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A Review of Federal Aviation Administration Fatigue Research

Transitioning Scientific Results to the Aviation Industry

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Abstract. Human fatigue remains a significant challenge in aviation. Basic scientific research has studied fatigue and created a solid scientific understanding. Current efforts seek to transfer the available research into operational environments. This document reviews the research and development conducted by the US Federal Aviation Administration over the past 50 years and focuses on studies that have led to the successful transition from science into the aviation industry. Further, this article reviews current strategies and methods used to transition research into workplace operations.

Keywords: fatigue, performance, aviation, countermeasures, solutions

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Background

My mind clicks on and off. I try letting one eyelid close at a time when I prop the other open with my will. But the effort is too much. Sleep is winning. My whole body argues dully that nothing, nothing life can attain is quite so desirable as sleep. My mind is losing resolution and control.
C. Lindbergh, *The Spirit of St. Louis*, 1954

Fatigue was certainly a challenge to Charles Lindbergh and other early aviators. The quote above is vivid testimony to the fatigue that Lindbergh experienced in the first solo transatlantic flight. Most aviators of that period worried about reliability of engines and systems, the availability of ground and air-based navigational equipment, and exhaust manifold fumes. Pilots had to deal with the challenges of flying into, rather than on top of, bad weather. At that time, human factors such as fatigue were not prioritized issues (Nesthus & Avers, 2009).

Today, system reliability is high, and aircraft events are seldom caused by a single factor of failed hardware or electronics. Today, the most frequent safety threat stems from the reality of occasional suboptimal human performance. Human factors such as worker fatigue are a last frontier for moving the accident rate ever closer to zero.

This paper examines fatigue, and reviews why it is an important issue in the aviation industry. It summarizes the efforts of the US Federal Aviation Administration (FAA) to quantify, understand, and remediate fatigue risk in aviation work environments. The paper reviews research and development and focuses on the most recent fatigue awareness and mitigation efforts that are transitioning into the aviation industry. FAA research began with describing problems and is currently offering a range of practical solutions. It addresses the work environments of air traffic control/management, airways facilities technical operations, pilots, flight attendants, and maintenance/engineering. It is relevant to all aviation workers (Nesthus & Avers, 2009).

Introduction to Fatigue

O sleep! O gentle sleep! Nature's soft nurse, how have I frighted thee, that thou no more wilt weigh my eyelids down and steep my senses in forgetfulness?
William Shakespeare, *Henry IV, Part II*, Act III, sc. 1.

Today's aviation industry is a 24/7 operation that produces a variety of challenges for flight crew, cabin crew, air traffic controllers, airways facilities technical operations, and maintenance and ramp crew. Individuals in these safety-sensitive positions are commonly challenged by extended duty periods, highly variable schedules, frequent time zone changes, multiple flight legs or segments, and restricted sleep opportunities. These operational requirements are a challenge to the human body's biological rhythms for managing sleep and alertness. Studies indicate that acute sleep loss, chronic sleep loss, sustained periods of wakefulness, and circadian factors resulting from this form of misalignment all contribute to fatigue and fatigue-related mishaps (Caldwell, 2005; Rosekind et al., 1996). While loss of sleep is quite possibly the strongest contributor to fatigue, it does not fully represent all aspects of the issue of fatigue.

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Table 1. Physical, mental, and emotional fatigue symptoms

Physical Symptoms	Mental Symptoms	Emotional Symptoms
• Slowed reaction time • Lack of energy, weakness, or light headedness • Repeated yawning • Heavy eyelids • Eye rubbing • Nodding off or head bobbing • Microsleeps • Headaches, nausea, or upset stomach	• Difficulty concentrating on tasks • Lapses in attention • Failure to communicate important information • Failure to anticipate events or actions • Making mistakes even on well-practiced tasks • Forgetfulness • Difficulty thinking clearly • Poor decision making	• More quiet or withdrawn than normal • Lack of motivation to do the task well • Irritable or grumpy with colleagues, family, or friends • Low morale • Heightened emotional sensitivity

Fatigue Definition

Fatigue is a multidimensional construct that has been defined in a number of ways (Åkerstedt et al., 2004; Dodge, 1982). Most commonly, it is described as sleepiness or a general tired feeling resulting from extended wakefulness, insufficient sleep, or circadian disruption (Åkerstedt, 1995a, 1995b; Dinges, 1995). This definition provides an accurate description but fails to represent the performance consequences associated with fatigue. Fatigue is more than sleepiness, and its effects are more than falling asleep. Fatigue is a complex state that has psychological, physiological, and emotional implications that can impact the safe performance of routine and nonroutine work activities (e.g., Arnedt, Wilde, Munt, & MacLean, 2001; Avers, King, Nesthus, Thomas, & Banks, 2009; Carskadon & Roth, 1991; Co, Gregory, Johnson, & Rosekind, 1999; Costa, 1997; Maruff, Falleti, Collie, Darby, & McStephen, 2005; Mitler et al., 1988). See Table 1 for a more extensive list of personal fatigue hazards.

Example Accidents and Incidents

Fatigue has been identified in a number of accidents caused by pilots, cabin crew members, and maintenance technicians. Some accidents occurred at night or during the midnight shift, some occurred after consecutive extended duty days or sleep restriction, and others occurred with time zone or shift changes. Regardless of the underlying cause, fatigue resulted in personal injury, aircraft damage, and even death. To date, the US National Transportation Safety Board (NTSB) has identified fatigue as a contributor in more than 300 fatalities in airline accidents. See Table 2 for examples of accidents and NTSB conclusions regarding causal factors (Nesthus & Avers, 2009; Rosekind, 2011).

