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Fatigue Solutions for Maintenance: From Science to Workplace Reality

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16. Abstract Thirty delegates, mostly from the FAA's Aviation Safety (AVS) business unit, but also from U.S. industry and Transport Canada, assembled for a two-day workshop in Oklahoma City, OK. The workshop format combined key presentation topics, each followed by structured discussion. Following the discussion, the delegates generated a rank-order listing of the most important actions needed to reduce maintenance fatigue risk. Section 2.0 of this report elaborates on the "top ten" actions identified: <ol style="list-style-type: none"> 1. Enhance Employer and Worker Fatigue Awareness 2. Continue and Expand Fatigue Countermeasure Education 3. Support and Regulate Fatigue Risk Management Systems (FRMS) 4. Quantify Safety and Operational Efficiency Impact of Fatigue 5. Regulate Hours of Service Limits 6. Establish Baseline Data of Fatigue Risk with Existing Event-Reporting Systems 7. Integrate Fatigue Awareness Into Safety Culture 8. Ensure That FRMS is Considered in Safety Management Systems (SMS) Program 9. Create and Implement Fatigue Assessment Tools 10. Improve Collaboration of FRMS Within and Across Organizations <p>The workshop delegates felt that the FAA is addressing many of these challenges, but there is substantial opportunity to increase attention to each topic. Their consensus was to address the challenges not only with research and development but also with operational activity and possible future regulation.</p>			
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High-value workshops are much more than an agenda and a technical report. Behind the scenes are hours of concept development, proposals, financial requirements and approvals, invitations, and other endless logistics. The administration of the Chief Scientific and Technical Advisor Program, the Aircraft Certification Workshop Program, and the Human Factors Research Lab of the Civil Aerospace Medical Institute provided all of the necessary support to ensure the success of the workshop. In particular, Victoria Frazier and Carla Hackworth went to extremes to ensure the operational and logistical success of this workshop.

Dr. Bill Johnson, Chief Scientific Technical Advisor for Human Factors in Maintenance, facilitated the workshop for key AVS personnel, industry leaders, scientists, and international regulators. A successful workshop relies on excellent speakers and active participants. We thank the workshop speakers and delegates for their engagement in the issues and their responsiveness to coordination requests. Their contributions will advance the implementation of fatigue solutions in the maintenance industry.

Special thanks to Tara Bergsten for pre-workshop support, Darin Nei, Suzanne Thomas, and Elizabeth Hensley for administrative support of the workshop proceedings; to Katie Budd, Erin McManus, and Brittney Goodwin for travel and purchasing support; and Janine King and Suzanne Thomas for final proofing and formatting of the report.

We trust that this final report, because of the delegates listed, will help ensure continuing aviation safety as it applies to the challenges of human fatigue in aviation maintenance.

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EXECUTIVE SUMMARY

U.S. domestic and international aviation enjoy an excellent safety record. The industry and government must continue to identify and mitigate potential aviation risks to ensure the current high level of safety. The Federal Aviation Administration (FAA), the National Transportation Safety Board (NTSB), and the U.S. Congress, among others, have identified human fatigue as a target of opportunity for risk reduction. The second annual Chief Scientific Technical Advisor (CSTA) workshop on maintenance human factors focused on hazards and viable, science-based solutions associated with human fatigue in maintenance (Johnson, 2010f).

Thirty delegates, mostly from the FAA's Aviation Safety (AVS) business unit, but also from US industry and Transport Canada, assembled for a two-day workshop in Oklahoma City, OK. The workshop format combined key presentation topics, each followed by structured discussion. Following the discussion, the delegates generated a rank-order listing of the most important actions needed to reduce maintenance fatigue risk. Section 2.0 of this report elaborates on the "top ten" actions identified:

1. Enhance Employer and Worker Fatigue Awareness
2. Continue and Expand Fatigue Countermeasure Education
3. Support and Regulate Fatigue Risk Management Systems (FRMS)
4. Quantify Safety and Operational Efficiency Impact of Fatigue
5. Regulate Hours of Service Limits
6. Establish Baseline Data of Fatigue Risk with Existing Event-Reporting Systems
7. Integrate Fatigue Awareness Into Safety Culture
8. Ensure That FRMS is Considered in Safety Management Systems (SMS) Program
9. Create and Implement Fatigue Assessment Tools
10. Improve Collaboration of FRMS Within and Across Organizations

The workshop delegates felt that the FAA is addressing many of these challenges, but there is substantial opportunity to increase attention to each topic. Their consensus was to address the challenges not only with research and development but also with operational activity and possible future regulation.

Human biology and 24/7 operations make some level of fatigue inevitable. However, fatigue levels are often enhanced and compounded by corporate convenience, employee desire to make overtime pay, or misuse of available rest periods. The group agreed that this continues because regulations permit schedules and practices that promote fatiguing conditions. Companies may establish shift schedules that are an inherent hazard to safe work. A grounded aircraft may require someone to work continuously for 40-plus hours. Workers may "swap shifts" to work a 40-hour week in less than three days. Maintainers are susceptible to fatigue risks due to both extended duty periods and night work. We must address these work safety challenges.

There was 100% agreement among delegates that the industry needs stronger regulations that require companies and individuals to manage fatigue risk. The FAA should not simply set an "hours of service" rule for maintenance workers. Instead, there should be regulations that can be flexible to different types of operations and maximize safety. For example, a rule could give companies the option to use a fixed duty time limit or demonstrate equivalent safety with a Fatigue Risk Management System (FRMS). Years of proven scientific research have provided many tools to manage fatigue risk. Companies can use training materials for workers and their managers, as well as tools for safe scheduling and for predicting and assessing fatigue. The bottom line is that fatigue is an inevitable risk. The workshop proceedings focus on management of fatigue risk and on improving data collection to justify possible future regulation.

FATIGUE SOLUTIONS FOR MAINTENANCE: FROM SCIENCE TO WORKPLACE REALITY

WORKSHOP PROCEEDINGS

Background

The stories and reports about aviation maintainers legally working more than 60-70 hours without sleep are plentiful. Other tales describe mechanics working continuous double shifts for more than 45 days. Maintenance fatigue issues have been on the National Transportation Safety Board's (NTSB's) "Top Ten Most Wanted List" since as far back as 1995, stemming from the ValuJet accident in Florida.

- In 2000, a Federal Aviation Administration (FAA) field study, collecting 50,000 hours of acti-graph data in aviation maintenance organizations, showed that the average amount of sleep for mechanics was about 5 hours.
- In 2006, an FAA survey of international Human Factors Programs in Maintenance Organizations revealed that more than 80% of the respondents believed fatigue was an issue.
- In 2008, an FAA Conference on fatigue revealed that scientists, regulators, company management, and labor representatives all agreed that personnel fatigue is a recognized safety hazard in the aviation maintenance industry, and we need to take action.
- In 2010, the FAA Administrator publicly committed to review *all* aspects of FAA regulations that address fatigue.

- The FAA's response to NTSB recommendation A-97-71, concerning the development of science-based maintenance duty time limitations, is currently "Open—Unacceptable Response."

