2.0 HUMAN FACTORS IN AIRLINE MAINTENANCE: PAST, PRESENT, AND FUTURE

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This paper offers a historical perspective on human factors with the primary emphasis on the 1990s and the progress industry and government have achieved in airline maintenance human factors. While aviation-related human factors finds substantive roots back to the 1940s, it took nearly 50 more years for the term "human factors" to become a common term to airline maintenance personnel. The paper reviews the recent ten-year history since the FAA mounted a concerted effort to apply research and development to pragmatic issues in aviation maintenance. The FAA research team, working with the international airline community, has created procedures, software, and guidance that are now applied daily to enhance human performance and to ensure continuing safety. Finally, the paper forecasts the next ten years of maintenance human factors activity.

INTRODUCTION

This paper has the goal of reviewing the history of human factors with major emphasis focused on the past ten years of research and development applied to airline maintenance. The paper uses the past decade, from 1988 to 1998, to forecast maintenance human factors activities for the first decade of the 21st century.

The best way to review the past decade of progress in airline maintenance human factors is to review agendas and presentations from the semi-annual and annual FAA-sponsored meetings addressing human factors in aviation maintenance and inspection. We shall look at who has participated and how presentation themes have evolved. The FAA human factors research program activities are also an excellent means to "take the pulse" of the industry. We shall review that research and offer an assessment of the impact of the research.

Definitions and Models

The industry has evolved to a level where the "definition of human factors" is not a necessary title for a conference presentation. However, even today, definitions are a function of whom you ask. Some would readily offer the opinion that human factors is "maintenance resource management." Others cannot avoid the vision of a "bearded guru" facilitating "feel good sessions" and then reporting the results in scientific psychobable. There may be validity to both definitions. Many argue that human factors is the study of the human at the center of a given system… that human factors address human capabilities and limitations to minimize error and maximize performance. There are a variety of disciplines associated with human factors, including but not limited to, industrial and safety engineering, organizational and educational psychology, cognitive and computer science, and more.[1,2]

The approach to understanding and applying human factors can be simplified using a model. The SHEL model, developed in the ‘60s by E. Edwards, may be the most common model discussed in aviation human factors circles3. However, this author suggests an easier to understand model developed by Dr. Michael Maddox for a maintenance human factors course that we offer. The PEAR model is a means to consider human factors within any organization or context. As we consider the past, present, and future direction of human factors, the PEAR works.

Human factors analyses must first consider the human (People). Studying People includes such factors as the following: size, mental and physical capability, attitude, training, age, adaptability, and other such characteristics. It is imperative to understand People in order to proceed with good human factors analyses. E stands for Environment in which People work. The Environment is not limited to such physical measures as temperature, humidity, noise level, and illumination, but also to the organizational environment including such factors as labor contracts, management-worker cooperation, and workplace communication. A is for Actions which People perform in the Environment. Actions describe what the human must do to complete the variety of daily work tasks. Formalized methods for job task analysis (JTA) are important tools that human factors professionals use to define Actions. JTA results help to create precise specifications for hiring, training, designing equipment and information, and determining all critical aspects of job performance. Finally R is for the Resources that are necessary for People working in a defined Environment to perform Actions. Resources include such things as tools, computers, information, other people, time, and more. PEAR works well to understand and address all issues related to human performance in maintenance. It even works to consider the history of human factors.

THE PAST

Human Factors from the Beginning of Time

With “tongue in cheek” we contend that at the very start of creation, a form of the PEAR model was considered. The human was “designed” to be compatible with and/or adaptable to the Environment of earth. The design/evolution of humans had to consider the Actions the human would be likely to perform and the Resources likely to be available. The Creator had an advantage over those of us working in maintenance human factors; He had generations of time for the human to evolve. We, on the other hand, strive to eliminate and mitigate human error in maintenance at work, immediately! While the “beginning of time” story has reasonable validity, it was not until the 1900s that the human began to fly and maintain heavier-than-air aircraft. Thus, we shall jump ahead accordingly.

