factors: how the interactions of people, machines, and environment influence the performance capabilities of physically fit, emotionally stable, human operators. However, management practices, such as labor relations and work scheduling, also affect employee stress and fatigue. While conditions that affect a person's fitness and mental health generally influence his performance limitations, little is known about the magnitude of this relationship. Concerns about aviation management practices are addressed later in this chapter.

For those types of human error that do not follow predictable patterns, intervention techniques and limitation methods are difficult to develop. Furthermore, any change to a complex system like aviation safety can have wide-ranging and often unpredictable effects; thus, there are few simple solutions to the problem of human error-caused mishaps. Nonetheless, the options fall into two main categories: preventing or limiting the number of errors, and compensating for errors that occur. This section will outline the methods used or available at present and serves as the basis for later discussion of many needed changes in Federal human factors policies.

Preventing Errors

While preventing all human error is impossible, error rates can be reduced. In aviation, as in other fields, rules and procedures are used to limit errors by modifying or restricting human behavior through standards governing personnel qualifications, operating rules, and equipment design.

The first and basic step in minimizing error is employee selection—allowing into the system only those operators least likely to make mistakes. Airline pilots and air traffic controllers must meet prescribed health, age, and training requirements and pass written and operational tests of skills and knowledge. For the select group that survives the culling, continued quality is maintained through training and monitoring. Indeed, Federal regulations require the periodic testing of flight crewmembers to check results of training and operational experience, including flight proficiency and system knowledge. Pilots and controllers are also monitored through required periodic medical examinations, possibly including drug and alcohol testing in the near future. [3]

Potential errors can be forestalled by restricting human behavior. Careful control of the operating environment is the most wide-ranging of the methods for addressing human error in aviation. Federal regulations in this area address airline procedures such as pilot flight-time, emergency operations, and the use of checklists. Air traffic rules, including instrument approach and departure procedures, separation standards, and weather minimums set operational limits for users of the National Airspace System.

Training, monitoring, and operating rules are not enough, however, if the environment is poorly designed. "If human factors engineering is done properly at the conceptual and design phase, the cost is high, but paid only once. If training must compensate for poor design, the price is paid every day."[4] The Federal Government has the responsibility for setting appropriate standards for aircraft, airports, and navigation aids. Ideally, equipment is designed to reduce, not induce, human error.

To be optimally effective, these methods for controlling human behavior must be preceded by an understanding of the root causes of human error. However, this is an area still in need of much work. Most of the Federal Aviation Regulations (FARs) aimed at limiting human error are based primarily on past regulatory experience, not on scientific evidence. While previous experience is of course important, it is often insufficient or inappropriate in a changing environment. Recent technological developments, such as cockpit automation devices and displays, have outpaced the Federal Aviation Administration (FAA) regulatory process.

Compensating for Errors

An alternate approach to addressing human error assumes that errors will occur and then mitigates or nullifies them. Central to this method is an understanding of what errors occur; such information is provided by accident and incident investigations, which usually identify the human errors involved. Successful ways of compensating for known human errors entail changes to vehicles, equipment, or the environment. Modifying human behavior, even with respect to known types of human error, is a preventive measure as discussed in the previous section.

Monitoring of some type is often involved in negating errors. Warning devices are ubiquitous in jetliner cockpits and have proven invaluable. For example, the ground proximity warning system, required under FARs in 1975, has essentially ended controlled flight into terrain accidents by U.S. carriers. However, alerting systems or other devices may cause, as well as solve, problems. Excessive false alarms unnecessarily distract operators and may lead to the device being ignored or disabled. Consequently, a full system approach is required for all human error solutions.

Outside monitoring of airline flights is accomplished through the Federal air traffic control (ATC) system. Air traffic controllers detect gross navigation and guidance errors and provide useful information on weather and airport conditions to flight crews. En route controllers, in turn, are automatically monitored—ATC computers record the separation between aircraft under positive control and sound an alert if the distance falls below minimum standards.

On the technological forefront of human error control are "error-resistant" or "error-tolerant" systems based on automatic devices similar to those

[3] Drug and alcohol testing is used currently at some air traffic control facilities.

[4] Earl L. Wiener, "Cockpit Automation," to be published in *Human Factors in Aviation,* E.L. Weiner and D.C. Nagel (eds.) (San Diego, CA: Academic Press, forthcoming), draft chapter, Mar. 23, 1987.

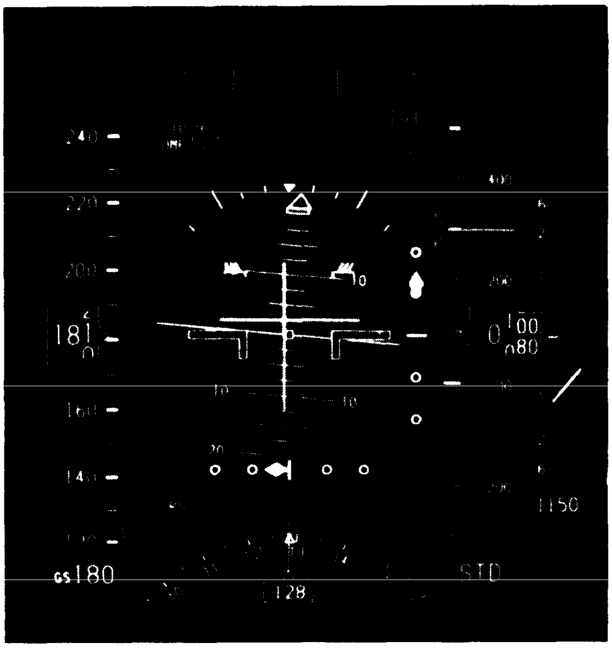


Photo credit: Boeing Commercial Airplane Co.

Electronic cockpit displays indicate aircraft attitude, speed, heading, altitude, navigation, and warnings, such as windshear.

discussed earlier. The difference is that error-resistant systems have the additional capability of controlling and correcting the pilot's error. For example, fly-by-wire technology on the Airbus A-320 prevents the pilot from exceeding the operating envelope of the aircraft—on-board computers will not allow the aircraft to stall or overspeed, regardless of the deflection of the control stick. However, systems that seize control are themselves potential sources of error. Error-resistant systems should not take the place of error prevention methods, but can serve as the last line of defense against human errors.

Human Factors Data

Human error must be identified and understood before appropriate solutions can be proposed. Data are needed from both controlled laboratory experiments and actual flight operations.