The FAA has taken a leadership role in conducting applied, fatigue-related research and development (R&D). The stated goal of the research is to identify and develop viable, science-based methods for preventing or reducing fatigue in the maintenance work environment. Given the importance of the issue, the research has taken a bi-directional approach that targets both short-term and long-term solutions. To date, the applied R&D deliverables have successfully influenced the work force, but the fatigue issue has not gone away (Caldwell, 2005). The fatigue challenge requires continuing action from organized labor, airline managers, scientists, airframe manufacturers, FAA inspectors, FAA regulators, and others.

To facilitate the implementation of practical, science-based solutions, the Aviation Safety Chief Scientific and Technical Advisor (CSTA) program, with the Aircraft Certification Directorate, funded the 2nd annual Maintenance Human Factors Leaders Workshop, "Fatigue Solutions for Maintenance: From Science to Workplace Reality" (see Figure 1).



Figure 1. Maintenance Fatigue Leaders Workshop delegates in action.

Workshop Delegates

The workshop planners invited participants who had a demonstrated commitment to developing solutions for the issue of human fatigue in aviation maintenance. The majority of invitees were from the FAA's Flight Standards Service. Other participants were from industry, academia, and government services (see Figure 2). Thirty delegates participated in the workshop, and all of them brought considerable expertise from either operations or science.

Workshop Format

The workshop fostered discussion, analysis, and recommendations regarding human fatigue and science-based solutions for the aviation maintenance workforce. There were 10 formal presentations following the introductions. Each presentation involved substantial solution-oriented discussion. This format produced relevant conversation and was the basis for many of the workshop's recommended action items.

Prior to the workshop meeting, each delegate identified their number-one challenge and top-three solutions regarding fatigue in aviation maintenance. These challenges formed the basis for workshop introductions and discussions.

Workshop Presentations—Day 1

This section summarizes each workshop presentation and the corresponding delegate discussion.

Welcome Session. Dr. William (Bill) Johnson, Chief Scientific Technical Advisor for Maintenance Human Factors, opened the meeting and welcomed the delegates (Figure 3). Dr. Johnson summarized the results of the last maintenance human factors workshop and identified four objectives for the current meeting. Specifically, he challenged workshop delegates to:

- Agree on practical, science-based approaches that will reduce fatigue in aviation maintenance,
- Create an execution strategy for implementing identified approaches,
- Develop an action-oriented report that creates responsibility and recognition for action and accountability for inaction, and
- Take action on workshop conclusions, and challenge stakeholders to support and implement actions at all levels.

Federal Aviation Administration (FAA)	Non-FAA
<ul style="list-style-type: none"> ▪ Civil Aerospace Medical Institute ▪ Aircraft Certification ▪ Flight Standards ▪ Air Traffic Organization ▪ FAA Safety Team ▪ Incident Investigation ▪ Data Analysis 	<ul style="list-style-type: none"> ▪ Air Carriers ▪ Manufacturers (Fixed and rotary wing) ▪ Maintenance Repair Operations ▪ Labor Unions ▪ Scientists ▪ International Regulators ▪ Outside Industry

Figure 2. A depiction of delegate affiliations.



Figure 3. Maintenance Fatigue Leaders Workshop Day 1.

Workshop Introductions. The workshop began with an extensive introduction and discussion session centered on a prioritized list of challenges and solutions. Each speaker identified what he or she considered to be the most significant challenge to human fatigue in aviation maintenance, as well as three viable solutions to overcome that challenge. Dr. Katrina Avers concluded the introduction session with a summary of the delegates' prioritized list of challenges and solutions. Figure 4 lists the prioritized fatigue challenges and appropriate solutions for each.

FAA Accident Investigation: A Case Study of Maintenance Human Factor Error. Ms. Victoria Anderson, senior accident investigator, was a member of the FAA team responsible for investigating the Alaska Airlines Flight 261 accident that occurred on January 31, 2000 off the coast of Southern California. Ms. Anderson offered a detailed description of the flight and subsequent investigation. The investigation revealed that the plane lost pitch control because of the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads. The FAA and NTSB identified a number of factors that contributed to the accident. The causal factors ranged from the difficulty of performing the lubrication task and falsified maintenance records to the complexity of measuring the acceptable wear limits. The NTSB and the FAA do not typically investigate fatigue in maintenance personnel, but Ms. Anderson felt it could have been a contributing factor in this instance since the task was completed at night and under difficult conditions. She noted that most accident investigator's do not ask the questions necessary to determine if mechanic fatigue is a causal factor. She challenged us to conduct additional root-cause analysis to identify human factors errors originating from maintenance or manufacturing.

The delegates agreed that fatigue-related, root-cause analysis is currently insufficient. We must identify causal factors such as fatigue. The FAA, NTSB, and maintenance organizations need to use fatigue assessment tools to determine the role of fatigue in aviation incidents and accidents. Although root-cause analysis is necessary for defining the fatigue problem in maintenance, additional fatigue countermeasures are necessary to reduce fatigue. The delegates noted that regulatory restrictions on hours-of-service limits and personal responsibility should be the focus of interventions. Regulations, however, may take years to change and are only one part of the solution.

Safety Culture and Maintenance Fatigue. The Honorable John Goglia, former NTSB board member and aviation safety consultant, stated that the fatigue problem in aviation maintenance is obvious, and the focus should be on action items and developing a plan for change. He suggested following the model that was set forth

Challenges		Solutions	
Industry Culture	1	Fatigue Education	
Fatigue Assessment	2	FRMS	
Scheduling Practices	3	Fatigue Research	
Government Inaction	4	Assessment	
Fatigue Education	5	Hours of Service Limits	
Work Life Balance	6	Safety Culture	
Fatigue Research	7	Collaboration	
Root Cause Analysis	8	Public Relations	

Figure 4. Pre-workshop ranking of fatigue challenges and solutions.

by Mothers Against Drunk Driving (MADD). This organization did not have success at first, but they were strategic and persistent to mitigate change. The primary message is that human fatigue is a hazard just like drunk driving. To initiate change, the industry must take a four-pronged approach. First, we need to begin a fatigue education campaign in maintenance schools. Second, we must identify fatigue as a legal hazard and include it in the development of safety management systems. Third, we have to improve fatigue assessment techniques and collect data across incidents. Finally, we must conduct return-on-investment or cost-benefit analyses to achieve industry buy-in.

Many delegates agreed with these key intervention points. There was substantial discussion regarding future mechanics and the current technical and human factors training. All agreed that we must educate mechanics in the maintenance schools regarding fatigue and their responsibility to be professionals that are "fit for duty." On a parallel course of action, we must also communicate the safety hazards and legal liability of fatigue to company legal departments and senior executives. To provide the necessary information for organizational change, we must continue to collect data and assess risk. Overall, fatigue solutions require more than the science; we must communicate and market the solutions to invested stakeholders.

Fatigue in Aviation: Breaking the Communication Barrier. Mr. David Burch is a senior customer support representative for Bell Helicopter Textron, Inc. With his 40-plus years of aviation maintenance experience, he provided a unique examination of human fatigue in helicopter maintenance and manufacturing operations.

Several factors contribute to human fatigue in helicopter maintenance operations. Like other aviation maintenance operations, the helicopter maintainer is often under extreme pressure to keep working until the job is complete and the aircraft airworthy. However, most helicopter maintainers work by themselves and their work often goes unchecked. The environment

provides an additional level of difficulty. For instance, maintenance frequently occurs in remote locations with limited access to water or power. Given these constraints, Mr. Burch noted that formalized or standardized training is often limited. He speculated that individuals do not have a personal incentive to complete training unless it is mandated.