Human Factors in the 20th Century

While some 747 captains will say that human factors began with glass cockpits, the industrial revolution is a more likely initiating event for the study of human factors. A variety of sources would contend that human factors, as a formal science, started somewhere near the turn of the century. Two industrial engineers, Frank and Lillian Gilbreth, applied a formal task analytic approach to raising the efficiency of surgeons.4 The classic example of the surgeon requesting scalpel and the assistant repeating the request and providing the scalpel is an early example of human factors at work. This procedure permitted the doctor to concentrate on surgery rather than on finding the correct instrument. The verbal challenge- response, of course, is used in all cockpits today. Incidentally, today the scalpel is likely to be a laser beam, yet human factors personnel continue to study the performance of medical professionals.5

THE PRESENT

By 1910, the U.S. Army was conducting pilot selection and accident investigations based on pilot medical factors. Therefore, it is the field of medicine that may deserve the claim to the first formal study of human factors in aviation. Of course, it can also be reasonably argued that inventors from Leonardo DaVinci to the Wright Brothers considered all items in the PEAR model. Icarus, unfortunately, failed to consider Environment during any human factors analysis he may have conducted.

Military aircraft production drove much of the early consideration of human factors.6 During the ‘40s military aircraft were in heavy production throughout the world, driven by WWII. Investigations during the war lead to the conclusion that cockpit design was a problem. The original design, and between-model modifications to displays and controls, caused the pilot to commit errors. The term “engineering psychology” emerged in the ‘40s with the focus on designing aircraft with an improved match to the capabilities and limitations of humans. At a minimum, the early engineering psychologists had to ensure standardization of displays and controls (a.k.a., knobs) within and between aircraft types. The attention to knobs and dials, by the way, resulted in the somewhat humorous term “knobology,” which is indeed a small and ongoing subset of human factors.

In the late ‘40s and ‘50s, professional societies of human factors engineers and psychologists formed the Ergonomics Research Society (1949 in the U.K.) and the Human Factors Society (1957 in the U.S.) In 1995 the Human Factors Society evolved to the Human Factors & Ergonomics (HF&E) Society, thus encompassing all physical, physiological, and cognitive aspects of the human in any given system. Today the HF & E Society has over 5,000 active members throughout the world.

Maintenance human factors began receiving attention in the early ‘50s at Wright Air Force Base in Ohio. Researchers there focused on such aspects as selection and training of maintenance personnel. Even then researchers were lamenting the growing complexity of aircraft and the associated electronics equipment!

Human factors research evolved substantially from the ‘60s through the ‘80s. Manned space flight research made significant contributions to formal studies of the human in the system. While the PEAR model was not formally used all aspects of PEAR were applicable. The design of the complex fighter jets introduced increasingly complex aircraft and weapon systems that could easily overload human processing capability. The importance of the situation awareness was highlighted, not only by the military aircraft, but also by a few famous commercial incidents and accidents. In other industries, such as nuclear power electric generation, many examples of human error taught us that humans sometimes did not fully understand the complex systems that they were “controlling.”

Critical incidents like the aircraft accidents at Tennerife (1977), the United DC8 fuel exhaustion accident off the Oregon coast (1978), and the nuclear plant Three Mile Island (1979) focused considerable attention on the study of human factors, such as training, communication, procedures, situation awareness, and crew resource management. Research, development, and products have evolved as a result of these accidents.

In 1988 the Aloha Airlines 737 encountered the famous “convertible aircraft” phenomenon. This accident placed focus on the aging aircraft fleet, but just as much attention was focused on maintenance human factors. The Aloha Accident report identified numerous human factors issues including, but not limited to, training, use of procedures, and use of a manufacturer’s service bulletins.7

In 1988 the U. S. Congress passed the Aviation Safety Research Act (PL 100-592).8 Within that law was the expressed intent to study all aspects of human factors in aviation safety including human factors in maintenance. That Act, and the associated ongoing funding, without doubt, has had the single greatest impact on the current international airline and government attention to human factors in airline maintenance. Since 1988, the FAA Office of Aviation Medicine has invested an average of $1.25M per year on maintenance human factors research and development. The FAA R&D has been matched by considerable aviation industry services and participation in-kind. The success story of the research program constitutes the next subsection of this paper.