One valuable source of field data is post-accident analyses. However, such data may result in only limited understanding of the cause of the human error, especially if no flight crewmembers survive or information is restricted because of litigation concerns. Another data source is reports from crewmembers concerning aviation incidents. The Aviation Safety Reporting System (ASRS), administered by the National Aeronautics and Space Administration (NASA) at the Ames Research Center and funded by FAA, collects such reports and FAA guarantees anonymity and immunity from enforcement actions to reporters.[5] ASRS was designed to gather analytical data, with emphasis on human behavior. To assure participants that the data would be kept confidential, NASA was chosen to host the system, since it is not a regulatory or enforcement agency and had experience in human factors research. The program has proven valuable, supporting numerous studies by government, industry, and academia.

ASRS has become so popular with the U.S. aviation community that the average number of reports has increased from fewer than 800 per month in 1985 to over 1,700 per month in 1987. Until recently, the ASRS budget had not grown, forcing NASA to divert resources to data processing at the expense of data analysis and special studies.[6] For fiscal year 1988, FAA increased ASRS funding from $1.5 million to $1.9 million.

While industry and academia have conducted research in selected areas, the only consistent Federal human factors research effort for civilian flight crews has been maintained by the Aerospace Human Factors Research Division at NASA Ames Research Center. During the past 10 years, research has emphasized automation, communications, cockpit resource management, use of simulators, visual perception, human sleep needs, and pilot fatigue. In recent years, FAA has provided only limited support for NASA's human factors research and development. However, a 5-year interagency agreement was initiated recently and NASA's Office of Aeronautics and Space Technology has obligated fiscal year 1989 funds for human factors research on aviation safety and automation at Ames and Langley Research Centers.

FAA has supported selected cockpit research projects both by NASA and private contractors,

[5]For more details on the anonymity and immunity provisions of Aviation Safety Reporting System, see ch. 4.
[6]William Reynard, chief, Aviation Safety, Reporting System, personal communication, Jan. 25, 1988.

and has conducted ATC human factors studies at the Civil Aeromedical Institute (CAMI), the FAA Technical Center, and with private contractors. CAMI, under the guidance of the Associate Administrator for Human Resource Management and the Office of Aviation Medicine, performs research and evaluation on the influence of sleep patterns, alcohol, noise, drugs, and age on performance; stress management techniques; field performance measurement and evaluation (including operational errors); supervisor/manager selection and training; and job/task analysis for better selection criteria.

Human performance data from actual operations are difficult to obtain. Flight data recorders, cockpit voice recorders, or video cameras could be used to collect such data. However, pilots and controllers are sensitive to being monitored and are concerned about the possible misuse of data, and few objective measurement criteria have been established. While laboratory research provides insight into the effects of automation, aeromedical stressors, and crew interactions on operational safety, these findings must ultimately by verified in the field. NASA Ames, in conjunction with the Air Line Pilots Association (ALPA), and some air carriers, has collected some field data. Additionally, a number of university research projects, on topics such as cockpit resource management or automation in modern cockpits, are based on information gathered directly by human factors specialists riding in jetliner cockpits.

INDUSTRY AND FEDERAL ROLES IN HUMAN FACTORS

Growing Concerns

Human factors problems in commercial aviation are not new: standards for personnel age, health, training, and work shifts, along with aircraft design and operation requirements and the ATC system are all directed at preventing or minimizing human errors. However, new technologies, Federal regulations and advisories, and industry and union initiatives have been more effective in preventing other types of accidents, and the rate of pilot error-involved accidents has not declined in the past decade. Additionally, rapid changes in airline operating and hiring practices and developments in cockpit technology have outstripped the FAA regulatory process. Most of the regulations dealing with human factors are not based on modern scientific findings, and few have been revised or reassessed in recent years. These problems are presented in detail below.

Pilot Selection and Training

Rapid expansion of commercial airlines during the past decade has created shortages in the supply of qualified pilots. The situation has been exacerbated by increased retention of military pilots who were once the mainstay of the airlines (see chapter 5) and declines in general aviation pilot training. For example, the number of new private pilot certificates issued annually dropped from over 58,000 in 1978 to fewer than 35,000 in 1986.[7] Additionally, ALPA statistics indicate that the number of airline pilots reaching retirement age per year will increase until at least 1999. The large commercial carriers are increasingly recruiting pilots from the smaller Part 121 regional and Part 135 commuter airlines, resulting in rapid turnovers in the regionals' pilot work force, greater than 100 percent per year for some. The training burden on these smaller carriers is enormous. For example, in 1987, the flight crew training costs at one regional airline exceeded the pilots' salaries.[8] Moreover, large and small carriers alike have been forced to lower their selection criteria for new hires (see chapter 5). FAA is just beginning to address FARs regarding training, experience, age, or health requirements.

Age and Health.—Given the changes in the operating environment, the shortages in the pilot supply, and advances in medical understanding and technology, the age and health standards for air carrier pilots might need refocusing. The rule requiring mandatory retirement at age 60 for air carrier pilots is one example, since from a medical perspective, age is a coarse predictor of human capabilities.

[7]U.S. Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation* (Washington, DC: published annually).

[8]J. A. McIntyre, Air Line Pilots Association, personal communications, Mar. 3, 1988.

FAA statistics show clearly that general aviation pilots 60 to 69 years old have accidents at twice the rate of pilots 50 to 59 years of age.[9] However, data are not available on what percentage of retired airline pilots continue to meet all the physical and mental competency requirements for commercial transport pilots. Questions that need examination include: what types of medical testing would be necessary to allow these pilots to remain in the work force? What criteria should be measured and what is the appropriate frequency of examinations?

While drug and alcohol testing has been widely discussed and might be required of transportation workers by the Federal Government, other forms of on-site monitoring such as testing pilot fatigue over long flights have rarely been addressed. The capability exists or is being developed for real-time monitoring of certain physical and mental parameters of operator health. The potential of these methods for improving operational safety is unknown, although it could be substantial in the case of drowsiness, fatigue, or illness. However, the sensitive issue of privacy and other concerns must be considered and balanced against safety gains.

Experience.—FAR pilot qualifications have been considered by many to be too low. For example, a jetliner copilot can meet all requirements with only 250 total hours of flight-time.[10] Until recently, this has not been a concern since the airlines have traditionally set their own standards much higher than the Federal requirements. However, while still well above FAR minimums, the average qualifications (total flight-time as well as other indicators of experience) of new pilots are decreasing (see chapter 5).