Discussion following Mr. Burch's presentation focused on two actionable items. First, we must focus on educating the individual maintainer. Since many maintainers work in isolation, it is important that they have some awareness regarding personal fatigue levels, hazards, and countermeasures. Mr. Burch challenged the group to develop a short and simple "mantra" for fatigue that can be used in the field. We must break the communication barrier between researchers and maintainers to influence operational change. The research should be in actionable terms that are meaningful to the maintainer. The delegates also pointed out that we must communicate with the companies and recognize their economic restrictions. Everyone agreed it would be beneficial to collect data and then communicate the return-on-investment for fatigue-related interventions.

Maintenance Fatigue: The Union Perspective. Mr. John Hall, Director of Flight Safety for the International Association of Machinists and Aerospace Workers, discussed work limits and how they have an impact on fatigue. He discussed the current regulations, which require 24-hours off in a 7-day period or the equivalent thereof in a month. Mr. Hall noted there are no hourly limitations concerning how long a person can work in a day. In other words, aviation maintainers can work 24 hours a day for multiple days and still be legal under the current regulations. In addition, under the currently, companies can legally keep their mechanics on the clock for extended duty days. Mechanics often do not complain because many are willing to work overtime to earn the extra income. Mr. Hall suggested a number of solutions, including hourly limits (daily, weekly, monthly), fitness for duty testing, and use of fatigue countermeasures.

The delegates agreed that there must be shared responsibility between the worker and the company for fatigue risk management to be successful. Many believed that implementing fatigue countermeasures will reduce fatigue-related incidents and result in a number of positive outcomes, including increased productivity, reduced errors, reduced "do-overs" or time delays, fewer hours worked, increased wages, and increased employment.

Analysis of Aviation Safety Reporting System Reports for Maintainer Fatigue. Dr. William (Bill) Rankin, Technical Fellow for Maintenance Human Factors for the Boeing Commercial Aviation Services, described a content analysis of the fatigue-related maintenance reports in the

Aviation Safety Reporting System (ASRS). The ASRS is a tool that mechanics, pilots, dispatchers, and flight attendants use voluntarily to report errors. Dr. Rankin coded and analyzed the available reports for errors of omission and commission, as well as complicating factors such as time pressure and lighting. The results indicate approximately equal numbers of errors of omission and commission. Nearly half of the coded reports cited fatigue as the only contributing factor. Other compounding factors included time pressure, poor lighting, workplace distraction or interruption, stress, multitasking, and understaffing. Fatigue and time pressure appeared to be the most dangerous combination.

Delegates agreed that we must improve our data collection tools to reduce fatigue levels. The data collected in ASRS is useful but insufficient. The current reporting form relies on subjective reports of fatigue. Scientifically, we know that fatigue is often under-reported on subjective reports. The delegates agreed that forms should use objective questions that can provide data for existing fatigue modeling tools.

Workshop Presentations—Day 2

Fatigue Risk Management Systems Outside of the FAA. Mr. Don Osterberg, Senior Vice-President for Safety and Security at Schneider Trucking International, Inc., provided a compelling presentation on fatigue risk management and safety in the trucking industry.

Mr. Osterberg challenged the workgroup members to develop a platform or case for change. The case for change must be dramatic and based on known fatigue hazards and the industry's culture of safety. He noted that from an outsider's perspective, the current duty time operations are not indicative of a safety culture. To move forward, the industry's safety culture must change. Mr. Osterberg reviewed two types of culture: defensive and constructive. Defensive cultures are reactive, focus on negative outcomes, focus on blame, and maintain the status quo. On the other hand, constructive cultures are proactive, foster creativity and innovation, reinforce personal responsibility, and value performance. His company fosters a constructive culture and has been able to change beliefs, attitudes, behaviors, and outcomes on a large scale.

In the trucking industry, the case for change was rooted in the fact that fatigue was a causal factor in 36% of high-severity crashes. Schneider Trucking International, Inc. has taken a proactive risk management approach to fatigue, including:

- sleep disorder screening and testing,
- medical treatment of sleep disorders, and
- training and awareness of fatigue hazards and countermeasures.



Figure 5. Maintenance Fatigue Leaders Workshop Day 2.

Mr. Osterberg said that to achieve successful culture change, an organization must affirm and reward the behaviors that it values. His company is working to calculate the complete return-on-investment but has received multi-million dollar savings (15.7M) in healthcare costs alone in the first year.

The delegates (Figure 5) agreed that the industry culture regarding safety must change from a defensive culture to a constructive culture. The success of Schneider Trucking International could help make the case for change. Without restrictive duty-time regulations, developing a convincing return-on-investment argument may be the only way to initiate movement in the industry.

Meeting the Challenge: Managing Fatigue Risks within the Multi-Layered Maintenance Repair Organizational Culture. Mr. Bob Kelley, Aviation Systems Standards Quality Control Specialist for the FAA, discussed aviation maintenance fatigue and the organizational culture of maintenance repair organizations. First, he stated that fatigue training for flight crewmembers and maintenance personnel is not comparable. Flight crews have mandatory recurrent training; however, maintenance training regarding human factors and fatigue is not required. Many new hires from the maintenance schools have received little or no training regarding fatigue. Mr. Kelley's organization recognizes the hazards of fatigue and has begun development of a risk management program. One tool they use is a risk assessment form. People at all levels in the organization are required to sign-off on the mechanic's authorization to work when it appears he or she is a high-fatigue risk. Initial use of the form has revealed that it does elevate awareness regarding fatigue, but improvements are necessary.

The delegates believe the objective assessment of fatigue and use of predictive fatigue models can be operationally significant tools. Although real-time assessments of fatigue are important, we need to make predictive assessments, so we can assign tasks more strategically. We must assess fatigue levels for the beginning and end of employee work times. When employees are traveling, we must consider time changes and use of fatigue countermeasures in the risk calculations.

Fatigue Solutions Across Operations: Pilot, Air Traffic, and Tech Ops Fatigue. Dr. Thomas Nesthus, an Engineering Research Psychologist for the FAA at the Civil Aerospace Medical Institute (CAMI), provided an informative talk on other segments of the aviation industry and their use of applied, science-based solutions for fatigue risk management. Dr. Nesthus discussed how ultra long-range operations used scientific modeling tools to optimize flight and rest schedules. In that study (Nesthus, 2009), researchers used fatigue modeling tools to demonstrate safety equivalence levels for flights not covered under existing flight duty time rules (flights exceeding 16 hrs). Other operations, including air traffic and technical operations, are working to incorporate fatigue-modeling tools and apply Fatigue Risk Management Systems (FRMS) to their operations. Correct application of an FRMS provides continual assessment and the ability to improve alertness in operations.

Fatigue modeling tools can enable alternative, but equivalently, safe operations that are not restricted by hours of service limits. The delegates agreed that this approach could be economically feasible and give the maintenance industry the flexibility needed to improve safety.

