

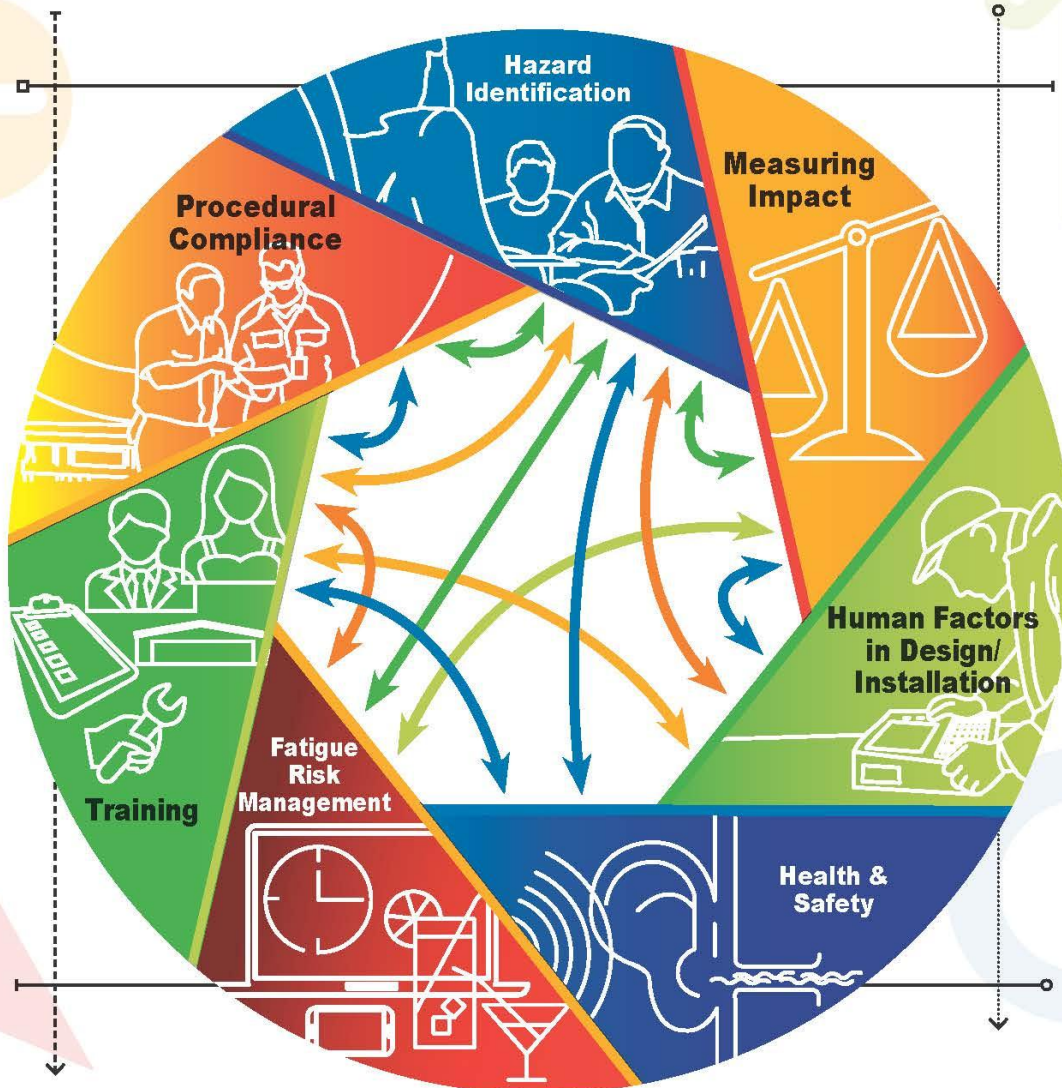


**Federal Aviation
Administration**

September 2014

Operator's Manual

Human Factors in Aviation Maintenance



PRELUDE

In 2005 the Federal Aviation Administration (FAA) worked with industry representatives to complete the *Operator's Manual for Human Factors in Aviation Maintenance (Op's Manual)*. That manual earned broad U.S. and international acceptance. A Spanish and Chinese translation influenced its international distribution and value. The Op's Manual won the FAA Administrator's *Award for Use of Plain Language*. Document design, simplicity, and concise delivery of technical information were the key features that made the Op's Manual useful for maintenance and engineering personnel. In 2008, the FAA and industry published an encore manual dedicated to airport operations.

This new 2nd Edition of The Operator's Manual for Human Factors in Aviation Maintenance follows the same successful format as the 1st Edition. Selected chapters of the 1st Edition are substituted with chapters more relevant to today's aviation maintenance challenges. Repeated chapters are significantly enhanced. As with the 1st Edition, contributors remained disciplined to keep the information concise and limited to only relevant information.

ACRONYMS

A4A	Airlines for America (formerly Air Transport Association of America; Air Transport Association (ATA))
AC	Advisory Circular
AMT	Aviation Maintenance Technician
ASAP	Aviation Safety Action Program
ASRs	Aviation Safety Reports
ASRS	Aviation Safety Reporting System
ATA	Air Transport Association
CAMI	Civil Aerospace Medical Institute
CASA	Civil Aviation Safety Authority
CAST	Commercial Aviation Safety Team
CFR	Code of Federal Regulations
CRM	Crew Resource Management
DAH	Design Approval Holders
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
HF	Human Factors
HFACS-ME	Human Factors Analysis and Classification System – Maintenance Extension
FRM	Fatigue Risk Management
FRMP	Fatigue Risk Management Plan
FRMS	Fatigue Risk Management System
IATA	International Air Transport Association
ICA	Instruction for Continued Airworthiness
ICAO	International Civil Aviation Organization
LMEC	Latent Medical or Environment Conditions
LOI	Letter of Investigation
LOSA	FAA Maintenance and Ramp Line Operations Safety Assessment
MEDA	Maintenance Error Decision Aid
MRO	Maintenance Repair and Overhaul
MxO	Maintenance Engineering Organization
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
OSH Act	Occupational Safety and Health Act

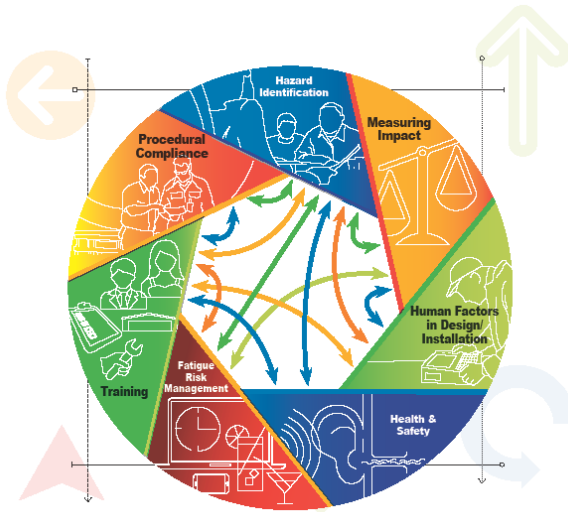
OSHA	Occupational Safety and Health Administration
REDA	Ramp Error Decision Aid
ROI	Return on Investment
SMS	Safety Management System
UK CAA	United Kingdom Civil Aviation Authority



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INTRODUCTION

This manual recognizes that readers already know the importance of human factors — a science that pays attention to physical, psychological, and other human attributes to ensure that we work safely and efficiently with minimal risk to others and equipment. The chapters discuss seven critical human factors topics that contribute to the goal of creating

and reinforcing a safety culture where employees practice safe habits, both at work and at home.

Seven Human Factors Topics

- Hazard Identification
- Procedural Compliance and Documentation
- Human Factors Training – Evolution and Reinforcement
- Fatigue Risk Management
- Human Factors Health and Safety Program
- Considering Human Factors Issues in Design and Installation
- Measuring Impact and Return on Investment (ROI)

The references, by design, are few and limited to those providing the most relevant information. Chapters have identical format and include:

1. Chapter topic introduction
2. Why the topic is important
3. How to implement the program component
4. How to know the program component works
5. Key references and links

Operational data and practical experience from the U.S. and other countries are the basis of the seven critical topics. The International Civil Aviation Organization (ICAO), the U.S. Occupational Safety and Health Administration (OSHA), Airlines for America (A4A), Transport Canada, United

Kingdom Civil Aviation Authority (UK CAA), the European Aviation Safety Agency (EASA), the International Air Transport Association (IATA), and information from other entities contributed to this manual. The seven contributors to this manual have worked in aviation maintenance, medicine, and engineering for an average of 35 years. The contributors characterized the seven topics and related steps discussed in this manual as “information they wish they had known years ago.”