The rapid expansion of air carriers has also resulted in junior cockpit members advancing to captain without the "seasoning" that was common in the past. While pilots formerly spent several years as flight engineers and then several more as co-pilots before moving into the left seat, promotion to captain with only months of experience is increasingly common at some airlines.[11] For example, at one mid-sized commuter, 45 out of 70 captains were in their first year of employment.[12] Additionally, the replacement of three-person crew aircraft with two-person crew transports means that newly hired crew members increasingly receive their initial jetliner experience as co-pilots.[13]

Total time, whether hours in a logbook or years in a crew position, does not give the complete picture of pilot experience, skill, or quality of training. For example, full-motion flight simulators or advanced training devices enable a pilot to meet with more emergencies and unusual situations in a 4-hour training session than he may experience on the line during a 20-year career. However, few measures of pilot ability other than flight-time have been collected broadly and consistently. Alternative measures or tests of skill and experience could prove useful.

Airline Training Programs.–FARs give wide latitude to carriers with respect to training programs, and flight simulators and computer systems add dimensions to the training process. Modern cockpit technology has shifted the primary tasks of the pilots from physically flying the aircraft to managing it. The adequacy of current training programs and standards have been questioned; FAA has stated that the entire pilot training and rating system needs reexamining and has initiated a program to do so.[14] Additionally, the importance of early training and conditioning and their effect on future pilot performance have not been fully considered in commercial aviation,[15] but are receiving increased attention by several airlines.

Some airlines have implemented training programs, called cockpit resource management (CRM) training, which focus on flight crew management and communication. Line oriented flight training (LOFT), full mission crew coordination training conducted in flight simulators, is also considered valuable by a number of airlines and military aviation groups worldwide. For example, United Airlines

[9] Anthony I. Broderick, associate administrator for Aviation Standards, Federal Aviation Administration, personal communication, Mar. 31, 1988.

[10] 14 CFR 121.437 (Jan. 1, 1987).

[11] Progression to captain at Part 121 air carriers currently takes several years on average. John O'Brien, director of Engineering and Air Safety, Air Line Pilots Association, personal communication, Feb. 29, 1988.

[12] McIntyre, op. cit., footnote 8.

[13] However, the flight engineer position might not be effective as a training base, as many flight engineers have had difficulty transitioning to a pilot position. Delmar M. Fadden, Boeing Commercial Airplane Co., personal communication, Mar. 1, 1988.

[14] David Hughes, "Four-Year Pilot Hiring Boom Creates Problems for Carriers," *Aviation Week & Space Technology*, Oct. 5, 1987, p. 97.

[15] Frank Monastero, aviation consultant, T.M. Monitor Corp., personal communication, Feb. 23, 1988.

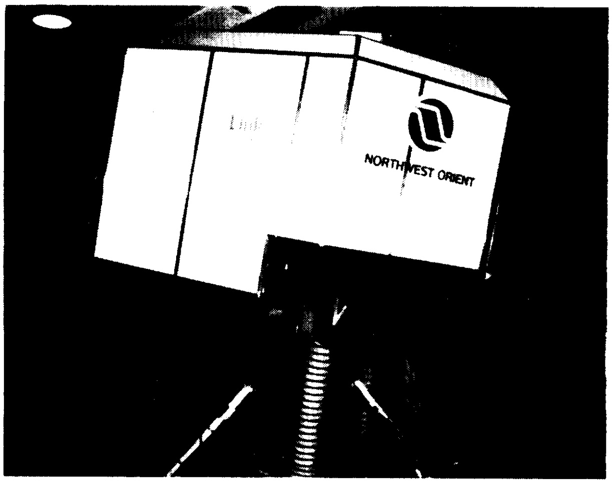


Photo credit: The Singer Co

Photo credit: National Aeronautics and Space Administration

Full-motion flight simulators re-create jetliner operations so realistically that pilots can be trained in them and certified without flying the actual aircraft.

conducts an annual 3-day training and proficiency checking program using CRM and LOFT. FAA has supported this type of training by granting waivers to United and Pan Am, allowing them to reduce their cockpit crew recurrent training and proficiency checks to one per year instead of the normal 6-month check.[16] There are yet no data proving that CRM is effective, and no regulations mandating CRM.[17] However, a Joint Government/Industry Task Force on Flight Crew Performance, formed by FAA in August 1987, has drafted an advisory circular on CRM/LOFT. Research is also underway by the University of Texas at Austin to evaluate the effects of CRM/LOFT on pilots at a number of airlines and military squadrons.[18]

Type Ratings.–Unlike automobile or truck drivers, airline pilots must be licensed for a specific vehicle model. A pilot licensed to fly a B-737 is allowed to fly any version or derivative of the B-737, provided he is trained on their differences, but cannot fly a B-727 unless he first receives a full course of instruction, passes a written and flight examination, and is granted a "type rating" for the B-727. Type, as used with respect to pilot ratings, ". . . means a specific make and model of aircraft, including modifications thereto that do not change its handling or flight characteristics, . . ."[19]

Common type ratings of derivative aircraft offer economic advantages to airlines and manufacturers alike. It is much less expensive for a manufacturer to obtain FAA certification for a derivative than for a new type, since only modifications need close scrutiny. One benefit is that manufacturers are able to offer aircraft innovations to the airlines without developing totally new aircraft. For example, new, technologically-advanced B-737s and DC-9s, (MD-80 series) are covered by type ratings issued in the 1960s (supplemented by pilot training on the modifications).

The manufacturing emphasis on derivatives reflects their popularity with airline management. Fleet expansion by derivatives instead of different types usually permits lower crew training costs: less time is required to train pilots in multiple models and new simulators are not necessary. Single type fleets also enable greater flexibility in crew scheduling. The importance of type considerations is reflected in the

[16] Richard S. Jensen, Ohio State University, "Feasibility Study for the Assessment of Cockpit Resource Management Training," prepared for U.S. Department of Transportation, February 1987, p. 10; and O'Brien, op. cit., footnote 11.

[17] Ed Cook, "The Regulator Horizon," *Cockpit Resource Management Training: Proceedings of the NASA/MAC Workshop,* NASA Conference Publication 2455, Harry W. Orlady and H. Clayton Foushee (ds.) (Moffett Field, CA: National Aeronautics and Space Administration, Ames Research Center, 1987), p. 178.