FAA Maintenance Fatigue Research: From Science to the Real World. Dr. Katrina Avers, an Industrial-Organizational Psychologist for the FAA at CAMI, is the chairperson of a multi-disciplinary maintenance fatigue workgroup focused on the development of integrated, scientifically based approaches to mitigate fatigue in the aviation maintenance industry. Dr. Avers explained that existing operational conditions (i.e., lack of fatigue education requirements, FAA regulations inconsistent with current fatigue studies, and maintainers not getting enough sleep) are likely to contribute to fatigue-related accidents/incidents. However, she emphasized that it is difficult to develop real-world solutions without science-based documentation.

Dr. Avers emphasized the need for the Maintenance (MX) industry to participate in research by collecting fatigue data. She further emphasized that sharing the collected data with FAA scientists would help pinpoint problems, increase safety, and inform fatigue risk management researchers so that fatigue product development integrates the individual, company, and regulator for maximum benefits.

Dr. Avers provided a progress report on completed and pending research projects for managing fatigue risk. Current data suggests that science-based fatigue risk management can successfully reduce fatigue risk in maintenance operations. Dr. Avers referenced a number of free resources that companies can access at www.mxfatigue.com. The Web site includes fatigue assessment tools (i.e., sleep diary, symptom checklist, a supplemental incident/accident form for collecting and reporting fatigue data) and fatigue awareness materials (i.e., fatigue countermeasures workshop, “Grounded” DVD, “MX Fatigue Focus Newsletter”). Pending projects include an operational handbook that will provide instructions and tools for implementing an FRMS, a return-on-investment assessment/calculator for fatigue management intervention, and recommendations for service. All delegates agreed that we must continue to develop practical science-based solutions that are relevant to maintenance operations. Some indicated that they are using the FAA resources. They look forward to the results of continuing development. We must improve collaboration among government, industry, and unions on applied research programs to influence change in the industry.

From the Laboratory to the Runway—Science-Based Management Approaches That Fit Industry. Dr. Daniel Mollicone, President and Chief Executive Officer for Pulsar Informatics, Inc., presented research on the use of mathematical models to predict fatigue. Although his research is extensive, Dr. Mollicone focused on the practical applications of mathematical models. His company is currently developing a fatigue risk assessment tool for the

maintenance industry. Individuals can enter their work and sleep history online to provide a self-assessment of predicted fatigue risk for a given period of time (e.g., 10-hr shift). Managers can also use the tool to make informed decisions regarding the risk level of their employees. For example, a manager could use the automated tool to make scheduling choices regarding overtime. Dr. Mollicone indicated this tool would be available as a beta version in June 2011.

The risk assessment tool promises to be useful both predictively and post-analytically for incident/accident investigations. Dr. Mollicone encouraged the delegates to consider a more extensive version of the tool that could predict how much fatigue is too much fatigue and what the individual cost would be at each level of fatigue. He has developed an analytic approach that could help organizations economically maximize their workforce. To develop this approach accurately, the industry needs to determine what is important. In other words, what do we want to change? Some examples include rework delay, equipment delay, healthcare costs, time-off claims, damage to aircrafts, and employee turnover. Regardless of which criteria we select, it must be measurable and occur at least tens to hundreds of times each year. The delegates agreed that this route warrants further attention and could be a critical catalyst for change.

WORKSHOP ACTION ITEMS

The workshop delegates identified and prioritized ten actions that can reduce the risk of worker fatigue in aviation maintenance. Although maintenance was the focus of the workshop, the list of actions transfers to most work environments (see Table 1).

Enhance Employer and Worker Fatigue Awareness

More than 30 years ago, a group of mothers established MADD to aid victims of alcohol-induced traffic accidents and associated crimes. A primary part of their mission statement is “. . .to increase public awareness of the problem of drinking and drugged driving. . .” MADD has evolved from a small handful of grieving mothers to one of the most powerful grassroots lobbying and educational organizations in the world. They made alcohol- or drug-impaired driving a public issue and successfully lobbied to change laws, educate younger and older people alike, and create public awareness.

Fatigue is like impaired driving. Numerous studies have shown that fatigue results in the same performance impairment as alcohol and other drugs (e.g., Arnedt, Wilde, Munt, & MacLean, 2001; Lamond & Dawson, 1999; Maruff, Falleti, Collie, Darby, & McStephen, 2005; Mitler, et al, 1988). However, fatigue levels are

Table 1. Prioritized List of Actions

Rank	Action Items
1	Enhance Employer and Worker Fatigue Awareness
2	Continue and Expand Fatigue Countermeasure Education
3	Support and Regulate Fatigue Risk Management Systems
4	Quantify Safety and Operational Efficiency Impact of Fatigue
5	Regulate Hours of Service Limits
6	Establish Baseline Data of Fatigue Risk With Existing Event Reporting Systems
7	Integrate Fatigue Awareness into Safety Culture
8	Ensure that FRMS is Considered in SMS Program
9	Create and Implement Fatigue Assessment Tools
10	Improve Collaboration of FRMS Within and Across Organizations

more difficult to assess. Currently, there is no quick blood or breathalyzer test equivalence to provide an on-site measure of fatigue. Is it possible to create such procedures or devices? The answer from many is *yes*, and we have seen the automobile and trucking industry taking innovative approaches to measure on-site fatigue with eye blink technology. Overall, there is minimal market demand to measure fatigue and a fatigue “breathalyzer” is not possible yet. We must make fatigue a public issue if change is going to occur. An organized and integrated movement may be necessary to change laws, improve education, and create awareness.

Unfortunately, high-visibility events drive public and industrial awareness of fatigue. Events that expose fatigued pilots or air traffic controllers receive extensive media coverage. For each of the public events, numerous other occurrences avoid discovery. This is true in hospitals, nuclear power plants, transportation, security, and most other industries. The fatigue threat is especially prevalent in industries that operate around the clock. The high-visibility events bring short-term public attention to the matter until media attention wanders to the next front-page topic. The risks associated with worker fatigue must remain high priority even when the topic is not in the news.

Fatigue and its associated risks are not limited to industry, it is a societal problem that must be communicated. The workshop delegates recommended a communication and education campaign for aviation maintenance workers and suggested creating a “mantra” for fatigue risk management in maintenance. This idea is public relations-oriented. The recommendation is to develop

standard promotions and catch phrases that maintenance workers will remember and use. We can promote fatigue awareness with everything from signage and calendars to hats and tee shirts. While this may sound elementary, the delegates ranked fatigue awareness as the number-one way to make maintenance workers and employers aware of the fatigue risk.

The delegates suggested that fatigue awareness should be an effort that involves the labor unions, the professional and industrial organizations, scientists, and the government. The campaign is likely to be most successful if it promotes the financial, health, and safety benefits of fatigue risk awareness. Many suggested that comparing fatigue impairment to alcohol impairment was an easy concept that the public could understand. Although it is useful as a general rule of thumb, the scientific members cautioned against such a comparison, since there are situations where this is not the case. For example, your circadian rhythm can help you be more alert, even when you have been awake for extended periods.

The committee recommended that the FAA assume the role of a leading organization to promote fatigue awareness to all aviation employees. Such promotion need not be limited to those FAA employees who fly or control aircraft. The promotional materials can be distributed to other government agencies and commercial organizations as well. Figure 6 shows 12 examples of posters promoting fatigue awareness. Another example of promotional materials is the MX Fatigue Newsletter, published quarterly and available on the FAA Web site, www.mxfatigue.com.



Figure 6. Twelve fatigue posters available for downloading from the FAA Maintenance Human Factors Web site.

