This maintenance technician is trying out a head-worn display of maintenance instructions. Federal Aviation Administration image.

Human Factors in Aircraft MRO

Significantly impacting the safety, efficiency, precision and overall integrity of aircraft operations

Human factors (HF) play a critical role in aviation maintenance ensuring aircraft safety and reliability. It is human factors that too often affect MRO functions that can cause or contribute to many aircraft accidents. Some examples of HF maintenance errors are parts installed incorrectly, missing parts and also required checks not being performed. As the aviation industry continues to grow, the importance of reliable and competent maintenance, repair and overhaul (MRO) services also grows.

Human factors is the study of the relationship between humans and machines. There's been such an emphasis on recognizing and responding to human factors in aircraft MRO, that the Federal Aviation Administration's (FAA) Flight Standards Service Aircraft Maintenance Division, together with the Office of Aviation Medicine (AAM), developed and formalized the agency's Human Factors in Aviation Maintenance and Inspection research program. This program was implemented in response to a congressionally mandated requirement (Aviation Safety Research Act, Pl. 100-591, 1988) and is aimed at reducing the number of accidents and incidents resulting from human error in maintenance.

This strategic program plan describes industry-government-labor partnerships that characterized the human factors in aviation maintenance and inspection research program at the time. The plan provides historical scientific explanation and rationalization of the need for applied human factors research and development.

Significant Impact

Dr. Maggie J. Ma, FRAeS, certified human factors professional (CHFP), technical fellow customer support, Boeing Commercial Airplanes, Seal Beach, California, explains that human factors can significantly impact safety, efficiency and overall reliability through:

- Investigating events and near misses to understand contributing factors (a.k.a. performance shaping factors), so we can manage/influence human behaviors — preventing and mitigating human errors and violations.
- Designing for maintainability; applying Human-Centered Design (HCD) approach and design for maintainers to ensure they can perform their tasks (maintaining/servicing/inspecting the aircraft) safely and efficiently in the actual operational environments.
- Ensuring effective and ease-of-use of work instructions and user interfaces of maintenance applications/systems.
- Understanding changing demographics of aircraft maintainers, their changing needs/preferences in seeking information, using

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technologies, learning, as well as impact of new technologies on the workforce and performance (e.g., artificial intelligence, drone assisted visual inspection, human-robot teaming).

Dr. Bill Johnson is president and chief scientist of Drbillj.com LLC, Atlanta. Over the past 15 years he has spoken to many FAA airworthiness inspectors (perhaps 2,500 ASIs), FAA certification inspectors, NTSB and other international investigative and defense personnel, and U.S. and International airline and MRO employees. At the start of each of his classes he asks the class to use a blank sheet to list the top five HF challenges related to airworthiness.

"I started doing this in 2010," Dr. Johnson says. "Surprisingly, the lists have not changed radically in that 15-year period and there is a high overlap between U.S. and international audiences. That says that the age-old challenges have not gone away and need continuing reinforcement. These lists include: company safety culture; enough qualified MRO personnel; management and self-induced time and quality pressure; fitness for duty (mostly fatigue); communication; complacency; procedural compliance; learning new technology; and more."

When it comes to recognized HF challenges, there was an initial industry "Dirty Dozen," a list of the twelve most frequent pre-cursors or contributing factors to human errors that can lead to incidents and accidents. This list has evolved and expanded to be called the "Filthy Fifteen," which includes modern stressors and influences in aviation maintenance. The three additions to the original twelve help address risks from new technology regulations and workforce changes:

- Lack of Communication
- Complacency
- Lack of Knowledge
- Distractions
- Lack of Teamwork
- Fatigue
- Lack of Resources
- Pressure
- Lack of Assertiveness
- Stress
- Lack of Awareness
- Norms
- Technology Overload
- Information Overload
- Procedural Drift

Advances, Technologies and Training

What's available to aid HF in aircraft MROs and keep the Filthy Fifteen at bay? Dr. Johnson explains that while procedural compliance is still a primary challenge, "New delivery methods like hand-held computers make it easier to always have the right documentation available. Younger workers are likely to consult documentation when they have a device readily available. FAR Part 5, related to Safety Management System (SMS) is working for airlines and most MROs. With proper scaling, it will also have a positive impact on general aviation MRO operations. Tied closely to SMS is voluntary reporting. FAA inspectors are adopting the attitude/philosophy that it is better to find ways to address hazards and possibly increase risks rather than find ways to punish

Aviation MRO professionals work on an airplane at the Xiamen Airlines - Fuzhou Maintenance Base in Fuzhou, China. Photo courtesy of Dr. Maggie Ma.

Dr. Maggie Ma helped launch the Ethiopian Airlines (ET) Maintenance Line Operations Safety Assessment program in Addis Ababa, which is a Boeing and ET collaborative effort. Photo courtesy of Ethiopian Airlines and Boeing.

personnel and organizations that make mistakes. FAA, company management, organized labor and individual workers are thinking more like risk assessors."

DOT TSI Mx HF classes use the PEAR model, which was created by Dr. Johnson and another developer in 1995. The model (actually a mnemonic) was initially designed to be understood and used by the aviation maintenance and engineering audience. PEAR remains a main HF training paradigm for FAA inspector training and is also widely used by the Civil Aviation Safety Authority (CASA), Australia training program. PEAR is the basis for maintenance HF training at many airlines and maintenance, repairs and operations. For over two decades, the term "PEAR" has been used as a memory jogger to characterize HF in aviation maintenance. PEAR prompts recall the four important considerations for HF programs:

- People who do the job
- Environment in which they work
- Actions they perform
- Resources necessary to complete a job

Dr. Ma notes that the release of ICAO Doc 10151: Manual on Human Performance (HP) for Regulators in 2023 been a very useful tool. The document has defined the five principles of human performance and provided guidance to the regulators and the regulated on how to best support human performance in aviation.