[18] John A. Wilhelm, The University of Texas at Austin, personnel communication, Feb. 9, 1988.

[19] 14 CFR 1.1 (Jan. 1, 1987).

fact that the only new aircraft types introduced by a U.S. manufacturer in the 1980s are the B-757 and B-767, and they have a common pilot type rating.

The safety and economic issues at stake over type ratings have caused considerable controversy. FAA certificated the DC9-80 (MD-80) with a two-person crew, instead of the customary three-person crew, in August 1980. However, this caused such contention that a Presidential Task Force had to be established. The report of the Task Force affirmed the FAA decision. The main point of discussion among the manufacturers, FAA, and the pilots unions still centers around when two different aircraft versions are the same type. While handling and flight characteristics are the only type criteria in current regulations, cockpit changes are a substantial human factors concern. However, cockpit certification does not receive the level of quantitative analysis by FAA as do other aircraft component certifications. Effectively, the cognitive aspects are considered by using subjective assessments of flight crew workload based on the judgment of test pilots who rate a new cockpit as "better" or "worse" than a comparable one. Quantitative engineering evaluations, such as the performance criteria used for engine designs, are not feasible for many aspects of modern cockpits.[20]

Currently, FAA is developing new standards for determining separate type ratings. Cockpit design and pilot training will be prime considerations in an FAA advisory circular, which is to be issued for public comment in 1988.

Advanced Cockpit Technology

Automation.–"Automation," or assigning to machines or computers physical or mental tasks previously performed by the crew, is a frequently cited means of reducing human error. While totally eliminating humans from the operational loop is not yet feasible nor necessarily desirable, partial replacement is becoming increasingly common. Theoretically, automation minimizes or prevents operational human errors by reducing the physical or mental workload of the human operator, or by eliminating the human from an operational control loop. Used appropriately, automation is a valuable tool; the autopilot, a flight-path control device, is one such item.

Automated devices can provide for more efficient and precise flight operations, but they also require monitoring and proper setting, areas where people can and do make errors. For example, digital navigation equipment is susceptible to keyboard entry or "finger errors. " Such errors can easily go unnoticed by the crew; it is believed that KAL 007 flew off course because of a keyboard error. [21] A broader

[20]U.S. Department of Transportation, Federal Aviation Administration, *Aviation Behavioral Technology Program: Cockpit Human Factors Research Plan* (Washington, DC: Jan. 15, 1985), pp. 20-21.

[21]Earl L. Wiener, "Beyond the Sterile Cockpit," *Human Factors, tel. 27, No. 1,* February 1985, pp. 75-90.

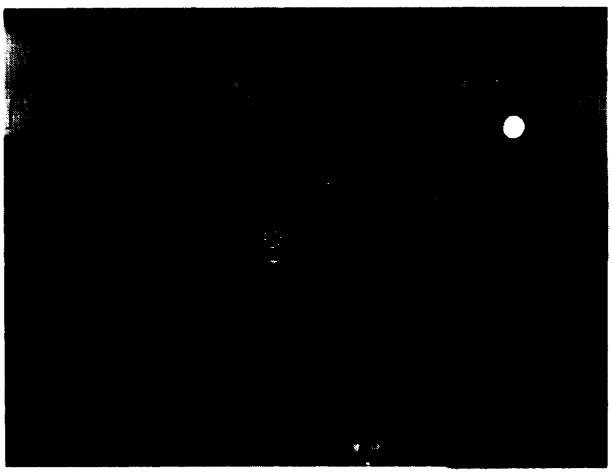


Photo credit: Boeing Commercial Airplane Co.

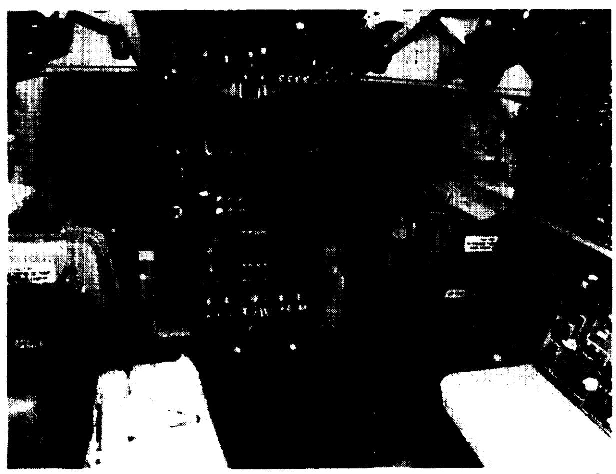


Photo credit: Boeing Commercial Airplane Co.

In modern cockpit designs (left), electronic displays replace many electromechanical instruments (right), as shown in these photographs of Boeing 747 cockpits.

problem is that automatic devices are often installed one item at a time, especially in older aircraft, without the consideration of the overall pilot-cockpit system.

There are no FARs relating cockpit automation to human performance, and no real expertise within FAA, to address this issue. For example, the advanced cockpit electronic systems on the Boeing 757 and 767 airplanes required an "equivalent safety" deviation from current regulations to be certified.[22] Automatic devices for the cockpit, which have subtle effects on human performance, are treated the same as other pieces of hardware in the regulations. Human error hazard analyses are not required in the design, test, or certification stages.[23] Some basic standards for cockpit design are included in FARs, but they do not address technological developments of the past decade such as CRT displays and flight management systems. For example, although the use of color has increased in modern cockpit devices, FAA has set standards only for warning, caution, and advisory lights. There are no rules governing other uses.

Participants at OTA's Workshop on Human Factors in Commercial Aviation Safety stressed that the use of automation will only increase, and most believed that FAA is unprepared to handle current and future automation issues. The role of the human in an increasingly automated environment needs to be studied and bases established for setting standards. ATC is also likely to be increasingly automated. Box 6-A describes automation programs now being planned.

Box 6-A.-Air Traffic Control Automation

One aspect of the National Airspace System Plan, the Advanced Enroute Automation System (AERA), could bring sweeping job changes for air traffic controllers through automation. AERA is software to be introduced in three stages as part of the Advanced Automation System (AAS), the Federal Aviation Administration's (FAA) planned upgrade to the entire air traffic control system (see chapter 7). The effectiveness of automation in accomplishing job tasks and the consequences of individual controller performance differences is being studied at the Civil Aeromedical Institute. FAA plans to study controller selection and training requirements for AERA. An FAA contractor has built and installed prototypes of portions of AERA algorithms in a simulation laboratory. Used for subjective evaluations of controller interactions with automation, this initial test system does not have enough realism for quantitative efficiency measurements. Controllers taking part in the testing provide their views on the utility of the automated aids and the nature of inter-controller coordination in the advanced environment. FAA plans to quanify the benefits of AERA in real-time evaluations once the AAS contractor has installed hardware at the FAA Technical Center (scheduled for 1994). At present, there are no firm plans for AERA hazard analyses, and data gathering for the real-time evaluations has not been articulated.