Continue and Expand Fatigue Countermeasure Education

Fatigue education is the second highest ranked action item to combat fatigue in the workplace. This recommendation is closely ranked and associated with the first action item, enhancement of employer and worker fatigue awareness.

Training efforts must demonstrate the benefits of proper rest to the employee and to the employer (e.g., Rosekind, Gander, Connell, & Co, 2001; Rosekind, Co, Neri, Oyung, & Mallis, 2002; Rosekind, et al, 2001). It must show “what’s in it for me.” Training must reinforce the professional responsibility of the worker to be “fit for duty.” It must also teach executives and managers to schedule work, overtime, and rest in a safe manner. Education must present the science of sleep and scheduling in an understandable and useful manner. Most importantly, education must motivate learners to modify any poor habits that cause fatigue (Avers, Johnson, & Hauck, 2010; Avers & Johnson, 2010).

Fatigue education must also focus on the families and friends of shift workers. Often shift workers must sleep in the daytime or the early evening, when household, business, sports, and other family activities usually take place. Family members must learn about proper rest and schedules to ensure that their loved one is safe at work.

Another opportunity to institute fatigue awareness education is in the maintenance schools operating under Title 14 of the Code of Federal Regulations (CFR) Part 147. We should sensitize aspiring mechanics to fatigue issues during their initial training.

The delegates felt that industry should also educate the congress regarding current regulations like Title 14, CFR Part 121.377. While congress has applied considerable pressure to alter fatigue-related rules for pilots, there are no such actions for maintenance. Delegates felt that such education might encourage the FAA to address the fatigue safety risk with improved regulations. Of course, the industry delegates from both management and labor used the adage “Be careful what you wish for...”

The FAA’s Maintenance Fatigue Research Program created and teamed with maintenance operations to distribute a significant amount of fatigue education materials from 2009 to present. Figure 7 shows the home page for FAA’s fatigue countermeasure resources. It includes about 90 minutes of fatigue-related training and a 20-minute video. The video, *Grounded*, won 12 video production awards in its first month after production in 2010 and received numerous testimonials on how it has changed people’s lives (Johnson, 2010a). The fatigue awareness program is now in place at selected airlines and maintenance repair organizations. The FAA Safety Team incorporated the fatigue awareness training as a core part of their annual training program. That means that all aviators and companies that participate in the FAA Safety Awards Program must make fatigue awareness training their first training objective. This initiative will reach out to about 20,000 maintenance and flight crewmembers in 2011. This type of activity is representative of the educational materials recommended by the workshop delegates; it must continue.



Figure 7. Home page for fatigue awareness training and the Grounded video.

Support and Regulate Fatigue Risk Management Systems

The International Civil Aviation Organization (ICAO) defines FRMS as a “scientifically-based, data-driven flexible alternative to prescriptive flight and duty time limitations that forms part of an operator’s Safety Management System and involves a continuous process of monitoring and managing fatigue risk.”

Most workshop delegates favored a regulation that permits the company to demonstrate how it will manage fatigue. Such a regulation would set maximum service limits in lieu of an accepted FRMS. The organization could show how they will manage fatigue if they choose to exceed the regulated service limits. An FRMS is comprised of many of the elements shown in Figure 8 (Hobbs, Avers, & Hiles, 2011).

In the workplace, a number of factors can influence fatigue, including working hours, staffing levels, and the availability of break periods. Employers have the responsibility to use available resources to manage fatigue risk and optimize the safety of their operations. An employee, after training, has the responsibility to utilize fatigue countermeasures at home and report for work “fit for duty” (e.g., Dawson & McCulloch, 2005; Dinges, Maislin, Brewster, Krueger, & Carroll, 2005).

FRMSs are widely used to manage fatigue among flight crews, the railroad industry, and drivers of commercial vehicles, among others. Successful implementation of an FRMS in these industries has yielded substantial improvements in personal health and well-being, as well as significant improvements in safety and reductions in organizational costs (Gander, Marshall, Bolger, & Girling, 2005; Kerin & Aguirre, 2005; Moore-Ede, Heitmann, Dawson, & Guttkuhn, 2005). For example, Schneider

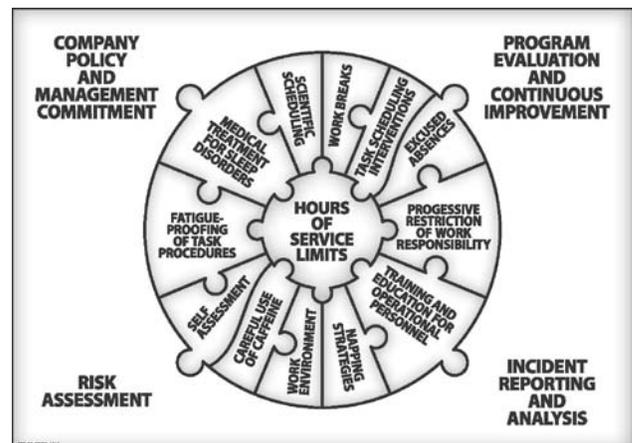


Figure 8. Components of an Fatigue Risk Management System (FRMS).

Table 2. Example Countermeasures to Accomplish FRMS Goals

Countermeasures	1. Reduce fatigue	2. Reduce/capture fatigue-related errors
Hours of service limits	X	
Scientific scheduling	X	
Napping strategies	X	
Training and education for maintainers and inspectors	X	X
Training and education for supervisors and planning staff	X	X
Excused absences		X
Medical treatment for sleep disorders	X	
Self-assessment		X
Fatigue detection technology	X	X
Work breaks	X	X
Work environment		X

Replicated from FAA Office of Aerospace Medicine Technical Report 11/10.

Trucking International Inc. has reported multi-million dollar savings in annualized health care costs alone.

Despite the benefits of fatigue risk management systems, they are still uncommon within maintenance organizations. In the typical aviation maintenance operation, there are two key goals for an effective FRMS. The goals are: 1) Reduce fatigue levels to an acceptable level, and 2) Reduce fatigue-related errors.

Reduce Fatigue to an Acceptable Level. The first and most obvious goal of an FRMS is to reduce the level of fatigue experienced by personnel at work. Fatigue reduction interventions should minimize fatigue in the workplace. Interventions can include duty time limits, scientific scheduling, napping, education, excused absences, and in some instances, medical testing and treatment.

Reduce Fatigue-Related Errors. Despite efforts to ensure that employees are well-rested and alert when they report for duty, it is not possible to eliminate fatigue from the workplace. Interventions can involve two approaches: measures directed towards reducing the risk of the individual, and measures directed toward reducing the risk of a task for a fatigued worker. For example, reducing the risk of a task by taking work breaks and simplifying work task steps can help. We should not assign fatigued

workers to critical tasks. Matching the worker to the task is part of an FRMS.

An FRMS must fit each organization. One size does not fit all. Effective fatigue risk management requires that everyone take responsibility for the problem and use multiple strategies to reduce fatigue. Table 2 offers examples of how different tools help accomplish each fatigue risk management goal.

Quantify Safety and Operational Efficiency Impact of Fatigue

Any aviation maintenance technician, especially from the airlines, will tell stories about "...the time we put in 64 continuous hours on an emergency engine change..." There are plenty of stories and even admissions of serious mistakes. In most cases, these stories never make it to the ears of senior management. There is seldom a reason for FAA inspectors to know of these excessive hours because the FAA does not have a rule that limits hours of service.