These straightforward suggestions provide the key components for setting up and/or overseeing successful human factors programs that will benefit your company, business partners, external customers, employees, and the entire industry. The suggestions will also help to ensure compliance with human factors regulations, as appropriate. Keep in mind the following points when using this manual:

- These are seven topics, from many, that a maintenance human factors program may consider.
- Topics are not necessarily in order of importance.
- Apply any or all of the topics; however, they should be coordinated.
- Base your human factors activity on the identified requirements and resources of your organization. One size does not fit all.
- The role of company leadership, with labor representation, is critical in establishing and sustaining a human factors program.
- Supplement this operator's manual with additional references as necessary.
- Human factors programs are a critical part of your safety management system and corporate safety culture.

Why Use the Operator's Manual?

You may ask, “What is in it for me?” Below are some of the many reasons for using the information in this manual.

- ICAO Safety Management System (SMS) standards and the evolving regulations are requiring programs to collect the proactive and predictive data offered by voluntary reporting systems (see Chapter 1).
- A 2007 European Aviation Safety Agency (EASA) Safety Analysis and Research study analyzed all worldwide commercial aircraft accidents from 1990 to 2006 and found that in 8% of the accidents, the primary cause was maintenance (see Chapter 1).
- A summary of multiple airlines and maintenance, repair, and overhaul (MRO) organizations shows that challenges from technical publications and company

procedures are in the top four most reported events from FAA's Aviation Safety Action Program (ASAP) (see Chapter 2).

- The #1 factor for which FAA initiates Letters of Investigation (LOI) and takes administrative actions on AMTs is failure to follow written procedures as defined in Advisory Circular (AC) 43.13-1 (A&B) (see Chapter 2).
- The National Aeronautics and Space Administration (NASA) reports that, from 2010 to 2013, approximately 83% of maintenance Aviation Safety Reports (ASRs) was related to technical publications and other written company procedures (see Chapter 2).
- Training is a critical part of every aviation industry position. Halldale Publishing estimates that the annual expenditures on all training equipment, services, and personnel exceeds \$500 billion USD (see Chapter 3).
- Training is inevitably the top intervention for identified organization risk reduction (see Chapter 3).
- Human Factors training is instrumental in fostering a positive safety culture and serves to introduce the workforce to concepts related to risk assessment, voluntary reporting, event investigation, and peer-to-peer support (see Chapter 3).
- One study found that fatigue costs employers more than \$136 billion USD per year in health-related lost productivity and that the majority (84%) of the costs related to reduced work performance (see Chapter 4).
- According to operational data collected in a maintenance organization, individuals working 16-hr days or longer were four times more likely to be involved in a personnel injury incident/accident than an individual working an 8 hr day (see Chapter 4).
- Changes in the workforce are perceptible with 19% of the current workforce over age 55 years and 27% in the obese weight category (see Chapter 5).
- Telephone interviews using the U.S. Census Occupational Code systems show that the occupation "aircraft engine mechanics" ranked 48th in mortality among 206 occupations included in the census (see Chapter 5).
- The National Business Aircraft Association Safety Committee has made pilot adjustment to advanced avionics systems one of its top focus areas for 2014.¹ Proper installation and attention to human factors issues is an important contribution to the safety goal (see Chapter 6).
- Inspection Authorization certificate holders and FAA Aviation Safety Inspectors (ASIs) have expressed the need for human factors guidance for avionics and other appliance installations and approvals during discussions in Inspection Authorization renewal workshops (experience from authors Johnson and Brys) (see Chapter 6).

- When not driven by regulation, human factors programs and other safety interventions demonstrate an impact on cost and other safety-related performance measures (see Chapter 7).
- Since 2010, industry has applied the FAA Return on Investment (ROI) procedures and software to demonstrate positive return on safety interventions that have reduced ground damage, affected worker communication, streamlined the application of technical manuals for cabin crew, reduced rework and equipment damage by changing procedures, and more (see Chapter 7).
- FAA/Industry surveys in 2010 and 2014, identified “Establishing the Value of Human Factors” among the top 5 challenges related to maintenance human factors.^{2,3}

Key References and Links

1. National Business Aviation Association. <http://www.nbaa.com>
2. Johnson, W.B. (2010). Maintenance Human Factors Leaders Workshop Proceedings. Retrieved from:
http://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/roi/mx_hf_wrkshop_proceedings_final_report_with_cover_reduced.pdf
3. Avers, K.E., Johnson, W.B., Banks, J.O., & Wenzel, B. (2014). The Transition from Event Reports to Measurable Organizational Impact: Workshop Proceedings Report. Retrieved from: <http://ntl.bts.gov/lib/51000/51600/51649/201405.pdf>



HAZARD IDENTIFICATION

Chapter 1

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Airline and MRO Safety Management Systems (SMS) have advanced rapidly in the past decade. Conceived by the International Civil Aviation Organization (ICAO) and put into practice through regulation by the national aviation authorities, SMS will soon be a standard requirement for airlines around the world. Airlines will be required to implement SMS in various organizations within the airline, including the Maintenance and Engineering function, while national aviation authorities are passing regulations requiring maintenance organizations to implement an SMS as well.

One of the major components of an SMS is Risk Management. Risk Management requires that safety of flight hazards be identified, that the hazards be assessed for risk, and that unacceptable risk be mitigated to acceptable levels.

A hazard is a potential source of harm; for example, a condition, object, or activity with the potential of causing injuries to personnel, damage to equipment or structures, loss of materials, or reduction of the ability to perform a prescribed function. Because an SMS is regulated by national aviation authorities, these hazards relate specifically to safety of flight. However, many airline maintenance and engineering organizations also include hazards related to personal injury, equipment damage, and environmental damage in their SMS. Risk is defined as the hazard consequence severity times the probability of attaining that severe a hazard consequence.

An SMS recommends three approaches in identifying safety hazards (see Figure 1):

1. Reactive approach—investigation of accidents, incidents, and events.
2. Proactive approach—active identification of safety hazards through the analysis of the organization's activities, using tools such as mandatory and voluntary reporting systems, safety audits, and safety surveys.
3. Predictive approach—capturing system performance as it happens in real-time during normal operations such as observations of AMT performance during a heavy check.



Figure 1. Three Complementary Approaches for Hazard Identification

In the previous version of the Operator's Manual (2006), this chapter was entitled "Event Investigation." However, because of the movement to implement SMS in the industry, and because event investigation is only one of three important hazard identification approaches, this updated chapter in the Operator's Manual update will discuss all three hazard identification approaches.

1.1 Why Hazard Identification Is Important

- A. Hazard identification is part of a major component of an SMS.
- B. Incorrectly performed maintenance, due to workplace hazards, has been the second leading primary cause (after pilot error) of commercial aircraft hull-loss accidents over the past several decades.
 - a. A European Aviation Safety Agency (EASA) Safety Analysis and Research study, which analyzed all worldwide commercial aircraft accidents from 1990 to 2006,¹⁰ found that in 8% of the accidents, maintenance was the primary cause.
 - b. Maintenance was the primary causal factor of 3% of global fatal accidents between 2002 and 2011.¹¹
 - c. The International Air Transportation Association Safety Reports (IATA) from 2003 – 2008 found that incorrectly performed maintenance was causal (either as a primary cause or an initial link in the accident chain) in 20% to 40% of the worldwide aircraft accidents for those years.¹²
 - d. Maintenance events counted as an average of 10% of threats that led to 432 aircraft accidents between 2009 and 2013. Maintenance Operations, including Standard Operating Procedures and Training Systems, were found to be a latent condition for 8% of the 338 non-fatal accidents worldwide between 2009 and 2013.¹²

Threat: *Any condition that increases the complexity of the operations, and, which, if not managed properly, can decrease safety margins and lead to errors.*

Latent condition: *Conditions present in the system before the accident and triggered by various possible factors.*

- C. The Flight Safety Foundation estimates that 27,000 ramp accidents and incidents, one per 1,000 departures occur worldwide each year. The injury rate is 9 per 1,000 departures. Ramp accidents cost major airlines worldwide at least \$10 billion USD a year.
- D. Hazard identification programs help identify and communicate hazards or factors contributing to errors and violations to create corrective actions and prevent future events.
- E. Hazard identification programs, such as event investigation, are a primary requirement for identifying and communicating human performance issues within an organization.

1.2 How to implement a Hazard Identification process

The three different hazard identification processes may be owned and maintained by different functions within the Maintenance and Engineering organization. Reactive processes are often owned by Quality Assurance, although they can also be owned by a safety department or production. Proactive processes are often owned by Quality Assurance and Safety. Predictive processes are often owned by production. However, all of them have some basic requirements for implementation.