Human Factors: Current Status Since 1988

The Aviation Safety Research Act, ten years ago, initiated funding to the FAA Office of Aviation Medicine to conduct maintenance human factors research. However, soon the three-legged stool of government, operators, and manufacturers combined intellectual and fiscal resources to enhance the maintenance research program. From the very inception of the program, the FAA knew that "research" was not the goal…pragmatic results and recommendations were the goal. The research tasks described within this section, therefore, are the pragmatic results of a coordinated effort of government and industry. It would require more pages than this paper will allow to describe all of the activities and products of the research program. Instead a few major categories and projects shall be highlighted.

Conferences on Human Factors in Airline Maintenance and Inspection

"I personally am very excited about the fact that people are willing to spend their valuable time to get together and talk about something which, it is fair to say, we know little about [Maintenance Human Factor]. We in the FAA are not sure where this interest will take us, but most likely to somewhere that we would rather be compared to where we are today. Because of the lack of maturity of the subject matter, as some might say, we are in a position where we might be able to make significant contributions to aircraft maintenance and aviation safety with a fairly modest investment of time and resources. It will be exciting to be a part of this activity."

> Anthony J. Broderick
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> FAA Associate Administrator for Regulation and Certification
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> To an audience of 40 at the first Workshop on Human Factors in Maintenance and Inspection, October 1988

An excellent means to assess the past ten years, or current status, of human factors in airline maintenance is to use the FAA maintenance human factors workshop attendance, type of participation, and presentation topics as a measure of progress.

The first meeting, ten years ago, attracted 40 participants, of which 14 were speakers. There was no non-U.S. international participation in meeting. By 1997 international participation had grown to nearly 50 of the total 294 attendees. The coordination between FAA, ATA, and Transport Canada for 1998 is an important and clear message that the industry and governments worldwide have recognized the value of these workshops. And, as an industry, we know much more than Mr. Broderick rightfully predicted ten years ago.

Table 2.1 FAA Conferences on Human Factors in Maintenance and Inspection

Meetings		Attendees	Presenters

Year	Title	Location	US	Intl.	Gov.	Academic	Industry	Consultant
1988	Human Factors Issues in Aircraft Maintenance & Inspection	Washington, DC	40	0	3	4	6	1
1989	Information Exchange and Communications	Alexandria, VA	78	4	4	2	6	3
1990	Training Issues	Atlantic City, NJ	92	4	3	4	5	5
1990	The Aviation Maintenance Technician	Alexandria, VA	74	5	6	1	7	0
1991	The Work Environment in Aviation Maintenance	Atlanta, GA	66	8	2	4	4	4
1992*	Maintenance 2000	Alexandria, VA	95	8	2	0	6	2
1992*	Science, Technology, and Management: A Program Review	Atlanta, GA	85	18	3	8	3	5
1993*	Trends and Advances in Aviation Maintenance Operations	Alexandria, VA	79	10	1	1	11	3
1994*	The Human Factors Guide	Albuquerque, NM	70	13	0	1	1	10
1996*	Maintenance Performance Enhancement and Technician Resource Management	Alexandria, VA	141	36	5	5	9	4
1997*	Human Error in Maintenance	San Diego, CA	246	48	3	4	9	4

** Preregistered only. Actual registrants were approximately 40% more.*

As one reviews the topics and agendas since 1988, it is clear that concepts proposed and presented in the early days are success stories of the later conferences. One example is the industry's request for applied maintenance human factors research. Conference attendees requested wide-spread dissemination of FAA research data. The result was the print publication of all program documents from the very start of the program in 1988. The materials and software were published and distributed, on CD-ROM, starting in 1991 and on an annual basis since that time. In fact, the FAA CD-ROM was the only reason for airline personnel to require CD-ROM players in the early '90s. The 1998 conference marks the distribution of the 7th FAA CD-ROM on Human Factors in Maintenance and Inspection—About 14,000 CD-ROMs have been distributed worldwide. The FAA maintenance human factors research program is one of the few programs that successfully accomplished the goal of wide-spread distribution of technical publications and software programs.