When fatigued mechanics or crew members make errors, they are often attributed to procedural errors, memory lapse, or mistaken communication. Typically, an event investigation does not have a sufficient root-cause analysis to determine if fatigue was a significant

contributing factor. As a result, there is a limited amount of formal data to show that fatigue is a significant risk to safety or efficiency in maintenance operations. The aviation industry does not know the cost of fatigue-related error, and the government cannot quantify the safety impact. The industry needs tools to investigate maintenance fatigue.

The U.S. trucking industry has measured the impact of fatigue and radically altered company procedures for truckers through semi-annual fatigue countermeasure training, health and wellness coaching, evaluation of sleep disorders, and proactive fatigue management. Regulatory changes pending include sleep apnea screening in commercial motor vehicle physical exams.

Government and the aviation industry must cooperate to collect estimates of: 1) the financial impact of the event/damage, 2) the level of flight safety risk caused by maintenance fatigue, 3) the cost of implementing FRMS programs, and 4) the probability that an FRMS would have prevented the event/error. These data could make it straightforward to demonstrate the return-on-investment. Further, these data could help in the determination of the need for fatigue-related regulation (Johnson, 2010c; Johnson, 2010d).

Once the industry has quantified the financial and safety risk of fatigue, it can implement the appropriate interventions and measure the impact. If the industry knew the issues that contribute to fatigue risk, it could reinforce the procedures and employee behavior that reduce such risk.

The FAA Maintenance Fatigue Working Group has initiated an important first step in assessing worker fatigue. Figure 9 shows the 10 questions used to assess worker fatigue. A representative assembly of maintenance managers, maintenance worker organizations, scientists, and regulators created the form. These questions do not ask if the worker felt “tired.” Instead, the questions are factual and relatively easy to answer. A few scientific calculations can determine if the worker’s level of efficiency is fatigue-related.

The 10 FAA-developed questions and other such data collection tools are imperative steps to quantify and then minimize fatigue-related risk (Johnson & Avers, 2010).

Regulate Hours of Service Limits

The workshop delegates ranked “Hours of Service Limits” as another high priority action. The recommendation is consistent with the prioritization of FRMS regulation. In 2010, the FAA-Industry Maintenance Fatigue Working Group took a survey on whether or not we need a duty-time regulation. With 85% of the members voting, there was 100% agreement that the FAA should propose a duty-time rule. At the workshop and in the working group, delegates felt that neither industry nor individuals would fully address fatigue without a regulation. Many believed that a FRMS could supplement the hours-of-service limits if equivalent levels of safety were demonstrated.

General Description of Work and Sleep History (* indicates 'required' items)

Describe your work / sleep history prior to the work task, even if the problem was not related to work hours / sleep history.

	Hours	Minutes	
Length of commute to work:*	<input style="width: 50px;" type="text"/>	<input style="width: 50px;" type="text"/>	
Work schedule (Local Military Time):*	Start		End
<i>day of task</i>	<input style="width: 50px;" type="text"/> (mm/dd 00:00)		<input style="width: 50px;" type="text"/> (mm/dd 00:00)
<i>Additional information regarding schedule.</i>	<i>1 day prior</i>	<input style="width: 50px;" type="text"/> (mm/dd 00:00)	<input style="width: 50px;" type="text"/> (mm/dd 00:00)
	<i>2 days prior</i>	<input style="width: 50px;" type="text"/> (mm/dd 00:00)	<input style="width: 50px;" type="text"/> (mm/dd 00:00)
	<i>3 days prior</i>	<input style="width: 50px;" type="text"/> (mm/dd 00:00)	<input style="width: 50px;" type="text"/> (mm/dd 00:00)
	<i>4 days prior</i>	<input style="width: 50px;" type="text"/> (mm/dd 00:00)	<input style="width: 50px;" type="text"/> (mm/dd 00:00)
	<i>Enter 'NA' if you did not work.</i>		
Typical sleep period (Local Military Time):*	Go to sleep		Wake up
Sleep period in the 24 hrs prior to work task (Local Military Time):*	<input style="width: 50px;" type="text"/> (mm/dd 00:00)		<input style="width: 50px;" type="text"/> (mm/dd 00:00)
1st nap in the 24 hrs prior to work task (Local Military Time):*	<input style="width: 50px;" type="text"/> (mm/dd 00:00)		<input style="width: 50px;" type="text"/> (mm/dd 00:00)
2nd nap in 24 hrs prior to work task (Local Military Time):*	<input style="width: 50px;" type="text"/> (mm/dd 00:00)		<input style="width: 50px;" type="text"/> (mm/dd 00:00)
	<i>Enter 'NA' if not applicable.</i>		

Rev 03/24/2010

Figure 9. The FAA 10 Questions form used to assess worker fatigue.

Example Service Limits From International Regulations			
Major Category	Range of Regs	IFA	Hybrid?
Max Scheduled Hrs	8-24 hrs	12 hrs	12 hrs
Max Hrs with OT	11-24 hrs	16 hrs	16 hrs
Max Hrs this Month	196-646 hrs	288 hrs	300 hrs?
Min Rest between Shifts	11	8 hrs uninterrupted	8 hrs uninterrupted
Min 24 Hr Break/Week	48-0	48	TBD Hrs
Time of Day	Makes a Diff.	Consider	Manage

Figure 10. Examples of international duty time service limits with IFA recommendations.

Figure 10 shows example service limits for maintenance workers from regulations around the world. The second column shows maximum hours in ranges. The rules from China allow only 8 hours of scheduled work per day. The FAA rule allows 24 hours maximum. The third column is a list of recommendations from the International Federation of Airworthiness (IFA) published in 2007 as Duty Time Limitations and Rest Periods (www.ifairworthy.com). The fourth column is a hybrid version of IFA recommendations and discussions within the FAA-Industry Maintenance Fatigue Working Group (Johnson, 2010b). The combination of the Hybrid column and FRMS information could be the preliminary basis for a U.S. regulation.

Establish Baseline Data of Fatigue Risk With Existing Event Reporting Systems

A number of data systems and processes collect safety information in advance of a serious event. Such proactive and predictive systems are an important part of an organization's safety management system.

There are an increasing number of fatigue-related reports submitted to NASA's Aviation Safety Reporting System (ASRS). In these reports, the submitter usually describes the circumstances and can explain why fatigue is a contributing factor. This is useful information, but it is insufficient for an accurate assessment of fatigue. The delegates suggested a change to the ASRS form to incorporate the set of 10 FAA-developed fatigue questions. This information could provide baseline data for all errors even when fatigue is not reported as a contributing factor.

The Aviation Safety Action Program (ASAP) provides a means for aviation workers to voluntarily report incidents, safety observations, or both. These reports are confidential and, in most cases, prevent the reporter from receiving any serious FAA or company disciplinary action (see AC 120-66B). Some airlines have already incorporated the 10 FAA fatigue questions into all ASAP reports. The shared ASAP database, W*BAT, has already incorporated the 10 FAA fatigue questions

as an option on the Web-based data entry forms. Again, this information is a means to provide proactive and predictive measures regarding fatigue-related risk.