- A. Select a manager/department to be responsible for the process.
- B. From the very beginning, ensure that the program is a cooperative endeavor of labor, management, and, if appropriate, the regulator. Obtain the buy-in and participation of frontline employees because they are a valuable asset in discovering hazards (see Figure 2).
- C. Write the policies and procedures needed to implement the process.
- D. Develop and implement a reasonable, consistently applied, company disciplinary policy and/or implement a Just Culture.

Why Maintenance Technicians Are a Valuable Asset in Hazard Identification



Adapted from Shuichi Yoshida 2nd International Quality Symposium, 1989

Figure 2. The Iceberg of Ignorance

1.2.1 Reactive Hazard Identification Processes

- A. Select an investigation process, like the Boeing Maintenance Error Decision Aid (MEDA), that systematically determines the hazards or contributing factors to events, and, based on these findings, allows the organization to develop and monitor a comprehensive fix.
- B. Select and train all investigators—management as well as labor—in a consistent manner to minimize interpretation differences later. Invite/encourage regulatory inspectors to attend such training sessions.
- C. Identify screening criteria to determine which events will be investigated.
- D. Establish a team to review the investigation findings and to select areas for improvement.
- E. Inform all personnel on the status of improvements in progress. Use newsletters, company/labor websites, crew meetings, and posters to demonstrate and remind everyone that the process is working and somebody is actually tracking the progress.
- F. Create a database for documenting investigation information and measures of change.

1.2.2 Proactive Hazard Identification Processes

- A. Develop a voluntary hazard reporting process where hazards can be reported via paper and pencil, telephone call in, and the company intranet.
 - 1. Guarantee confidential or anonymous non-punitive reporting.
 - 2. Use callbacks to get more hazard information from the reporter.
 - 3. Let the reporter know what is being done to address the hazard that was reported.
- B. Consult applicable guidance on other voluntary reporting systems, such as the Federal Aviation Administration's (FAA's) Aviation Safety Action Program (ASAP), and implement the process.

1.2.3 Predictive Hazard Identification Processes

Maintenance and Engineering organizations already use some predictive hazard identification approaches, including engine condition monitoring and a reliability program. However, Maintenance and Engineering organizations are encouraged to implement a predictive behavior observation program like Maintenance Line Operations Safety Assessment (LOSA).

- A. Determine areas of need for targeted LOSA observations and carry them out. LOSA can also be a general, non-specific, observation.
- B. From the observations, select behaviors that need improvement (e.g., use of calibrated equipment).
- C. Implement interventions to change the selected behaviors.
- D. Carry out more observations to determine whether the behaviors have changed. Repeat process.

1.3 How to Know the Hazard Identification Processes Are Working

1.3.1 Reactive Hazard Identification Processes

- A. Events are investigated to find the hazards (contributing factors), and corrective actions are developed to reduce the likelihood of future occurrences.
- B. Deviations from existing procedures are uncovered during the investigations, and they are corrected.
- C. The number of events caused by human performance decreases.
- D. The operator saves time and money by decreasing interruptions to revenue flights, rework, personal injuries, and equipment damage.

1.3.2 Proactive Hazard Identification Processes

- A. Employees are using the hazard reporting processes.
- B. Hazards are being assessed for risk, and unacceptable risk is being mitigated.
- C. The employees are being informed on the disposition of their hazard reports.

- D. Employees are voluntarily reporting performance issues through ASAP or equivalent program.
- E. Acceptance and growth of the fair-but-accountable safety reporting culture ("just" culture).

1.3.3 Predictive Hazard Identification Processes

- A. LOSA has been implemented and is finding hazards (workplace performance issues) that need to be addressed, as well as recognizing positive behaviors to be showcased in training.
- B. Interventions have been implemented to manage identified threats and errors.
- C. Observations have shown that the interventions were successful in changing employee behavior in a positive manner.

1.4 Key References and Links

Reactive Hazard Identification Processes

1. MEDA User's Guide
(http://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/media/meda_users_guide_updated_09-25-13.pdf) (MHF@boeing.com and 425-237-6982)
2. MEDA form
(http://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/media/meda_results_form_rev1.pdf)
3. Ramp Error Decision Aid (REDA) form
(http://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/media/reda_results_form_rev1.pdf)
4. REDA User's Guide form
(http://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/media/reda_users_guide_v-8_september2013.pdf)
5. Human Factors Analysis And Classification System – Maintenance Extension (HFACS-ME) (www.hf.faa.gov/docs/508/docs/maint_product638b.pdf).

Proactive Hazard Identification Processes

6. FAA Aviation Safety Action Program (ASAP) Policy & Guidance
(<https://www.faa.gov/about/initiatives/asap/policy/>)

Predictive Hazard Identification Processes

7. FAA Line Operations Safety Assessments (LOSA)
(http://www.faa.gov/about/initiatives/maintenance_hf/losa/)

General

8. FAA SMS (<http://www.faa.gov/about/initiatives/sms/>)
9. ICAO Integrated Safety Management website
(<http://www.icao.int/safety/safetymanagement/Pages/default.aspx>)
10. EASA Guidance on Safety Hazard Identification
(<http://www.easa.europa.eu/essi/documents/ECASTSMSWG-GuidanceonHazardIdentification.pdf>)
11. UK CAA Global Fatal Accident Review 2002-2011
(<http://www.skybrary.aero/bookshelf/books/2403.pdf>)
12. IATA Safety Report 2013 (<http://www.iata.org/publications/Documents/iata-safety-report-2013.pdf>)



PROCEDURAL COMPLIANCE and DOCUMENTATION

Chapter 2

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All activities in aviation maintenance are governed by a set of rules and a set of procedures compliant with these rules. Safety depends critically on complying with the rules and following the procedures. However, we still see “Procedure not followed” with depressing regularity in incident and accident investigations. Failure to follow instructions was the primary cause of maintenance errors reported through Boeing’s Maintenance Error Decision Aid (MEDA).¹ This chapter examines why this problem is so persistent and what you can do to ensure maximum compliance with procedures.

Procedures exist only as part of a human-controlled system of aviation maintenance. You must consider all aspects to improve the reliability of procedural compliance by eliminating sources of error. Compliance with procedures is a function of the:

- maintenance system,
- human user,
- documentation, and
- maintenance environment (technical, physical, and cultural)

First, the *maintenance system* produces and maintains the procedures developed by airframe, engine and component designers/manufacturers, and procedures modified by the operator to better suit local conditions. Errors from this system include inaccurate documents and documents in which the experienced aviation maintenance technician (AMT) will be able to see a “better” but unauthorized way of performing the task. These errors can be reduced through a well-designed feedback system from the ultimate user (the AMT or inspector) to the operator’s procedure writers and, ultimately, to the Original Equipment Manufacturer (OEM) and Design Approval Holders (DAH). The Federal Aviation Administration’s (FAA’s) Commercial Aviation Safety Team (CAST) Safety Enhancement task force on the 2001 Alaska Airlines accident (SE-170) recommended exactly such a feedback system.

Second, the *human user* of the procedure is easiest *but least effective* to blame for an incident. Most AMTs do follow the procedure correctly most of the time. The goal in safety is to replace

“most” with “all.” AMTs do not set out to cause errors but can be led to do so by the system surrounding them. Even if a procedure looks illogical, the pressure to perform may lead an AMT to try to complete it anyway, using a known but unauthorized work-around. All of the well-known stressors on humans such as fatigue, time stress, poor training, and the physical environment of the task contribute to an increased error rate.

Third, there is the *procedure document* itself. Research on documentation errors shows that good documents must have the right *content*, the right *readability*, and the right *organization*. *Content* means that the procedure needs to be both accurate and usable. Following the written steps should lead unambiguously to the correct result for the job. *Readability* means that the procedure needs to use unambiguous grammar and terms, and have diagrams that are designed for the ultimate user. For example, Simplified Technical English² is a proven way to reduce comprehension errors. *Organization* means that the procedure must fit with how a trained AMT would perform the task. Making the pattern consistent with actual AMTs' working habits has been shown to reduce errors.³ Well-designed documentation is critical to ensuring that the procedure specified by the documentation is followed reliably.

Finally, there is the technical, physical, and cultural environment within which the maintenance is performed. Much maintenance and inspection work takes place at night and, at times, outside. Any procedure must be *robust* enough to work reliably under environmental challenges. The cultural environment can also put adverse pressure on procedural compliance if the culture emphasizes, “getting the job done” ahead of compliance. The safety culture affects the proper use of procedures and other technical documentation.