Air-to-Ground Communication.—Verbal communication remains the weakest link in the modern aviation system; over 70 percent of the reports to ASRS involve some type of oral communication problem related to the operation of an aircraft.[24] Technologies, such as airport traffic lights or data link, have been available for years to circumvent some of the problems inherent in ATC stemming from verbal information transfer. (For more information on communications technologies, see chapter 7.) The ground collision between two B--747 aircraft in Tenerife in 1977, resulting in the greatest loss of life in an aviation accident, occurred because of a communication error.

One potential problem with ATC by data link is that the loss of the "party line" effect (hearing the instructions to other pilots) would remove an important source of information for pilots about the ATC environment. However, the party line is also a source of errors by pilots who act on instructions directed to other aircraft, or who misunderstand instructions that differ from what they anticipated by listening to the party line. Switching ATC communication from hearing to visual also can increase pilot workload under some conditions.[25] Further

[22]Delmar M. Fadden, Boeing Commercial Airplane Co., Office of Technology Assessment, op. cit., footnote 2.

[23]C.O. Miller, aviation consultant, personal communication, Feb. 13, 1988.

[24]Ralph L. Grayson and Charles E. Billings, "information Transfer Between Air Traffic Control and Aircraft: Communication Problems in Flight Operations, " NASA Technical Paper 1875, September 1981, pp. 47-61.

[25]Fadden, personal communication, op. cit., footnote 22.

study is necessary to define the optimum uses of visual and voice communications.

Management Practices

The judgment and skill of the pilots, mechanics, air traffic controllers, and other key people in the aviation system are influenced, to varying degrees, by management decisions. While many aspects of human behavior fall outside the sphere of management and are an inescapable part of a highly demanding and complex system such as commercial aviation, some depend on how the system is organized and operated. For example, airline management practices regarding pilot selection and training, as well as aircraft design, provide the underpinnings of pilot performance. A considerable amount of public debate has focused on airline operational pressures and employee stress.

The terms "stress" and "fatigue" are commonly used in everyday discourse, but with widely varying meanings and contexts. A "stress factor" is a physiological or psychological pressure or force acting on a person which compels him to act or react, physically, cognitively, or emotionally. Examples of stress factors in aviation range from noise, vibration, and glare in the cockpit, to anxiety over weather and traffic conditions, to anger, frustration, and other emotions. Chronic stress degrades performance and decisionmaking, and the overall effect of multiple stresses is cumulative. Another product of cumulative stress is fatigue, which can also result from inadequate rest, too much cognitive activity, increased physical labor, or disruption of physiological rhythms.[26]

Stress is difficult to measure in an operating environment, and little clinical evidence is available on the cause-and-effect relationship of stress, especially psychological or social stress,[27] with performance ability. Concern about stress is not new: workload and duty shift conflicts, ATC and weather delays, and labor/management problems are traditional occupational stresses in commercial aviation. However, developments since deregulation have exacerbated many of the environmental stress factors. Record amounts of commercial traffic, increased use of hub and spoke systems, crowded airspace and airport ground facilities, and the resulting schedule pressures have taken a toll on pilot, mechanic, and air traffic controller morale and, in some cases, performance.[28]

Schedule pressure is a function of the whole airspace system as well as of individual airline practices. Management attitudes, especially labor/management relations, determine how schedule pressure is interpreted in the cockpit and on the flight line. Additionally, airline mergers frequently have resulted in divisive seniority and pay scale arguments among management and the merging work forces. Cockpit crews comprised of pilots holding opposite views on unresolved merger issues bring additional stress to commercial flight operations.

Virginia Polytechnic Institute and State University, under contract to ALPA, is studying stress and its effects on airline pilots. One purpose of the research is to compare pilot populations from different carriers and to determine differences based on established psychological measures of stress. Surveys were conducted in July 1986, at one "unstable" and two "stable" major airlines. For this survey, the unstable airline was one that was sold, merged, or taken over in a 12-month period, had a net loss for the last two earning periods, and had employee wage/work rules concessions in the last contract. The pilots from the unstable carrier, with a long history of labor-management problems and its recent acquisition by another carrier, presented a distinctly different stress profile than the other pilots. While 55 percent of the stable airline pilots exhibited none of the high stress measures (such as low self-esteem, depression, and physiological indications), only 10 percent of the pilots from the unstable carrier showed no high stress. Additionally, 30 percent of pilots from the unstable airline indicated high stress on 4 or more stress measures as compared with only 5 percent of the pilots from the other airline. The stress profiles were so dissimilar among the airlines that 90 percent of the pilots who expressed high stress symptoms could be correctly identified by carrier affiliation.[29]

---

[26] H. Clayton Foushee, Aerospace Human Factors Division, National Aeronautics and Space Administration—Ames Research Center, in *Influence of Training, Operational and Maintenance Practices on Flight Safety*, op. cit., footnote 1, pp. 149-164.

[27] Cary L. Cooper and Stephen Sloan, "Occupational and Psychosocial Stress Among Commercial Aviation Pilots," *Journal of Occupational Medicine*, vol. 27, No. 8, August 1985, pp. 570-576.

[28] OTA, primary research, 1987.

[29] Linda F. Little, Virginia Polytechnic Institute, testimony before U.S. Congress, House Committee on Economic Stabilization, Subcommittee on Banking, Finance and Urban Affairs, May 12, 1987, and Linda F. Little, Virginia Polytechnic Institute, "The Pilot Research Project: 1987 Data," unpublished data.