The FAA and the U.S. Air Transport Association are working on a Line Operations Safety Assessment (LOSA) program for line and maintenance operations. This peer-to-peer safety assessment program has incorporated the 10 FAA fatigue questions. The value of this system is that it permits a formal assessment of normal operations without the potential topic bias that might occur when acquiring specific event-related fatigue factors. LOSA is not triggered by an event or accident. Data collected via LOSA can provide a general indication of baseline fatigue hazards within the workforce. Workshop delegates encouraged assessment of fatigue across incidents and accidents, from on-the-job injury to aircraft damage.

Integrate Fatigue Awareness Into Safety Culture

The term "Safety Culture" is the extent to which an organization has a shared value for safety. In a safe culture, the organization values safety, and each employee can articulate how they make a daily safety impact based on their specific job tasks. This attitude should extend to fatigue, where an organization values fatigue-based fitness for duty throughout the employee work period. That means that each employee can articulate exactly what he or she has done to ensure proper rest prior to the work period (Arboleda, Morrow, Crum, & Shelley, 2003).

Some of the delegates suggested conducting a cultural assessment to identify the current risks to worker and flight safety. The current system in the U.S. operates with limited duty time limitations. Companies and workers have taken advantage of the current regulation to work as much as they want, whenever they want. The current culture relies on company flexibility to offer extensive overtime, thus avoiding the cost of additional employee overhead expenses. Workers like the overtime because it places much-needed money in their pockets.

Some aviation maintenance workers engage in long flight commutes. They depart from home and fly to another city to work, often swapping shifts to work as much as possible in as few days as possible before returning home. In some cases, they return home to work another job. The current industry culture (workers, managers, and executives) appears to value the bottom line more than safety. There is minimal consideration of fatigue hazards in current aviation maintenance operations. A 1999-2000 FAA study of maintenance worker sleeping habits (Hall, Johnson, & Watson, 2001; Johnson, Hall, & Watson, 2002) showed an average sleep time of just over 5 hours. Since 2001, maintenance salary cuts have resulted in workers needing to work more hours to maintain a reasonable standard of living. These are the characteristics of the current culture.

Cultural assessment is often a challenge, and the utility of results can be limited and proprietary to the researcher. If the FAA conducts a cultural assessment of the maintenance industry, the research must use open-source materials and analytic tools that are available at no cost. There should be no necessity to hire a consultant specializing in cultural assessment. The results must be tangible and available for replication.

Ensure That FRMS is Considered in SMS Programs

The ICAO definition stating that an FRMS forms a part of an operator's SMS created extensive discussion regarding rules and requirements for a Safety Management System. Some delegates believed that an FRMS should be "called out" as an explicit SMS requirement.

It appears that an FRMS will not be required any more than a Flight Operations Quality Assessment (FOQA) or an ASAP. An SMS purist believes that an SMS should have ways to conduct risk assessment on all aspects of the organization. SMS requires evaluation and mitigation of all risks. Fatigue is one of many hazards that should be identified in a SMS.

The FAA-Industry Maintenance Fatigue Workgroup has developed a risk assessment tool to assess fatigue levels. The software tool contains a form that asks 10 key questions related to the work and sleep history of a worker (see Figure 9) (Johnson, 2010e). The online questionnaire computes an individual's fatigue levels. This tool is based on a biomathematical model and can analyze sleep and work histories to estimate fatigue risk.

Create and Implement Fatigue Assessment Tools

Workshop delegates ranked the need for fatigue assessment tools as number 9 of 10. However, the adage, "You don't need a weather man to know which way the wind blows," applies here. There are plenty of indications when there is a

fatigue risk. These factors include extended work exceeding 12 hours; work beyond 16 hours; repeated double shifts; less than 8 hours of undisturbed sleep between shifts; long commuting, and more.

While workers and employers should know many of the factors that affect the risk of fatigue, it seems that people want some indicator to tell them they are fatigued or not fit for duty. Fatigue scientists will emphasize that there is no way to have a concrete "yes or no" or "green or red light" to guide a worker with a definite answer.

Many of the "off-the-shelf" fatigue modeling software packages are sophisticated. They often require a knowledgeable analyst to enter the data and derive an answer. Boeing and the Jeppesen Company recently teamed to create an I-Phone application that helps keep track of a pilot's work and rest schedule including the complications of time of day, circadian rhythm, and the crossing of multiple time zones. This is an example of an easy-to-use software model that can be applied in daily use. Eventually the user can mentally automate the model and apply the information to their work and personal lives.

ZEO© or Sleep Alert© offer fatigue assessment devices that are a combination of rest measurement hardware combined with a software model. These devices focus on the amount and quality of sleep that are critical to assess fitness for duty. Like the Jeppesen© software, these devices help users learn more and improve the duration and quality of their sleep.

The FAA Maintenance Fatigue applied R&D program has worked with Pulsar Informatics to develop a software system that helps individuals assess their fatigue levels. It uses information from the 10 questions previously mentioned in Figure 9. Individuals can use the software to check their fatigue-based readiness for work. Figure 11 shows an example of the output report. The system was beta-tested during the summer and fall of 2011.

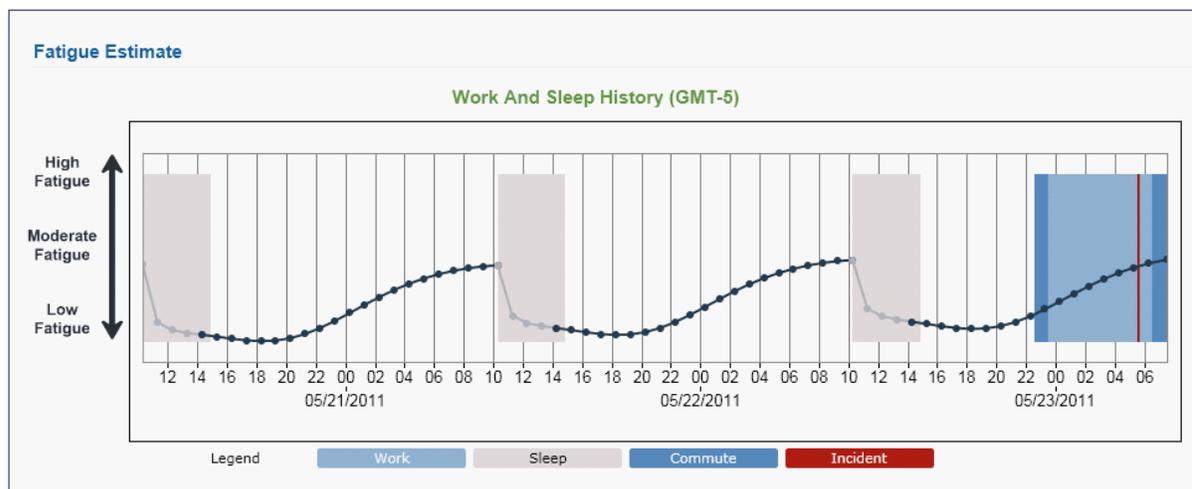


Figure 11. Example of the FAA's Fatigue Risk Assessment software output.

Fatigue assessment tools are a first step. Once people know they are fatigued, the challenge becomes acting upon that knowledge. It is customarily difficult to get people to act upon known hazards. For example, seat belts are a necessary safety device that can save your life, but some people still refuse to wear a seat belt. Having the tools and making people aware should result in improved fatigue risk management but the benefits may be limited if the assessment is not part of a comprehensive safety culture.