Advanced Technology Training

Participants at the 1988 meeting asked the FAA to explore advanced technology training, create computer-based training prototypes, and make recommendations regarding best use of such technology. The research program built numerous prototypes over the past ten years. More importantly, key research team members cooperated with the ATA Maintenance Training Committee to define and demonstrate such concepts as intelligent tutoring systems, smart simulations, and other types of distance learning. Example systems, designed and built in cooperation with airline or manufacturer partners include the following: the Boeing 767 environmental control tutoring system, with Delta Air Lines; the Aircraft Maintenance Team Training, with Lockheed-Martin Aerospace; the System for Training Aviation Regulations; and the Web-based Maintenance Resource Management Trainer (www.hfskyway.com). All of these systems were widely distributed to the aviation industry

Human Factors Information

The first meeting elicited a request for publications that were written for aviation maintenance managers. The goal was to produce useful documents for the airline maintenance community. Of course, the materials are useful to general aviation maintenance personnel, to regulators, and also to students in human factors programs. Examples of these products include the *Human Factors Guide for Aviation Maintenance*[9] *and the Human Factors in Aviation Maintenance and Inspection Website (HFAMI).* The third edition of the *Guide* is completed for this meeting. The HFAMI Website, operational since 1995, has had over 1.3 million hits, of which 1 million were after January 1997. The Website has won national Web awards and sets a standard for other government research programs.

Job Aiding for Maintenance and Inspection

Job aids usually capitalize on small computers to support workers. Typically job aids provide information and/or business process automation. Numerous job aids were developed and delivered to industry and government as part of the research. Examples of these systems include an automated Coordinating Agency for Supplier Evaluation system (CASE), a Document Design Aid (DDA, distributed on the 1998 CD-ROM), and the On-line Aviation Safety Inspection System (OASIS).

OASIS is an FAA research success story of the ‘90s. The system evolved from a small research prototype, called the Performance ENhancement System (PENS), to a major full-scale implementation for all FAA aviation safety inspectors worldwide. OASIS offers the inspector nearly all documents and access to databases necessary to complete FAA inspector responsibilities. The system is fielded to nearly 800 inspectors and 1,300 more units will be deployed in 1998. An extensive effort of user-centered design ensured a very useable system that received wide-spread user acceptance. The system was fielded properly with extensive user training and telephone service support. The PEAR model best describes the complete human factors analyses that was used to specify, create, deliver, and support OASIS.

THE FUTURE: FORECAST FOR MAINTENANCE HUMAN FACTORS

For this paper we shall look ahead five to ten years, since that will be most helpful as we conduct current projects and plan for the future.

It is reasonable to expect that airline maintenance human factors activities will accelerate over the next ten years. This projection is founded in the fact that the past ten years has introduced and educated much of the airline industry and governments to maintenance human factors. Airlines have either hired human factors specialists on the internal staff or are using human factors consultants. Universities have started graduate programs specifically for aviation human factors. Many of the human factors students, who conducted research under FAA human factors funding, are graduating and taking positions with airlines and manufacturers. In addition, airline and manufacturing personnel are attending human factors courses offered by private companies or organizations such as the IATA Learning Center. These trained personnel shall have a significant impact as they integrate human factors into their respective organizations.

The PEAR model is an excellent model to provide structure to a forecast of the future. The People available for the next ten years are likely to follow recent trends. It is very likely that there shall be an increasing number of females entering the maintenance workforce. With the trend towards outsourcing airlines will hire fewer technicians. The repair stations shall increase hiring. The number of FAR 147 schools are down and the graduating classes are smaller. There shall be a shortage of trained qualified personnel. It is likely that People entering the airline maintenance workforce will be less passionate about the industry and about aircraft than past maintenance employees. For example, today's generation did not grow up building model airplanes and flying piper cubs. In many cultures the aspiring airline maintenance worker has never owned or fixed a car much less an aircraft. These People trends shall influence selection, training, certification, equipment and procedure design, workplace design, and more. The past ten years have seen airline maintenance environments grow to accept and capitalize on diversity in the workplace. That positive trend shall continue.