Robust: A process, system, organization, etc. able to withstand or overcome adverse conditions.

With so many potential sources of procedural compliance errors, it should be a matter of industry and regulator pride that so few slip through our error-proofing barriers to become damage or accidents. However, “Procedure not Followed” has been demonstrated repeatedly to be a major contributor to incidents, from the UK in 2004, to recent events in the U.S. (see NTSB /AAR-13/01 PB2013-103890 regarding Sundance helicopter). Good documentation design will help: a 1998 study showed that *all* of the errors arising from one work card occurred where guidelines for good documentation were not met.⁴ Later studies have shown that the same design principles apply to both paper documents and to computer/smartphone-based documents. Any program to improve procedures should include documentation design to improve procedural compliance.

2.1 Why a Procedural Compliance Program Is Important

- A. FAA's annual count of the highest number of administrative actions against AMTs is related to "failure to comply with maintenance instructions," as specified in Parts 43.13-1 sections related to General Aviation and Airliner maintenance.
- B. A 2012 government/industry Chief Scientist and Civil Aerospace Medical Institute (CAMI) workshop⁵ rated "Technical Instructions" as the number one maintenance human factors challenge.
- C. Documentation-related errors were reported in approximately 83% of National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) maintenance reports, from 2010-2013.
- D. It is widely accepted that maintenance documentation errors rank as the number one error reported to the FAA Aviation Safety Action Program (ASAP).
- E. The basis of any maintenance safety system is the assumption that all personnel will follow approved procedures.
- F. If the operator cannot guarantee that procedures are followed, then the level of safety in the system cannot be assured to the operator, regulator, and traveling public.
- G. With higher levels of procedural compliance come increased levels of personal safety and pride in the work accomplished.
- H. A well-designed procedural compliance program, which goes beyond mere punishment of those who make the errors, is a cost-effective way to ensure that "Procedure not Followed" is no longer a cause for concern for the operator, regulator, or traveling public.
- I. A procedural compliance program is an excellent way to improve the quality of documentation throughout the organization, leading to documents designed specifically for the ultimate user.
- J. The Industry-Government Commercial Aviation Safety Team (CAST) task force SE-170 has highlighted the importance of communicating documentation clarity issues between maintenance organizations and those who write the procedures.

2.2 How to Implement a Procedural Compliance Program

- A. Develop and communicate a company policy that specifically states that personnel must follow all company and regulatory authority policies, processes, and procedures at all times. Further, they must report difficulties using technical documentation.

- B. Understand how the procedures are derived, written, validated, used, and modified. This involves not just reviewing how the system *should* work but validating procedures with maintenance personnel who perform the work in an operational setting.
- C. Review the written procedures against the many Web-available guidelines for good procedure and pay attention to procedure modifications tied to different levels of user experience.
- D. This can often be such a lengthy process that some users ignore it and continue to use deficient procedures. Follow the guidelines, established in Air Transport Association (ATA) Specification 119⁶ and FAA technical report on SE-170,⁷ to work within organizations and with equipment suppliers to modify unclear or incorrect technical instructions. .
- E. Investigate any “Procedure not Followed” cases by conducting a root cause analysis and by asking *why* the user thought that the best course was to deviate from the procedure. Implement a Just Culture policy so that punishing the user is reserved for the rare cases where there was intent to cause harm to the system. Asking *why* will lead to ways to improve the system so that procedures are a better fit to the user and the environment.

Just Culture: *A culture in which front line employees are not punished for actions, omissions, or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful violations, and destructive acts are not tolerated.*

Perhaps the most difficult, but potentially most productive, change to influence procedural compliance is to modify the maintenance system so that it becomes less prone to the repeated errors of “procedure not followed.” AMT training and improved documentation design are obvious beneficial changes with obvious costs, but changing the system to respond to end-user difficulties with procedures is easy to dismiss with a memo to all concerned – which is just as easy for all in the system to ignore.

One initiative by CAST SE-170 to tackle this problem of changing the system between OEM, DAH, and end users was mentioned previously in Section 2.1. J and Section 2.2. D. This program and its associated final report⁷ used input from industry and government to make very specific recommendations on how user feedback can be used to change documents and procedures. SE-170 started from the complexity of servicing the horizontal stabilizer jackscrew on the MD-83 aircraft, which had led to the 2001 Alaska Airlines accident. It developed five challenges to

improve feedback among all players and recommended actions for OEMs, DAHs, MxOs, ASIs, and AMTs. The recommendations flesh out Section 2.2 points A through E, but the record concludes significantly that all of these things have been said before and remain valuable. Many, including writers and maintenance engineering departments, insist that they already follow the recommendations; however, reports to the NASA ASRS and through the FAA ASAP suggest otherwise. AMTs still fail to follow the written documentation every day.

Finally, the AMTs understand how work is conducted on the flight line, in hangars, and in shops, so the documents must reflect real-world working conditions. AMTs must refuse to accept instructions that are difficult to understand and use, and they must insist on timely responses to their recommendations. As that happens, the documentation culture can evolve to one where AMTs get the job done *because* of great procedures rather than *in spite of* the procedures.

2.3 How to Know the Procedural Compliance Program Is Working

- A. Rates of incidents, accidents, and regulatory findings all decrease, leading to increased reliability and system safety.
- B. Personnel are escalating reports about poor documentation or inaccurate procedures so that changes can be made.
- C. Maintenance delays and aircraft and equipment damage all decrease.
- D. "Procedure not Followed" becomes an increasingly rare finding in error investigations.
- E. Audit findings show a high level of procedural compliance.
- F. Personal professionalism and satisfaction increase.

2.4 Key References and Links

1. MEDA User's Guide
(http://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/media/media_a_users_guide_updated_09-25-13.pdf) (MHF@boeing.com and 425-237-6982)
2. ASD (2013). *ASD Simplified Technical English*, Specification ASD-STE100 Issue 6.
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HUMAN FACTORS TRAINING – Evolution and Reinforcement

Chapter 3

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Maintenance human factors (HF) training, as we know it today, was introduced around 1989. Continental Airlines followed a format similar to an existing flight deck initiative called *Cockpit Resource Management* training in its early maintenance HF training program. The concept of *Cockpit Resource Management* evolved into *Crew Resource Management* (CRM). In those first few years, Continental Airlines titled their training “Crew Coordination Concepts,” which later changed to “Maintenance Resource Management.” Eventually, it evolved into Maintenance Human Factors training, which is commonly used today. Unlike the early nineties, “human factors” is now a well-known and understood concept across all aviation occupations. However, it must continue to evolve to keep pace with the ever-evolving aviation maintenance challenges.

As the concept evolved, so did the training content. Early CRM training focused on worker communication. Maintenance personnel had to communicate with pilots, pilots with cabin crewmembers, labor with management, companies with government, and so on. The training explained communication theory and devoted a lot of time to role-playing about “feeling good” about yourself and about your co-workers. Some characterized the early CRM training as “touchy-feely” and not always in tune with the realities of the aviation workplace.

The evolution of HF training was driven in part by senior captains and first officers who helped training developers to understand the learner requirements to ensure that HF training would produce increases in safety knowledge and behaviors. The same thing happened in maintenance HF training. Credentialed, experienced aviation maintenance technicians (AMTs) contributed the necessary relevancy to the training. That stimulated HF discussions within the maintenance ranks. Course developers, instructors, and learners recognized the criticality of improving communication but also realized there were numerous HF challenges.

Human factors training remains as a critical part of a safe and efficient culture. Aviation authorities have published rules and/or delivered a variety of maintenance training materials (see

Section 3.4). When conducted properly, HF training provides a time to review the fundamentals, to learn about emerging practices, policies, and challenges, and to renew each worker's commitment to the corporate safety goals. Ultimately, HF training teaches workers to remain vigilant regarding their individual actions and how their actions influence workplace safety.

Knowing and applying HF principles to ensure a safe work culture is like an athlete practicing a sport through continuing conditioning and repeated proper practice. Similarly, organizations need to reinforce HF training (see the programs mentioned in this manual). Their commitment to corporate safety goals may include a formalized and written Just Culture policy, an active voluntary reporting system, training on and application of risk assessment and risk-based decision making practices for everyone in the organization; and recurrent HF training (whether or not for regulatory compliance).

3.1 Why Human Factors Training Is Important

The key reasons HF training is important are listed below. The reasons apply, whether used by a regulatory aviation safety inspector to interact with engineering, safety, quality, and training departments, or by individuals within organizations to gain leadership's commitment to and investment in an effective HF training program.