Improve Collaboration of FRMS Within and Across Organizations

The workshop delegates believed that fatigue risk management activity is often contained in localized parts of the organization. The multiple segments of the aviation industry must coordinate fatigue risk management to maximize effectiveness. There should be organization-wide fatigue committees.

The FAA is beginning to follow this suggestion. The maintenance fatigue R&D has created a variety of educational and promotional materials that are being applied outside of maintenance. The best example of this information sharing is the Web and CD-based Fatigue Awareness Workshop. It is currently being used for maintenance and cabin crew and modified for air traffic and technical operations.

Other examples for information sharing include the DOT/FAA-sponsored fatigue conferences (Johnson, 2009), the recent MITRE fatigue symposium, and the ICAO FRMS conference.

Section Summary

The section above described 10 actions that will address the known risk of fatigue in aviation maintenance. The range of solutions, from promotion to regulation, is wide. The recommendations can and should proceed

in parallel. However, the delegates believe there must be action on all of the recommendations to expect a cultural change in the aviation maintenance industry.

WORKSHOP EVALUATION AND COMMENTS

Organizers invited the delegates to evaluate the workshop. The evaluation consisted of 17 items designed to assess delegate perceptions of workshop content, participant benefits, and the overall quality. Delegates also provided comments or suggestions for future workshop improvements. Organizers provided a paper and online version of the form and asked delegates to complete it within one week. The survey closed April 8, 2011, and 20 workshop delegates responded (66%). The following sections will outline the results of the evaluation form.

Evaluations of Workshop Content

Organizers asked delegates to rate the workshop by indicating their level of agreement using a 5-point scale (strongly disagree, disagree, neutral, agree, or strongly agree). There were eight statements regarding workshop content. Figure 12 shows that respondents' perceptions of the workshop were overwhelmingly positive, with every respondent (100%) agreeing or strongly agreeing that the workshop covered useful material and was well organized, activities were constructive, visual aids and handouts were useful, the format encouraged active participation, and the pace was appropriate. The majority (94.8%) felt the workshop information was practical for their needs and interests, and thought the workshop contained the appropriate level of detail. Overall, the responses indicated that the workshop content was delivered in a manner that met the objectives of workshop organizers and delegates.

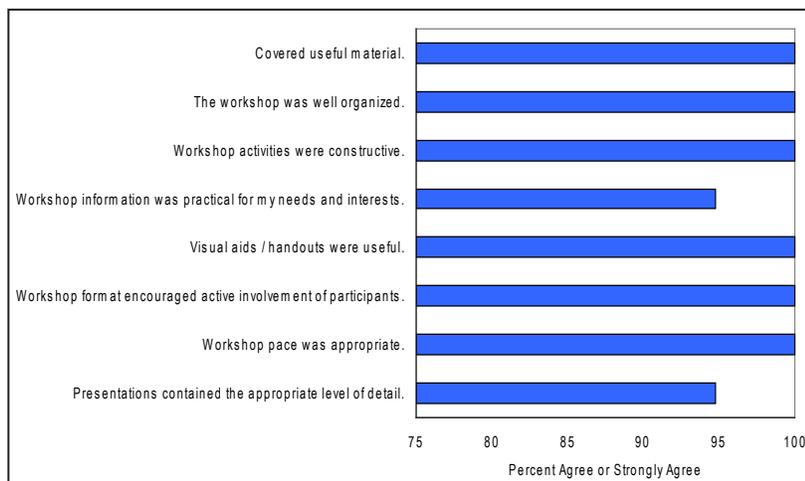


Figure 12. Delegate perceptions of workshop content.

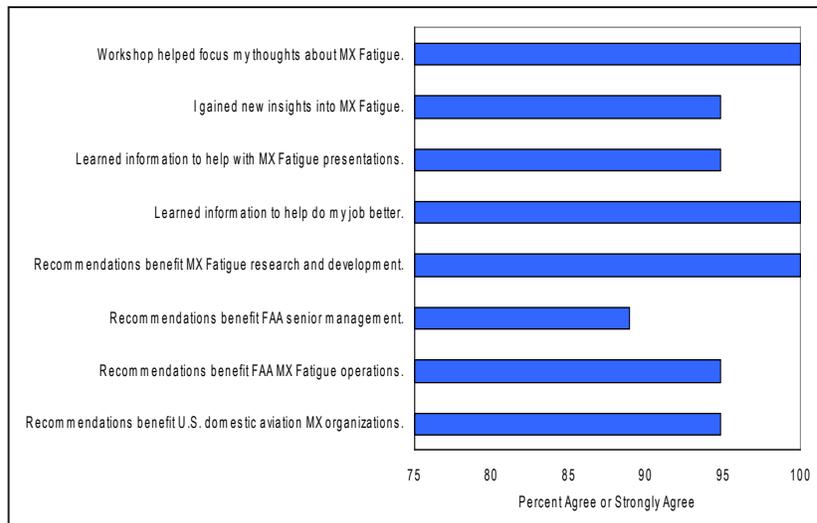


Figure 13. Delegate perceptions of workshop benefits.

Evaluations of Participation Benefits

To quantify the benefits of the workshop, delegates were asked to indicate their level of agreement with a series of eight statements regarding the benefits of the workshop (see Figure 13). All respondents (100%) agreed or strongly agreed that the workshop helped focus their thoughts about MX fatigue, they learned new information that could help them do their jobs better, and their recommendations could benefit MX fatigue research and development. The majority (94.8%) of respondents agreed or strongly agreed that they gained new insight into MX fatigue, learned new information to help with MX fatigue presentations, and that FAA MX fatigue operations and U.S. domestic aviation MX organizations would benefit from the workshop recommendations, while 88.9% felt that FAA senior management would benefit from workshop recommendations. Overall, the responses indicated that the workshop was personally beneficial and could have far-reaching implications for both the FAA and domestic maintenance operations.

Evaluations of Overall Quality

Each respondent was asked to assess the workshop on overall quality. Respondents were instructed to evaluate the course as *very poor*, *poor*, *neutral*, *good*, or *very good*. Even though a few respondents were neutral on some individual items regarding workshop content and participation benefits, all of the respondents thought the workshop training was either good (10%) or very good (90%).

Suggestions for Improvement

Workshop delegates were asked two open-ended questions to identify opportunities for future improvement. Overall, a simple analysis of the suggestions revealed a complimentary review and appreciation of the workshop. In particular, a number of respondents appreciated the perspective of delegates from outside of the industry and felt the time for the workshop could be extended for more in-depth discussion. The majority noted their expectation for continued action toward maintenance fatigue solutions.

WORKSHOP SUMMARY

This workshop utilized a multi-disciplinary approach involving mechanics, industry managers, government, scientists, safety inspectors, and aircraft accident investigators to develop science-based solutions. Overall, the workshop provided new insight into the practical application of fatigue research in the aviation maintenance industry. More importantly, it prioritized the action items that need to be pursued to reduce fatigue-related risk in maintenance. The workshop provided a reasonable representation of the core challenges, solutions, and provided guidance for continued fatigue research. Attendees indicated that more of such workshops should be conducted to utilize multiple perspectives as we collaborate to improve the future safety of aviation.

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