There is a trend for organizations to rely on computer/web-based training to satisfy the aircraft MRO requirements whenever they can for cost-saving reasons. Dr. Ma warns there is a lot of empirical evidence that CBT/WBT for human factors is not as effective as in-person facilitator led training. "Organizations

should implement in-person HF training to take advantage of the human interaction in learning and team building."

Increasingly, XR (Extended Reality) technologies — a broad term encompassing immersive technologies that merge the physical and digital worlds — are gaining in usage. Virtual Reality (VR) is being used for training and design/development activities. Mixed Reality (MR)/Augmented Reality is being used for training, remote assist, remote inspection, intuitive work instruction with built-in work-progress tracking and error-proof features. Dr. Ma says the fourth wave of computing — enabled by mixed reality immersive wearable technology — target users are first-line workers (2 billion) such as maintainers. Previously the key target computing users were information workers (480 million).

A Shift to Cognitive Interface Management

It is impossible to ignore the rise of AI. "AI is taking the world by storm and will transform aviation/aircraft MRO by transforming what people do and how people work," Dr. Ma says. "Correct AI use is likely to improve accuracy and efficiency like what automation has done. However, there will also be challenges like misinformation, mistrust, over trust and ethical concerns that are more complex than those concerns associated with automation. The Intl. Society of Human Factors and Ergonomics has released AI 'guardrails' for human use."

"Automation, like AI, can follow a lot of worker activity and provide real-time advice," Dr. Johnson says. "A smart computer will advise you a lot quicker than a co-worker who does not want to offend you. Automation can make it easier for workers to report and learn from personal errors and the collective errors of other workers. Manufacturers are increasingly offering a built-in test. No matter how much automation there is in the equipment we will always need a competent mechanic to help diagnose, service and R&R hardware."

Dr. Ma believes that both mechanical interaction and cognitive interface management have been important focuses for maintenance HF and will continue to be in the foreseeable future. "The trend in aircraft maintenance is becoming more proactive and predictive. HF needs to shift to assisting maintainers in proactive and predictive maintenance related training, planning and tasks. As airplanes and systems become more sophisticated, maintenance HF must engage early in the design and development and help to keep maintainers in the loop. [This] allows them to see the logistics behind how systems function and the 'whys' when something failed to work properly."

Technologies are evolving and AI is rapidly re-shaping the world and changing workplaces. Dr. Ma believes that investing in aviation HF research and innovations will help to understand how human performance is affected by these changes and how to keep maintainers and other aviation professionals safe, productive, efficient, healthy and happy. "We need to support new generations of maintainers based on their information search and consumption preferences and learning needs. We need more HF practitioners."

A technician's human factors will influence aircraft MRO performance. Investing in aviation HF research and innovations will help to understand how human performance is affected by these changes and how to keep maintainers safe, productive, efficient, healthy and happy. Photo courtesy of Ethiopian Airlines and Boeing.

Safety Culture

While implemented in the MRO trenches, the focus on HF must start at the top. An organization's safety culture is a pervasive attitude that places safety at the heart of every operational decision. Dr. Johnson says, "The concept of safety culture is increasingly familiar to management and the workforce. It is a safety culture evolution with new technologies ensuring continuing safety. That's true for all types of organizations. Enlightened management is continuing to move in the right direction. If management does not do the right thing then organized labor and individual workers will encourage them. The maintenance workforce is determined to do the right thing."

Dr. Ma quotes a common HF expression, "To err is human and to drift is human," when discussing organization culture and company policies/protocol (e.g., SMS) that manage human behaviors based on the understanding of human behaviors. "To prevent and mitigate human errors and violations, the key is to manage/remove contributing factors that precede errors and violations. Telling people to not make errors or not violate procedures or just punishing people won't prevent reoccurrence. Organization culture/safety culture should make people feel comfortable, and encouraged and incentivized to report events, near misses and any safety concerns. For example, by having established psychological safety among teams, established just culture and reporting culture, and an easily accessible/easy-to-use reporting system. Employees know what to report and have the options to report confidentially or anonymously." AVM

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Quick Reference
Aviation Safety Regulations Affecting Aircraft MRO Human Factors

International Civil Aviation Organization (ICAO)
Doc 10151: Manual on Human Performance (HP) for Regulators
Human Factors Training Manual (Doc 9683)
Human Factors Guidelines for Aircraft Maintenance Manual (Doc 9824)
Human Factors Digest No. 12 — Human Factors in Aircraft Maintenance and Inspection (Circular 253)

Federal Aviation Administration (FAA)
Human Factors Design Standard (HFDS), HF-STD-001B (2016)
Operator's Manual: Human Factors in Aviation Maintenance (2014)
FAA AC 120-92B Safety Management Systems for Aviation Service Providers (2015)
FAA AC 120-115 Maintainer Fatigue Risk Management (2016)
FAA AC 120-72A Maintenance Human Factors Training (2017)

EASA
Airworthiness Maintenance
EASA 145/JAR145, EASA147/JAR147, EASA66/JAR66
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UK Civil Aviation Authority (CAA)
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Information provided by Dr. Maggie J. Ma, FRAeS, certified human factors professional (CHFP), technical fellow customer support, Boeing Commercial Airplanes, Seal Beach, California.

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