Airline operating safety is based upon well-rested and alert flight crews. An analysis of ASRS data revealed that about 4 percent of crewmember error reports were directly associated with fatigue, and 21 percent mentioned factors directly or indirectly related to fatigue.[30] NASA-Ames currently has a comprehensive program underway to examine fatigue-related problems in short-haul and long-haul commercial and military flight operations. Already completed, the short-haul phase of the study examined flight crews before and after they had completed a 3-day, "high-density" trip, The findings illustrate the complexities involved in analyzing human performance. The post-duty crews, by all measures, were more fatigued than the pre-duty crews. However, the more tired post-duty crews performed significantly better and made fewer errors during the laboratory simulator sessions. The study concluded that flight crew communication and coordination patterns were largely responsible for the performance differences, Recent operating experience and crew familiarity can override fatigue factors in some short-haul operations.[31]

FARs, ostensibly addressing crewmember fatigue,[32] are silent on items such as pilot duty-time, considered crucial in other countries. Some experts believe that duty-time, the time spent in-flight, and on the ground for preflight, postflight, and between flight stages, is a superior measure for evaluating fatigue in air transport operations.[33] An analysis of the aviation regulations for nine industrial nations shows that only the United States and France do not explicitly consider pilot duty -time.[34] FAR work rules also do not consider the number of takeoffs and landings performed, the number of time zones crossed, and whether crew rest immediately precedes flight duty, issues considered important in many other countries.[35]

[30] R. Curtis Graeber, "Sleep and Fatigue in Short-Haul Flight Operations: A Field Study, " Flight Safety Foundation Proceedings, op. cit., footnote 1, pp. 142-148.

[31] Foushee, op. cit., footnote 26, pp. 149-164.

[32] 50 *Federal Register 29306* (July 18, 1985).

[33] Hans M. Wegmann et al., "Flight, Flight Duty, and Rest Times: A Comparison Between the Regulations of the Different Countries," *Aviation, Space, and* Environmental *Medicine,* March 1983, pp. 212-217.

[34] Ibid.

[35] The Federal Aviation Regulations (14 CFR 12 1.47) address duty time by exception: the minimum rest period a crewmember must have during any consecutive 24-hour period is 8 hours, implying an allowable duty period of up to 16 hours.

Federal Responsibilities

Throughout the history of aviation, safety improvements have come primarily from technological developments, such as reliability and performance increases in aircraft, navigation devices, weather forecasting, and ATC, FARs emphasize, with more precise standards, the technical aspects governing aircraft operations and certification rather than the human factors considerations. Although some human factors-related data collection, analysis, and research are supported and conducted by the Federal Government, FAA has requested little that can be applied to regulatory decisionmaking. FAA does not have a centralized and systematic approach to improving flight crew performance.[36] DOT (primarily FAA), NTSB, and NASA are the Federal agencies involved in civil aviation human factors.

FAA

FAA, and its predecessor the Civil Aeronautics Authority, have addressed numerous human behavior issues through guidelines and oversight. Many Federal regulations and advisories reflect efforts to prevent human error, although few of these rules are based on proven scientific principles. Time-tested procedures and regulatory experience are valuable background data for setting human factors standards, but as discussed in the previous sections, technological and managerial developments in commercial aviation have outpaced FAA's regulatory capacity. Pilot selection and training rules have not been substantially revised in decades, and cockpit design requirements ignore much of the current human factors knowledge.

FAA, recognizing the importance of human factors in aviation safety, has sponsored several workshops, conferences, and studies on human performance in aviation. However, none of these efforts has resulted in major policies, programs, or rules. The President's Task Force on Aircraft Crew Complement recommended in 1981 that FAA support and expand a number of human factors-related research areas.[37] By 1985, FAA had developed a Human Factors Research Plan comprised of ***23 research***

[36] Federal Aviation Administration, op. cit., footnote 20, p. 6.

[37] The President's Task Force on Aircraft Crew Complement, "Report of the President's Task Force on Aircraft Crew Complement," unpublished manuscript, July 2, 1981, pp. 8-12.

projects to address a number of cockpit- and pilot-related problems.[38] Because of austere budgets and the 2-year cycle for initiating new projects, few of its projects were initially funded. However, by 1987, 18 of the 23 projects had received some funding from FAA or other Federal agencies and 1 was completed. Additionally, the Transportation Systems Center was tasked under a project agreement with FAA to update the plan and publish a revision.

However, the underlying reasons for limited past FAA action on human factors still exist; FAA has never devoted the resources necessary to deal objectively with human factors issues. The Office of Flight Standards, responsible for establishing and enforcing air carrier operating regulations, has one person assigned as a human factors coordinator but no separate organizational element with human factors responsibility.

Regulatory policy must be supported as well by documented data and research findings. As discussed in chapter 4, FAA's data collection and analysis efforts could be revised to provide support for human factors research. Although FAA conducts and supports research projects on human factors in ATC, it has only recently devoted staff or budget for efforts in cockpit human factors. While a regulatory agency such as FAA need not necessarily undertake a substantial amount of fundamental research in any technical field, including human factors, it must have access to up-to-date scientific and technical research results so as to exercise timely judgment on technical issues. To do so, FAA needs trained staff to define and manage FAA-supported research efforts, to analyze and interpret findings, and to review and promulgate regulations.

Staff shortages are compounded by coordination difficulties inherent in the FAA management structure. Human factors responsibilities are spread piecemeal throughout FAA and the Department of Transportation. While cockpit-related research projects are managed under the Associate Administrator for Development and Logistics, primarily by the Program Engineering and Maintenance Service, the impetus must formally be provided by the Associate Administrator for Aviation Standards (AVS). For example, FAA's Transport Aircraft Certification Division, located in Seattle and responsible for approving commercial transport cockpit designs, cannot task the Program Engineering and Maintenance Service directly, but must pass all requests through AVS.

The Office of Aviation Medicine and its Civil Aeromedical Institute (CAMI) provide data upon which AVS can base regulations and advisories. However, most of the human behavioral studies at CAMI's Aviation Psychology Laboratory are directed toward ATC.[39] The effectiveness of another regulatory research source in human factors for FAA, the Transportation Systems Center, is diminished by the bureaucratic entanglements that result with inter-administration projects.

AVS collects and maintains field data, such as accident and incident reports and air carrier inspection findings, that could support human factors rulemaking. However, these data management efforts have provided few safety analyses. Additionally, the Office of Aviation Safety, located in yet another division and responsible for broad safety studies, has undertaken no recent human factors analyses.

NTSB

Human factors receive a great deal of emphasis in NTSB investigations of major accidents, the resulting determinations of probable cause, and recommendations for future accident prevention. NTSB has a separate Human Performance Division within its Bureau of Technology and usually includes a human factors specialist on each major accident investigation team. Report forms, interviews, and analytical techniques are designed to elicit detailed information on the performance of the people involved in the mishap and the environmental and operating conditions that were present.