The physical Environment shall not undergo radical change in ten years. Maintenance personnel shall continue to cope with environmental extremes related to temperature, lighting, ambient noise, odor, confined spaces, and time of day. Portable units to improve radical environmental conditions shall help. Design of new hangars and revisions to existing hangars shall improve the physical environment and layout. Improved textiles shall offer more comfortable working conditions even when the environment cannot be controlled. The organizational environment has evolved in the '90s and shall continue to evolve. Increasing teamwork and enhanced communications shall evolve and improve in the maintenance environment. While technology, such as E-mail, shall help to improve communications, an industry-wide raised consciousness regarding the importance of communication shall evolve. The result shall be a reduction in human error in maintenance. That must occur.

Maintenance Actions involve such activities as inspection, servicing, troubleshooting, removal, replacement, and tests. These activities shall continue for the next ten years—for the next one hundred years. However, modern aircraft shall require less of all the activities stated above. New aircraft contain improved self-diagnostic equipment, smarter software, new materials, and increased redundancy and reliability. For the past twenty years, we have forecasted that aviation maintenance technicians (AMTs) must increase their knowledge of electronics and of software. At the same time AMTs must maintain the existing aging fleet. Safe and proper servicing of hydraulic systems, sheet metal repairs, and airframe/powerplant inspections must go hand-in-hand with the new technology skills.

Other forces will drive the types of Activities AMTs will perform. Because there will be a shortage of qualified People to do the work, the maintenance community must find better and more efficient ways of getting things done with less. AMTs will need to hone their teamwork skills and act as a cohesive unit to compensate for any technical and personnel deficiencies projected to occur. Teamwork requires more than technical Actions; it requires AMTs to be competent in interpersonal Actions as well. To add to this, as maintenance processes become more complex, AMTs will need to gain a more global perspective of where they fit into the "system." Thinking globally enables AMTs to think about how their Actions affect others, thereby inculcating a culture of safety. Maintaining this perspective, and Acting on it requires a great deal of knowledge, flexibility, decision making, and leadership. In the future, AMTs will be required to use their heads just as much as they use their hands. Programs such as Maintenance Resource Management (MRM) are beginning to address this need.

Information technology shall dominate all change in maintenance Environments and People's Actions. Technicians shall master the software tools for improved tracking and control of the maintenance business process. Technicians will spend less of their Actions referring to the maintenance and fault isolation manuals because of improved electronic publications and other such electronic support equipment. Such job aides will stand-alone and/or will be an integral part of the prime system. The "thin-client" and other such portable information devices will be everywhere. The devices shall increase in power and decrease in size, to the extent that they will be a FOD hazard.

While information technology is a blessing it can also be a curse. Proven human factors principles must be applied to the specification and design of new technology systems. Bad ideas or bad designs do not improve on good computers. JTA and human-centered design must ensure the quality of the information technology. Tested human factors principles shall always be critical for successful design and implementation of new systems.

Resources shall also evolve. Training has improved over the past ten years and that trend shall continue. Training shall be provided "just-in-time," at the work site, by embedded software and by portable computers. Over the next ten years the line between training and job aiding shall become more clouded. The same portable, perhaps wearable, computer that provides electronic technical publications shall also provide on-the-job training and information. One result of this technology is that AMTs shall have a larger set of technical responsibilities because of the increased computer-based technical support available.

One Resource that will remain limited is time. We cannot reasonably predict that the complex task of aircraft maintenance shall ever evolve to eliminate the time pressure of schedules, push backs, and completion of an overnight check or the aircraft scheduled for an early morning flight.

SUMMARY AND CONCLUSIONS

Human factors, as a formal discipline, emerged in early 1900. By 1940, human factors design and engineering contributed to safety improvements in military aircraft. By the '50s, psychologists and industrial engineers were studying performance of maintenance technicians. However, the '90s became the decade for the applied study of maintenance human factors. During the '90s the FAA and airlines conducted extensive research and development and left a trail of useful products, procedures, and technical publications.

Finally, as we look to the future we emphasize that the research program has left many questions unanswered. The FAA and industry research is not over. It will never be over. The research has the responsibility to look to the future, to push the envelope, to continue to recognize the numerous opportunities that maximize human performance and minimize human error in airline maintenance. Industry and government must continue to cooperate in this important endeavor.

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