- A. Human Factors training is instrumental in fostering a positive safety culture. It serves to introduce (and reinforce) the workforce to concepts related to risk assessment, voluntary reporting, event investigation, and peer-to-peer support.
- B. Human Factors training for the workforce, including leadership, is a critical and cost-effective first step in identifying methods to recognize, understand, and manage human performance and related organizational safety issues.
- C. There is a return on investment for HF training. It improves work performance and promotes worker safety and health, which were the basis for the International Civil Aviation Organization (ICAO) and most national aviation authorities to mandate or recommend Maintenance Human Factors training.
- D. Initial and recurrent Human Factors training that covers new regulations, procedures, and equipment are opportunities to reinforce awareness of the issues that affect job performance.
- E. Human Factors training can mitigate performance-related safety issues at the forefront of information reported through voluntary reporting systems like the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) and the Federal Aviation Administration (FAA) Aviation Safety Action Program (ASAP).

3.2 How to Implement a Human Factors Training Program

Implementing a Maintenance Human Factors training program begins after leadership approval. Start by determining company goals for the training and identifying department-specific training requirements. A comprehensive, training development needs assessment is not necessary since most topics, content, and knowledge-skill levels are already identified industrywide. Integration of the new training into a system-wide Human Factors plan should increase the return on investment more than a single course.

A curriculum that covers the training topics listed below enhance your maintainers' understanding of and commitment to safe job performance. Training effectiveness will be enhanced by tailoring the training content for each topic to your organization's work environment and workforce needs. Be prepared to continuously evaluate the training against the organizational goals and dynamic job requirements and adjust accordingly.

Before developing training content: (a) review available training and media materials from other regulators, like the FAA, TC, CASA, UK CAA, and EASA (see Section 3.4), to capitalize on free course content and reduce cost and effort; (b) decide on delivery technique for content based on characteristics of the attendees; and (c) decide on using either an internal or external HF training provider, and ensure that instructors are qualified--instructor training may be required for internal personnel.

Here is a sample of materials suggested for a modern HF curriculum from EASA:

- General Introduction
- Human Performance and Limitations
- Social Psychology
- Factors Affecting Performance
- Physical Environment
- Tasks
- Communication
- Human Error
- Hazards in the Workplace

Here is a sample of additional materials suggested by today's HF Trainers:

- Safety Culture and Motivation
- The Power of the Individual in Safety Culture
- Safety Culture Leadership
- Fundamentals Review (PEAR, Dirty Dozen, Swiss Cheese)
- Personal Responsibility for Fitness for Duty, especially Fatigue Self-reporting

- Technical Publications, Job Cards, Etc.
- Professional Ethics and Pride in Workmanship
- Additional Physiology
- Crew Resource Management (team working between mechanics; between mechanics and flight crew; and between mechanics, flight operations, and maintenance control).
- SMS Introduction (Risk Assessment and Fundamentals of Threat and Error Management)
- Voluntary Reporting of Error (What to Report)
- Emphasize that workers may know the hazards better than management
- Peer-to-peer Assessments and Coaching such as Maintenance and Ramp LOSA
- How to Use Safety Data
- Safety and Cost Return on Safety Interventions (from employee data)
- Generation Thinking/Communication
- Social Media and Work

3.3 How to Know Human Factors Training Is Working

Key performance indicators are used to determine if your HF training is effective. They must be measurable, meaningful, and directly linked to the HF training content with predetermined criteria for success. They should be measured and their trends monitored against expected outcomes. Key performance indicators typically include individual and organizational-level data that captures changes in knowledge, attitudes, and performance.

Here are some examples of performance indicators:

- Pre- and post-training evaluations and workplace discussions from trainees show positive trends.
- Workforce acceptance/approval of the training experience.
- Increase in workforce requests for more/recurrent training.
- Workforce exhibits improved safety awareness and safe work practices via decreases in...
- Reduction in the number of HF-related contributing factors found during event investigations.
- Initial increase in reported events because of improved awareness.
- Realized return on investment (ROI) (see Section 3.4 for link to calculation methods).
- Continued approval and support from management.
- Regulatory program acceptance/approval.

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FATIGUE RISK MANAGEMENT

Chapter 4

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A fatigue risk management (FRM) program is used to mitigate the effects of fatigue. Conceptually, FRM serves to inform decisions regarding how to mitigate fatigue risk. FRM is a personal and professional

responsibility, as it applies to a maintainer as well as an organization. In practice, FRM, be it a plan, policy, program, or system, contains the processes and procedures (i.e., proactive, reactive, and predictive) used to maximize personnel alertness and minimize fatigue-related performance errors that create safety hazards and risk for the maintainer, team/crew members, the public, and aircraft/equipment.¹

Along with the FAA, the International Civil Aviation Organization (ICAO),² the European Aviation Safety Agency (EASA), Transport Canada,³ the Civil Aviation Safety Authority (CASA) of Australia,⁴ and worldwide agencies in the aviation, road, and rail transport industries have been promoting and, in some cases, requiring the use of FRM techniques. Most notably, Section 212(b) of Public Law 111-216, Airline Safety and Federal Aviation Administration Extension Act of 2010 "...requires each air carrier conducting operations under Title 14 of the Code of Federal Regulations (14 CFR) part 121 ...develop, implement, and maintain a Fatigue Risk Management Plan (FRMP)."

4.1 Why Fatigue Risk Management Is Important

We are a nation of sleep-deprived workers. It is estimated that adults attempt to function on 1 to 1.5 hr less sleep than the recommended 8 hr per night. Human fatigue costs U.S. businesses more than \$136 billion in lost productivity each year; the majority of which (84%) was related to reduced work performance.⁵ The losses do not include cost estimates associated with workplace injury, insurance claims, damaged aircraft, rework, unwanted events, or accidents.

Consider this:

- A. After 16 hr of being awake, our mental ability to perform work-related tasks decreases to a level consistent with having a blood alcohol concentration of 0.05%.

- B. After 24 hr of no sleep, mental impairment is consistent with performance deficits observed at roughly 0.10% blood alcohol concentration.
- C. Similarly, individuals operating on a 2-hour sleep debt over 2 weeks (i.e., 6 hr of sleep, instead of the needed 8 hr for 2 weeks straight) perform similarly to an individual that has been awake for 16 hr or longer.
- D. Operational data collected in a maintenance organization revealed that individuals working 16-hr days or longer were four times more likely to be involved in a personnel injury incident/accident than an individual working an 8-hr day.
- E. Individuals working 12-hr days were twice as likely to be involved in a personnel injury incident/accident as an individual working an 8-hr day.

The National Transportation Safety Board (NTSB) first identified personnel fatigue as an aviation maintenance-critical issue in 1995, stemming from the ValuJet accident in Florida. Since then, fatigue has continued to gain attention as a maintenance safety risk and, most recently (2013), was identified by the NTSB as a contributing factor in the Sundance Helicopter crash in Nevada.

Of concern to aviation safety is the finding that maintenance personnel tend to get 3 hr less sleep per night than is recommended, which is a sleep debt **twice** the national average. Sleepiness and fatigue associated with sleep debt is cumulative. This means that losing even an hour of sleep every other night over the course of a week will produce conditions that negatively affect performance. Some of the most critical performance errors associated with worker fatigue include, but are not limited to:

- impaired judgment and decision making,
- impaired communication skills,
- decreased attention span and ability to recall information,
- slower reaction times, and
- increased risk-taking.

Once you understand the prevalence and effects of fatigue in your organization, you must do something about it. We cannot overemphasize the importance of managing human fatigue risk in the aviation maintenance industry. Fatigue risk management enables maintenance organizations to:

- detect fatigue symptoms,
- identify fatigue hazards,
- assess the associated safety and health risks,
- implement fatigue countermeasures,
- determine acceptable approaches/tools for mitigating fatigue-related risks, and

- create science-based business practices for managing fatigue risks.

4.2 How to Implement a Fatigue Risk Management Program

There is no “perfect” FRMS that is appropriate for all operators. Each operator must develop an FRMS that is appropriate to its respective environment and fatigue risks. There are general guidelines on how to develop, implement, and evaluate an FRMS. The idea of an FRMS can be overwhelming if you try to do everything at once. To be successful, design and implement your FRMS in phases. If you break the design and development of your FRMS into manageable phases, you can spread your workload and resource allocations over time. There are many tools and resources available at “no cost” that you can use as you design and implement your FRMS (see Section 4.4).