NTSB accident database management and analyses are critically important, for they provide the only valid statistical safety trends currently available to the Federal Government (see chapter 4). While lessons can be learned from individual accidents, the greatest understanding comes from analyses of clusters of accidents. For example, the frequent occurrence of flight crew coordination

[38] Federal Aviation Administration, Op. cit., footnote 20.

[39] Ibid., p. 112.

problems in accidents has resulted in numerous NTSB recommendations urging the use of cockpit resource management training.[40]

NTSB analyses are sometimes published in detailed special studies, covering such topics as runway incursions, airport certification and operations, and commuter airline safety. However, NTSB has not undertaken a comprehensive analysis, and has published no special studies on human factors in aviation.

NASA

NASA has traditionally provided a substantial amount of fundamental aviation research. For human factors in civil aviation, NASA contributes a major share of research, supplemented only by applied research programs in industry and basic research at a handful of universities. NASA is in a unique position which enhances its human factors research efforts. While maintaining close working relationships with FAA, NTSB, the military, and the commercial aviation industry, nonregulatory NASA is viewed as an impartial party. This gives NASA access to sensitive data unavailable to other Federal groups.

[40] John K. Lauber, National Transportation Safety Board, "Cockpit Resource Management: Background and Overview," Cockpit *Resource Management Training*, op. cit., footnote 17, p. 12.

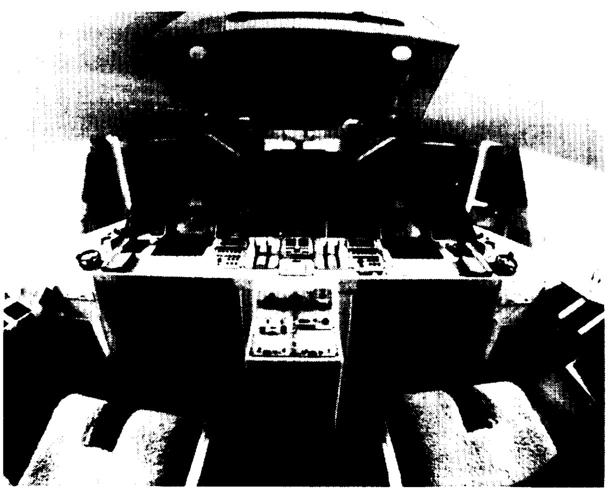


Photo credit: National Aeronautics and Space Administration

Researchers investigate the effects of future cockpit technology on human performance with the Advanced Concepts Flight Simulator at NASA-Ames Research Center.

Two research centers within NASA, Ames in California and Langley in Virginia, are responsible for most of the human factors work. Generally, NASA-Langley investigates the physical aspects of human factors, while NASA-Ames studies the psychological elements. Physiological measures of pilot workload and advanced cockpit displays are among the topics addressed at Langley. The operational implications of human factors research—cockpit resource management, information transfer, sleep cycle and fatigue, and the effects of advanced automation on flight crew performance—are important fields of study at NASA-Ames. For example, LOFT was developed from the use of full-mission simulation as a research tool at Ames.

NASA-Ames also administers the Aviation Safety Reporting System, the only broad source of human factors field data other than NTSB investigations available to the Federal Government. However, effective use of ASRS data has been hampered in recent years by level funding in the face of increasing reports, resulting in resources being diverted from analysis to processing. NASA-Ames increasingly has become the human factors information clearinghouse.[41] While all databases have limitations, ASRS analyses could provide information unavailable to FAA from other sources, such as the influence of new technologies or airline management practices on human performance.

Industry Responsibilities

Airlines and aircraft manufacturers regard safety seriously, giving clearly indicated safety problems quick and thorough attention. Understandably, however, industry rarely undertakes voluntary safety-oriented improvements unless the link between the improvement and safety is clearly established. FAA, as the regulatory agency, must shoulder primary responsibility for the absence of human factors standards.

The lack of objective cockpit certification standards is a case that illustrates how human factors-related decisions are made (or not made). According to one NASA official, most of NASA's fundamental civil aviation research efforts have focused on areas such as aerodynamics, propulsion, avionics,

[41] Graeber, op. cit., footnote 2.

and materials. Less emphasis is placed on human factors, since aircraft manufacturers do not consider human factors to be a technology that controls whether an aircraft design is feasible or not. The manufacturers cite airline concerns with reducing operating costs through better fuel efficiency and lower maintenance expense. The airlines do not usually question FAA-approved cockpit designs or other FAA-certified components, such as engines. FAA completes the circle, stating that no data are available, such as research findings from NASA, to justify establishing cockpit certification standards.[42]

This is not to say that the private sector has not done its best to ensure that cockpit designs are safe. Through Society of Automotive Engineers committees, industry groups (partially funded by FAA and other Federal agencies) have established some cockpit design standards. Compliance with these voluntary standards has traditionally ensured FAA approval of designs.[43]

Economic considerations play a major role in cockpit layout decisions. For example, a number of recent advances in cockpit technology have been driven by airline cost savings. Two-person v. three-person crew complements reduce salary expenses; common type ratings save on training and scheduling costs; automation allows more efficient and precise flight path control; and solid-state avionics have lower maintenance costs than electromechanical devices. "While no reputable manufacturer knowingly compromises safety for short-term cost savings, clear, comprehensive Federal requirements are important in assuring that no actual compromise in safety occurs."[44]

Moreover, OTA finds that a systems approach is needed for cockpit certification. While FAA can adequately ensure that a given cockpit design is not unsafe, the cross-effects of pilots flying in multiple cockpit versions has not been sufficiently addressed. The effects of standardization in cockpit design on pilot performance need to be more fully examined and documented. Additionally, certification approval of vastly different cockpit designs has been criticized by at least one U.S. aircraft manufacturer. Boeing based cockpit display designs on its research into color visibility in electronic displays. The research findings conflict directly with the color standards used for Airbus cockpits, yet FAA approved both standards.[45]

The airlines are left with the responsibility of accommodating differing cockpits. One option, purchasing uniform fleets, is rarely feasible. Different aircraft requirements for different markets, as well as mergers and acquisitions, have left airlines with diverse fleets. Training is the approach used by the airlines and approved by FAA to prepare pilots for these different aircraft. Provided he or she has the required training, a pilot can fly any number of different aircraft in revenue service, even in a single day. However, in present airline operations, very few pilots need to stay current in two or more aircraft that have separate type ratings.[46]

Innovations in training are readily accepted by airlines, provided that the costs are not prohibitive. Advanced simulators allow greater flexibility and safety and have become the preferred mode in training, and they also offer substantial cost savings. Cockpit resource management training has been adopted by a number of airlines.