The design and implementation of an FRMS can be done in five phases that mirror the SMS processes requiring policy development, risk assessment, risk management implementation, safety assurance, and promotion of SMS. The phases are planning and infrastructure development, fatigue risk assessment, implementation of fatigue mitigations, evaluation and continual improvement of FRMS, and FRMS promotion.

The FRMS can be developed as a separate, standalone program, which interfaces with the organization’s SMS, or it can be implemented as an integral part of the organization’s SMS.^{2,6,7} An effective FRMS shares the same building blocks of an FRMS, including: safety reporting, senior management commitment, continuous monitoring, process for investigation of safety issues that aim to identify deficiencies rather than blame, sharing information and best practices, training for operational personnel and involved stakeholders, implementation of standard operation procedures, and a commitment to continuous improvement.

- A. Develop plan and infrastructure. Before you can begin implementing an FRMS, you must develop a plan and establish an infrastructure that can support the FRMS. In this phase of development, you will focus on getting senior management commitment, developing policies and procedures, establishing FRMS documentation procedures, and conducting a gap analysis.^{2,8,9,10,11}
- B. Conduct risk assessment. Once the infrastructure and timeline are established, you must identify fatigue-related hazards and make assessments regarding their associated risks to the organization. You must evaluate the risk severity of a task or operational condition and the probability that the task or condition is at risk of fatigue.

- C. Implement FRMS processes. Once the hazard level of a task or operational condition is established, you can prioritize your FRMS interventions. You must develop interventions or countermeasures that are appropriate for the hazard level and implement them in the organization.
- D. Evaluate and continually improve FRMS. Once you have completed the infrastructure development, identified hazards, and implement FRMS processes as interventions, you must evaluate the effectiveness of your actions. This is a continual process that will result in revision and refinement of your fatigue risk management system.
- E. Promote FRMS. You must promote the FRMS materials to all invested stakeholders and utilize their feedback in the evaluation and improvement process. Once the FRMS is operational, you should promote the results of the FRMS to stimulate continued investment by stakeholders.

4.3 How to Know if the Fatigue Risk Management Program Is Working

Applying FRM strategies has significant worker and organizational benefits related to safety and health. The documented benefits include, but are not limited to:

- improved knowledge of fatigue and fatigue risk management,
- improved documentation of fatigue-related accidents/incidents,
- reduced fatigue levels,
- fewer on-the-job accidents and injuries,
- fewer physical illnesses,
- reduced absenteeism,
- reduced turnover,
- reduced morale problems,
- reduced insurance premiums,
- increased average sleep time and sleep quality, and
- improved quality of life.

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HUMAN FACTORS HEALTH and SAFETY PROGRAM

Chapter 5

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As a worksite, repair stations are subject to the general industry standards contained in the Occupational Safety and Health (OSH) Act. Since its enactment in 1970, industry has implemented the OSH Act with programs that focus on workplace safety and personal health. Consider the OSH hearing conservation standard that mandates employee protections when the noise levels exceed an action level defined in these standards. To comply with this mandate, employers have used barriers and enclosures to reduce the noise exposure. This is an example of a workplace safety initiative, as are guards, interlocking switches, and safety harnesses. Personal health protections include personal protective equipment such as hearing protections. As the workforce has changed, a human factors view of a safety and health program has emerged. Repair stations, like other industries, have recognized that their workforce is now older¹ and heavier.² These changes produce conditions where the workforce can comply with the OSH standards, yet has limitations from natural aging and obesity.

Latent Medical or Environment Conditions (LMEC): Physiologic limitations experienced by the AMT that originates from abnormal medical conditions, normal aging, and occupational exposures.

The results are Latent Medical or Environment Conditions (LMEC), which can form a link in an accident chain. As the first example of LMEC consider an older aviation maintenance technician (AMT) who is experiencing the natural decline in near vision, called presbyopia, that starts at age 35 years. Visual inspection of an aircraft is an essential element of the AMT's job. The process of inspection requires both good visual acuity and a thorough inspection procedure. An LMEC arises when the AMT's ability to identify defects accurately fails due to uncorrected presbyopia or reduced visual fields from the use of bifocals, progressive lenses, or other corrections. Hearing limitations present another LMEC, since communication is critical for the repair process. The workforce is becoming heavier (medical term *obese*) with a corresponding increase in diseases such as diabetes and musculoskeletal limitations. Consider an overweight AMT with preclinical

diabetes that limits sensations in the hands and feet. This reduced tactile sensation reduces the AMT's ability to use his fingers to feel sizes of screws or make other size estimates. In these three examples, the AMTs complied with OSH safety and health standards but their older age and obesity produced identifiable physical limitations. Alone, LMEC do not lead to an active maintenance error; rather, they form a link in the accident chain. Recognizing these risks as part of a Safety Management Systems (SMS) provides additional opportunities to break an accident chain before it leads to a human factors maintenance error. This chapter reviews the human factors component of a Health and Safety (HF H&S) program. An effectively functioning HF H&S program limits formation of LMEC, ensures compliance with OSH Act standards, and promotes the health of AMTs.

5.1 Why a Human Factors Health and Safety Program Is Important

- A. Evaluation of well-recognized maintenance error due to human factors have identified loss of tactile sensation, poor ergonomics, hearing loss, and reduced vision as LMEC that lead to maintenance incidents.
- B. Population studies (Bureau of Labor Statistics, 2006 to 2010) indicate that AMTs have a rate of non-fatal occupational injuries and illnesses that is nearly twice that of general industry.
- C. Telephone interviews using the U.S. Census Occupational Code systems shows that the occupation "aircraft engine mechanics" ranked 48th in mortality among 206 occupations included in the census.
- D. In 2009, older workers (those greater than 55 years) represented 19% of the U.S. workforce and are now the nation's fastest growing segment of the working population.
- E. For U.S. workers, 27.7% meet the criteria for obesity.
- F. Current estimates for type 2 diabetes in the United States are that 75 million have preclinical state, and 25 million have progressed to clinical disease.
- G. AMTs are experiencing exposure to new LMEC as repair stations transition to repair of composite structures from repairs that had emphasized metal structures.

5.2 How to Implement a Human Factors Health and Safety Program

- A. Complete a self-assessment about the readiness of the repair station to incorporate workforce health as part of a SMS. Establish that the health of the AMT is an integral part of air safety, which may be a new concept to many. Through a self-assessment, the repair station highlights assets and reveals gaps in its understanding of LMEC. The

results of the self-assessment are important in making an informed decision that identifies participants, goals, objectives, strategies, and plans.

- B. Identify leadership within the repair station for the HF H&S program. Leadership is critical to bringing together individuals, work groups, and divisions that will be needed to accomplish the task of controlling LMEC.
- C. Establish initial organization planning and priority setting. Like any initiative to manage human factors, controlling LMEC requires organization planning and priority setting. This step determines what LMEC are important to the repair station. Consider those that involve seeing, hearing, and tactile sensation.
- D. Define existing programs. While smaller repair stations may not have a formal Health and Safety division, larger facilities certainly do. This step looks at the current Health and Safety program to identify health-related gaps or needs. The objective is to avoid duplicating existing capabilities within the repair station.
- E. Agree upon a prioritized set of activities. Clearly identify what LMEC the organization wants to limit. For example, a repair station may have noted an increase in obesity among the AMTs. One effect of this condition is an increase in diabetes, which is known to cause nerve damage especially in the hands and feet. Affected AMTs may have poor sensation in their hands and feet. For this example, this step would result in a prioritized set of activities that assure AMTs have proper tactile sensation to identify screw sizes and tools by touch.
- F. Select and use measures as performance targets. The purpose of this step is to improve the health of AMTs by measuring their progress using a specific performance target. Consider a repair station that desires to limit the LMEC that results in poor communication. They select a performance measure such as the sound levels in the hangar. With this measure, an obvious performance target is a sustained 10% reduction in noise levels in the hangar as measured using a dosimeter two months after program initiation.
- G. Use audience-specific communications. Communicate to AMTs about LMEC, their origin from unhealthy lifestyles and exposures, and their measure through the SMS.
- H. Consider joint reporting through SMS and existing health and safety program. This step is especially important in repair stations with existing Health and Safety Programs. Reports about control of LMEC may be compiled with existing reports required by these programs.

- I. Consider scalability. If you have success controlling one LMEC, do not stop. Tackle another one. The goal is to break a chain of events that may lead to an active maintenance Human Factors event.
- J. Plan for sustainability. Just like any other aspect of a SMS, progress must continue. Active maintenance error can occur anytime. Control of LMEC is one part of a SMS.

5.3 How to Know if the Human Factors Health and Safety Program Is Working

- A. Evidence that the leadership of the repair station recognizes that both work-related factors and health factors jointly contribute to the occurrence of LMEC.
- B. Evidence of employee participation in a HF H&S Program.
- C. Demonstration that the workforce is knowledgeable about health-related risk factors that can lead to LMEC.
- D. Information specific to the repair station is available on workplace exposures, demographics of the workforce, and health risks for the workforce.
- E. Obvious employee participation in selection of LMEC and methods used for their control.
- F. Evidence of an established working relation with existing Health and Safety programs at the repairs station.
- G. Evidence that age-related training is available to workers with emphasizes of this training on the age-related loss of visual acuity and hearing.
- H. Evidence that interventions to prevent LMEC are promoted, accepted, and supported by the workforce.
- I. Access to the OSHA 300 records for occupational injuries and illnesses submitted to regulatory agencies.
- J. Development of a culture of safety within the workforce.

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CONSIDERING HUMAN FACTORS ISSUES in Design and Installation

Chapter 6

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Aviation maintenance tasks and working environments vary considerably. The work can range from a builder/operator/owner of an experimental or light sport aircraft to an aviation maintenance technician (AMT) working the flight line or hangar for a large Part 121 carrier. Work might range from tasks requiring no individual AMT certification, to general aviation maintenance, where the certified AMT returns the aircraft to service. It also includes an airline or maintenance, repair, and overhaul (MRO) organization, where the *return to service* is part of the approved maintenance program, rather than the responsibility of one certified AMT. This list of maintenance tasks is unlimited; however, there are many characteristics of maintenance work that apply to all maintenance. Examples include:

- Need for useable/understandable technical instructions, including instructions for continued airworthiness (ICAs) and FAA AC 43.13-1B and AC 43.13-2B.
- Requirements under 14 CFR Parts 43 and 21.
- AMT and organizational determination to expose poorly written instructions and to inform responsible parties.
- An orderly and logical approach to the maintenance task.
- A “sanity check” to ensure that a new or replacement part/component/appliance is not only mechanically and electrically compliant with the existing hardware, but is also aligned with the AMTs who must operate and maintain the system.
- The willingness to ask for help when an AMT has questions on the tasks being performed.

This chapter recognizes that an AMT may be the best person to ensure not only for safe physical installation, but also for alterations made to the aircraft, ensuring selected human-machine issues are addressed. For example,

- Visual access/viewing angles
- Readability

- Use of color
- Glare
- Nighttime applications
- Panel real estate issues, especially with repeated, piecemeal installations
- Integration of new technologies with existing controls and displays
- Management of avionics electrical loads during electrical system failures
- Reachability in the flight deck
- Load-shedding plan in electrical system failure events
- Pilot mental and physical workload/attention requirement

The AMT/installer cannot always solve the above sample list of issues. It may be necessary to consult with system users, local Federal Aviation Administration (FAA) Aviation Safety Inspectors, test pilots, and human factors specialists from the appropriate FAA Aircraft Certification Office. Maintenance training requirements are not heavy on system design and human-machine interaction. However, today's maintenance personnel must be able to speak up and seek guidance when there appears to be a human factors issue. This chapter sensitizes readers to such issues.

6.1 Why Considering Human Factors Issues in Design and Installation Is Important

- A. Before performing any maintenance on aircraft, the installer must understand the requirements for installing equipment. Depending on the equipment and installation, there could be a gap between the documentation provided by the manufacturer and the data required to install the equipment. The equipment may have even been certified outside the environment in which you are installing (for example, the equipment may have been certified for a small airplane, but does not meet the requirements for a helicopter or a transport category airplane). Therefore, it may be incompatible with your aircraft. The installer is the last sanity/human factors check before the equipment resumes flight.
- B. Original equipment manufacturer engineers, who may not be familiar with your specific installation, often write installation/repair instructions. If such instructions are not clear, make it your responsibility to notify the provider, and seek further guidance before performing the maintenance.
- C. While installers are not necessarily human factors specialists, they are responsible for ensuring compatibility between the equipment and the end user. For the most part, the installer, to help ensure compatibility, can perform simple, practical evaluations.

- D. Proper attention to human factors during installation not only helps ensure effective equipment use but also satisfies the customer and user.

6.2 How to Consider Human Factors Issues in Design and Installation

- A. Talk to your customers. Ask them how they are going to use the new equipment. Are they going to use it all of the time? Do they fly only during the day, nighttime, VFR, IMC? Knowing how they might use the equipment might help you deliver something that would meet or exceed their expectations. It will also help meet the expectations of the equipment designer.
- B. Do your homework before starting.
 - 1. Coordinate the plan before buying the hardware.
 - 2. Look at the installation material to identify any questions or concerns with the installation instructions as they pertain to your pending work.
 - 3. Identify areas that may be affected by your modification. Those could include, but are not limited to:
 - a. Ability to:
 - View
 - Read
 - Reach
 - b. Adequate lighting (day and night). Perform simple lighting evaluations to check night lighting using a moving blanket to block out light. Then evaluate any necessary dimming features.
 - c. Use of colors for added annunciators in the flight deck, 14 CFR 23.1322 discusses the proper color use for flight deck alerts.
 - d. Adequate knowledge for the pilot of the newly installed system. The manufacturer may provide a recommended Aircraft Flight Manual Supplement or pilot's guide.
- C. Consider a mock-up or prototype location before you start drilling or cutting holes. Check the planned installation with the owner/operator, if that is a reasonable option. However, you may have better experience, so weigh such input carefully.
- D. Check for experience of other installers or with FAA personnel who have seen and/or approved other similar installations.
- E. Do your homework and then have confidence in your experience and judgment.
- F. Use the following real-life example as a lesson for how human factors should be considered:



Figure 1. Helicopter with additional equipment installed.

Figure 1 shows a news helicopter in which AMTs found a way to install a large amount of equipment that the operator of the aircraft wanted installed in the aircraft for testing. How could an AMT make sure that they install this equipment safely and properly? The first thing that comes to mind when looking at this installation is pilot compartment view. Could the customer's pilot fly the helicopter in all phases of flight and still be able to see other traffic and obstacles with the equipment mounted in these locations? In addition to this and the items listed above, consider some other factors:

1. There appears to be an extra interior light for TV lighting. Consider asking yourself when faced with a similar installation: How will this affect the pilot's ability to see the instruments with the potential for additional glare on instruments as well as the ability to see outside of the airplane? (Tip: When doing interior glare evaluations, test pilots tend to wear white shirts, because not only do most professional pilots wear white shirts but also, they typically reflect more light back onto the instrument panel.) In order to find out, consider putting a dark blanket (moving blanket, large black felt cloth, or similar) over the exterior windows and evaluating the added lighting to the flight deck.

2. These installations add many flight deck controls for operating radios. Some appear to be easier to reach than others are. For these specific installations, consider sitting in the pilot's seat with the seat restraints fastened and try to reach all of the radios. Try inputting frequencies. Can you read all of the markings on the control? Try doing this while moving the flight controls around. Do the cyclic or collective controls get in the way? Do you have to lean forward in the seat in order to operate? Will a tall or short person be able to reach equipment from the seat?
3. Are there cautions and warnings associated with the installation? Are the visual alerts visible to the pilot? Are they visible with the flight controls moved around through their range of motion? Are there aural alerts? Are they the same volume as other aural alerts? Can the aural alerts be heard over the engine and other environmental noise in the flight deck during flight?
4. Do you have enough electrical power and safe wiring for the additional electronics?

Some of this seems like common sense, especially if you know what you are installing and how it will be used. However, be sure to take care and consideration so as not to overlook something. After the installation job is completed, make sure that you take the time to look at the big picture to double check how everything is working together.

6.3 How to Know That Your Consideration of Human Factors Issues in Design and Installation Is Working

- A. You understand the requirements of installing the equipment and know where you need additional assistance or additional data to complete the installation.
- B. There are fewer customer inquiries/complaints about newly installed hardware.
- C. Fewer reworks.
- D. Your customers increase their questions and ideas to improve or make other modifications to improve the aircraft.
- E. Increased customer satisfaction.

6.4 Key References and Links

1. Yeh, M., Jo, Y.J., Donovan, C. & Gabree, S. (2013). *Human Factors Consideration in the Design and Evaluation of Flight Deck Displays and Controls*. Washington, DC.: Federal Aviation Administration. November, 2013, Report No. DOT/FAA/TC-13/44.