Airline management has the responsibility of addressing the human factors problems that have arisen due to operating practices and management attitudes. Some airlines have employee assistance and counseling programs and provide for good communication in both directions along the chain of command. Others have conducted internal safety audits. The recent spate of mergers provides a laboratory for comparing the effectiveness of differing airline management practices. A number of U.S. airlines provide open access for NASA-Ames research.[47]

TWA established internal safety teams and conducted audits in 1976, 1980, and 1986. The teams, composed of line pilots and management personnel, were granted immunity from revealing information sources, and top management gave them permission to examine all areas of flight safety. As

[42]Susan Norman, National Aeronautics and Space Administration, Ames Research Center, personal communication, Nov. 19, 1987.
[43]Fadden, op. cit., footnote 22.
[44]Delmar M. Fadden, personal communication, Mar. 1, 1988.
[45]Fadden, op. cit., footnote 22.
[46]Ibid.
[47]R. Curtis Graeber, National Aeronautics and Space Administration Ames Research Center, personal communication, Mar. 2, 1988.

an outcome of the audits, TWA has instituted periodic labor-management safety meetings. The sterile cockpit concept,[48] now a Federal regulation,[49] came out of these TWA meetings, Additionally, TWA has instituted a nonpunitive program for monitoring flight data recorder approach information. Notably, while the program receives the support of TWA's pilots, in-flight monitoring is anathema to pilots at most other carriers. Airlines that carry out safety audits may find the process as important as the product. Employee perception that management recognizes and is addressing a problem can play a large part in the resolution of the problem.[50]

[48]During critical phases of flight (below 10,000 feet and all ground operations), crewmembers can perform only those duties required for the safe operation of the aircraft. For example, extraneous conversation, including pointing out sights of interest to passengers, is prohibited.

[49]14 CFR 121.542 ('Jan. 1, 1987).

[50]J.A. McIntyre, Airline Pilots Association, in *Influence of Training, Operational and Maintenance Practices on Flight Safety,* op. cit., footnote 1, pp. 118-124; and J.A. McIntyre, in Office of Technology Assessment, op. cit., footnote 2.

Labor's Role

Organized labor has an important role in the resolution of management-related human factors problems, and union contracts or initiatives often address issues not covered by Federal policy. For example, some pilot contracts establish duty-time limits, since FARs are not explicit in this area, and while FARs permit Part 121 pilots to fly 100 hours per month, few actually do.[51] Additionally, labor organizations provide publications, training programs, counseling sessions, and communication channels to management for member employees. Unions also support independent studies and research efforts, such as ALPA's stress survey, and ALPA has safety councils at each of its member domiciles.[52] For further discussion of labor-related issues, see chapter 2.

[51]OTA primary research, 1987.

[52]Ibid.

CONCLUSIONS AND POLICY OPTIONS

People are pivotal to aviation safety. While humans are largely responsible for commercial aviation's excellent safety record, human errors nonetheless cause or contribute to the vast majority of accidents. Moreover, the rate of pilot error accidents shows no sign of abating, while weather-related crashes are declining and aircraft component failures are rarely the sole factor in serious mishaps. Furthermore, accident and incident data analyses indicate that if only a portion of human error problems can be resolved, substantial reductions in accident risk can be attained.

Changes in aircraft technology and operating practices occurring during the past decade have widespread human behavior and safety implications that are poorly understood. OTA concludes that human factors concerns regarding cockpit automation, pilot selection and training, and airline management are not addressed adequately by current FARs.

Human factors is a fundamental technology that is as essential to the safe design and operation of aircraft as are aerodynamics, structures, and propulsion. However, human error hazard analyses are not presently a normal part of aircraft or ATC system design or certification. While the aircraft manufacturing industry and some airlines conduct human factors research, and will continue to do so, this research is fragmented, and the results are not always widely available.

OTA concludes that long-term improvements in aviation safety will come primarily through systematic operational human factors solutions and that such solutions will be found only with consistent, long-term support for research and development. Furthermore, without Federal backing, human factors research and application will lam guish for proprietary reasons.

FAA could make good use of the multidisciplinary human factors knowledge that is spread throughout the Federal Government, private industry, and independent research groups if it had the organizational structure to coordinate this understanding. For example, in 1985, FAA's Cockpit Human Factors Research Plan drew upon the widespread expertise in the United States and proposed a number of important projects; however, few received sufficient FAA funding. While FAA, as a regulatory agency, might not be expected to conduct much research in-house, FAA must address commercial aviation human factors issues in clear, precise advisory circulars and regulations. Congress may wish to direct FAA to allocate the resources for human factors expertise in regulatory support staffs, and to establish an agency focal point, such as a Program Office, that could serve as a catalyst and coordinator for cooperative efforts spearheaded by NASA, and including other FAA offices, NTSB, the Department of Defense, manufacturers, airlines, and unions.

The following are key areas and questions for federally supported research or regulatory efforts:

- *Operational data collection.* Ideally, regulations are based upon objective evidence from the operational environment, one area where the field of human factors is lacking. Federal and industry cooperation is necessary for establishing human performance measurement techniques and for ensuring proper control and dissemination of these sensitive data. Cockpit voice recorders, flight data recorders, and video systems could supply much of these data, provided a nonpunitive approach is taken with close union oversight and support.
- *Physiological and psychological factors.* What are the effects of stressors, singly or in combination, on pilot and controller performance? Advanced technology is changing the roles of pilots and controllers; what cognitive and personality traits are desirable for the operators of current and future aviation systems? What factors influence pilot and controller decisionmaking and what options are available for improving it? How applicable are current age and medical requirements?
- *Crew management.* How can crew coordination be improved? Should CRM training be federally mandated? What technology, procedures, or training methods are available for facilitating intra-cockpit and air/ground communication?
- *New technology.* It is possible to automate most of the flight deck and ATC functions currently performed manually by pilots and controllers; however, not all automation enhances safety. What is the optimal distribution of tasks between operators and automated systems? How can pilot and controller readiness to respond to emergencies be enhanced? What standards are required to ensure effective information transfer to the pilot or controller? How can ATC/cockpit communication be improved? To what extent should flight crewmembers be monitored by automated systems?