2. Federal Aviation Administration (2013). *Installation of Electronic Displays in Part 123 Airplanes*. AC 23.1311-1C.
3. Federal Aviation Administration (1998). *Acceptable Methods, Techniques, and Practices- Aircraft Inspection and Repair*. AC 43.13-1B.
4. Federal Aviation Administration (2008). *Acceptable Methods, Techniques, and Practices- Aircraft Alterations*. AC 43.13-2B.
5. Federal Aviation Administration (2004). *Standardized Procedures for Requesting Field Approval of Data, Major Alterations, and Repairs*. AC 43-210.
6. Read the manufacture's documentation and instructions.

6.5 Related Regulations

The list below focuses on small general aviation airplanes regulations, similar regulations can be found for Transport Category Airplanes and Normal and Transport Category Rotorcraft.

- 14 CFR 23.143(c)-Control Forces (Strength)
- 14 CFR 23.771-Pilot Compartment (Fatigue, Concentration)
- 14 CFR 23.773-Pilot Compartment View
- 14 CFR 23.777-Cockpit Controls (Reachability, Concentration)
- 14 CFR 23.1322-Warning, caution, and advisory lights (Perception)
- 14 CFR 23.1381-Instrument lights (View ability)
- 14 CFR 23.1523-Minimum Flight Crew (Workload)



MEASURING IMPACT and RETURN ON INVESTMENT

Chapter 7

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The previous chapters of this Operator's Manual have described programs and procedures that impact not only safety but also cost savings and other returns. Returns can include tangible paybacks to include:

- Maintenance Performance (like adherence to production schedules, ground damage, rework, post maintenance dispatch reliability, etc.)
- Operations Performance (like Schedule adherence, gate returns, cancellations, etc.)
- Employee Safety (lost time injuries, severity of injuries, etc.) (see Chapter 5))

Human factors (HF) interventions often generate important outcomes that are more difficult to quantify and calculate. Examples include:

- Increased voluntary reporting of events and company follow-up (see Chapter 1)
- Increased peer-to-peer assessments and intra-worker coaching (see Chapter 1)
- Increased root cause analyses (see Chapter 1)
- Increased adherence to procedures and technical instructions (see Chapter 2)
- Increased reporting and correction of problems with procedures and technical Instructions (see Chapter 2)
- Evolving HF training based on specific company needs (see Chapter 3)
- Increased attention to worker health and safety (see Chapter 5)
- Including challenges associated with aging maintenance workforce (see Chapter 5)
- Increased management and worker sensitivity to worker schedules and fatigue management challenges (see Chapter 4)
- Expanded consideration of human factors issues in selection and installation of equipment (see Chapter 6)
- Targeted reduction of HF-related unwanted events
- Reduction in regulator audit findings in relation to HF programs (effective interventions are applied as a result of safety investigations)
- Increased worker ratings of integration of HF into environment and practices

- Specific integration of HF into Safety Management System (SMS) programs

This chapter offers procedures to measure the impact and justify investments in human factors and other safety interventions. The tools described herein are relevant to other interventions that have quantifiable value.

The intangibles, listed above, are excellent measures of a Safety Culture. However, airline and maintenance, repair, and overhaul (MRO) organizations are driven by finance and that cannot be ignored. In airlines and maintenance organizations, the task of calculating Return on Investment (ROI) is usually the purview of the corporate finance department. ROI is perceived to be a “number crunching” task that is outside the responsibility, qualifications, and interest of operationally oriented maintenance and safety managers. As a result, maintenance and safety managers can fall short on the language and data to justify new and improved safety interventions. Regulatory compliance is often the justification for a safety intervention. However, proactive cost justifications/savings can have immense impact with corporate financial decision makers.

The ideas presented here help not only measure and justify but also sustain multiple safety and human factors initiatives by offering a straightforward consideration of ROI.

7.1 Why Measuring Impact and Return on Investment Is Important

- A. Human Factors programs and some safety interventions are not mandated by regulation. Therefore, they must have demonstrable safety and cost impact.
- B. Safety and human factors professionals are often asked to “justify” their programs. ROI offers the means to provide the justification in the financial and safety terms necessary to convince corporate personnel regarding the safety impact and value of HF and other safety initiatives.
- C. Impact statements and ROI calculations help maintenance and safety managers to offer a mid- and long-term view of such investments. Benefits from human factors and other safety interventions are seldom immediate. A long-term sustained program is necessary to create, foster, and maintain the culture change generated by attention to human factors issues.
- D. Motivation and enthusiasm for programs will continue as long as there is a quantifiable programmatic impact and financial payback.
- E. Sustainable safety and human factors programs should have a plan to collect measurable impact data to demonstrate ROI.

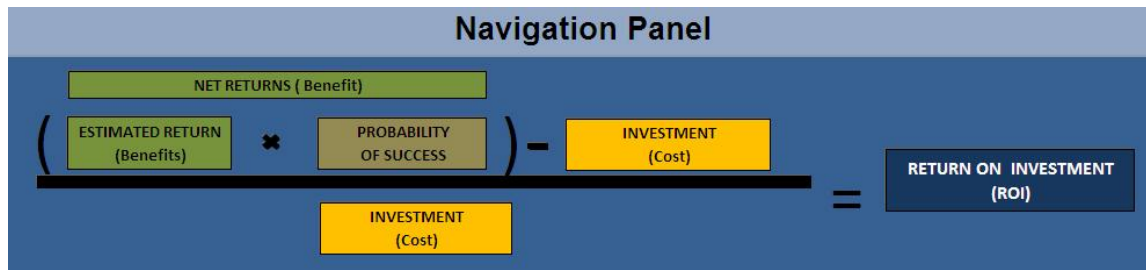
- F. The process and software, available from the FAA Maintenance HF website (www.humanfactorsinfo.com)⁵ has successfully demonstrated many ROI calculations in airline and MRO environments.

7.2 How to Calculate Return on Investment on Human Factors and Safety Programs

(The information presented in this section has been available on the Federal Aviation Administration Maintenance HF website (www.humanfactorsinfo.com)⁵ since 2009. It has been successfully applied by numerous airlines and other maintenance organizations since that time.)

- A. Useful cost justifications must be straightforward and easy to understand. ROI calculation does not require an economist. Maintenance and safety managers are best qualified for calculating ROI. They are the most knowledgeable of the likely costs, returns, and schedules that are necessary for an accurate calculation.
- B. Use small examples to calculate the return on human factors. Many small improvements add up and translate to big savings on big human factors projects.
- C. Use relevant organizational data from the event investigation system (see Chapter 1).
- D. Make ROI part of the discussion topics at maintenance meetings. Encourage ROI ideas from maintenance/engineering staff.
- E. How to calculate an ROI of a specific airport operations-related event:
 - 1. The basic equation for ROI is simple: divide benefit by cost (see Figure 1).
 - 2. Estimate the annual cost of a particular type of event like personnel injury, equipment, damage, rework, etc. The extent to which events are addressed is called "Net Returns (Benefit)."
 - 3. Determine the contributing factors to the event and estimate the cost to mitigate these factors. Keep it simple and call this "Investment (Cost)."
 - 4. Estimate a reasonable "Probability of Success" that the "Estimated Return (Benefits)" will be successful. Say, for example, that you estimate an 80% "Probability of Success." (If you are doing the ROI after-the-fact, then "Probability of Success" is not necessary.)
 - 5. Multiply "Estimated Return (Benefits)" by "Probability of Success." The result is the "Net Returns (Benefit)."

6. Divide ("Net Returns (Benefit)" minus "Investment (Cost)") by "Investment (Cost)."
This is the ROI.



It may not be possible to achieve a positive ROI (>1.0) within the first year.

Figure 1. Basic equation for ROI

7.3 How to Know that Impact Measurement and Return on Investment Are Working

- A. Discussion about ROI has increased among the ranks of maintenance management.
- B. The organization has identified and monitors impact measures like those listed in Section 7.1.
- C. The maintenance organization has conducted no fewer than five ROI calculations in the previous 12 months.
- D. ROI has been used to judge the value of a safety or human factors intervention at least two times in the past six months.
- E. A subgroup of mid-level maintenance managers have emerged as "mentors" for the ROI process.

7.4 Key References and Links

1. Johnson, W.B. (2013). Show Me the Money - Show Me the Safety: Is that too much to ask? Presentation to 2013 AVS Workshop on The Transition From Event Reports to Measurable Organizational Impact. Atlanta, Georgia, June 25 – 26, 2013.
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4. Johnson, W.B. (2006). Return on investment in human factors, *Civil Aviation Training Magazine*, April 2006. Available at http://hfskyway.faa.gov/2007/ROI_CAT%20Mag.pdf.

5. www.humanfactorsinfo.com. The FAA website for maintenance human factors and ROI software.

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