NTSB Recommendations

The NTSB is charged with (1) determining the probable cause of transportation accidents and (2) making recommendations to prevent their recurrence. The NTSB has identified fatigue as a prioritized hazard and listed it on the "Top Ten Most Wanted" list since 1990. They have provided specific recommendations for revisions to current rest and duty time limitations as well as implementation of fatigue risk management systems. The FAA has engaged in substantial fatigue research to address NTSB concerns and transition science to the aviation industry (Avers, Banks, & Hauck, 2009; Rosekind, 2011).

Summary

Researchers have for many years reported the disruptive effects of fatigue on sleep, performance, circadian rhythms, social and family relations, and longer term health status (e.g., Avers et al., 2009; Della Rocco & Nesthus, 2005; Schroeder and Goulden, 1983). Accidents and incidents provide evidence of the real-life consequences of fatigue in the aviation industry. The following paper will summarize recent FAA research and development and describe how applied research is being transitioned into the aviation industry.

Table 2. Examples of accidents and NTSB's conclusions regarding fatigue causal factors

Date (month/year)	Flight	Location	Fatalities	Contributing Factors
06/99	American Airlines 1420	Little Rock, AR	11	Pilot awake for 31 hrs, First Officer on a 3-day, 6-leg sequence
10/04	Corporate Airlines 5966	Kirksville, MO	13	Circadian disruption, 6th flight segment
02/09	Colgan Air 3407	Buffalo, NY	50	Commuting and acute sleep loss

Note. NTSB = US National Transportation Safety Board.

FAA Fatigue Research & Development: A Review

> Since no serious person would dismiss potentially detrimental consequences of fatigue to aviation, continuing studies of fatigue are being conducted. Time changes, equipment changes, and responsible monitoring of altered conditions in relation to fatiguing factors is a "communal" requirement of those engaged in aviation. (Mohler, 1965)

This statement demonstrates the FAA's commitment to aviation fatigue research. This research began in 1963 and continues today at the FAA's Civil Aerospace Medical Institute (CAMI; see the Appendix for a selected list of FAA reports on fatigue in aviation) in collaboration with a number of research institutions. There have been some changes in the type of research over the years, moving from basic assessment to fatigue countermeasures and interventions. In the last 20 years, the FAA has diversified its efforts and examined the impact of fatigue across types of operations. Today's aviation fatigue research extends to air traffic controllers, technical operations personnel, pilots, flight attendants, and maintenance technicians.

Air Traffic Control/Air Traffic Management

Like flight crews, air traffic controllers also engage in 24/7 schedules. In 1990, the FAA's CAMI revived a program of research on shift work in the FAA's air traffic control (ATC) facilities. The program built upon several CAMI studies from the 1970s that had focused on shift work and stress. Research in the late 1990s sought to replicate and extend the early findings, to understand how shift work issues were manifested in the ATC / air traffic management (ATM) environment, and then target fatigue countermeasures to transition from the laboratory to the workforce (Della Rocco & Nesthus, 2005; Nesthus & Avers, 2009). In 1999, the US Congress directed CAMI to study the effects of current shift patterns and rotation practices on the air traffic control specialist (ATCS) workforce and to determine the relative effects of fatigue across operations (Nesthus & Avers, 2009). In response to this mandate and the formation of an FAA/NATCA Article 55 Workgroup, CAMI researchers developed a multiphase research program. The first phase involved a comprehensive survey of the ATCS workforce. The second phase involved a more in-depth follow-up field study using objective measures to validate survey findings. The third phase involved a controlled laboratory study to empirically and directly compare the counterclockwise, rapidly rotating, 2-2-1 schedule (two evening shifts, two day shifts, one midnight shift) with a clockwise rapid rotation schedule (two day shifts, two evening shifts, one midnight shift) recommended by the scientific literature (Della Rocco & Nesthus, 2005; Nesthus & Avers, 2009).

Since the resurgence of CAMI's ATC fatigue research, the body of evidence regarding ATCS schedules revealed the following disruptive influences:

(1) sleep loss occurred toward the end of the week on counterclockwise, rapidly rotating schedules as employees rotated into early morning and midnight shifts, although there was no difference with the literature-recommended clockwise rotating schedule;
(2) decrements in cognitive performance were primarily evidenced on the midnight shift, although additional changes were observed on the early morning shift;
(3) performance did not differ appreciably between the clockwise and counterclockwise 2-2-1 schedules;
(4) straight early morning shift schedules resulted in as much sleep loss as the counterclockwise, rapidly rotating shift schedule with a midnight shift;
(5) on surveys, over half of the participants reported at least some fatigue and shift work maladaptation; and
(6) circadian rhythms were disrupted, though rotating days off (RDOs) following the midnight shift recovery sleep helped realign rhythms.

Scheduling pattern data suggested that slow-rotating schedules resulted in worse outcomes than stable patterns, and that quick rotations were better than straight-5 schedules (working the same shift every day for 5 days) (Della Rocco & Nesthus, 2005).

In 2009, another series of studies began. The FAA collaborated with the National Aeronautics and Space Administration (NASA) to conduct a similar comprehensive field study and national survey to reevaluate the issue of fatigue in air traffic operations. The results of the most recent studies are not yet available, but a review of the previous data argues for fatigue countermeasures and scheduling manipulations, particularly on the midnight shift (e.g., Cruz, Boquet, Detwiler, & Nesthus, 2003; Cruz & Della Rocco, 1995; Cruz, Detwiler, Nesthus, & Boquet, 2003; Della Rocco, 1999; Della Rocco & Cruz, 1995; Della Rocco & Nesthus, 2005).

Airways Facilities Technical Operations

Technical operations (TechOps) personnel conduct safety-sensitive tasks and maintain and operate all the equipment used in air traffic control. This equipment includes complex automation, communication, navigation, weather, lighting, and surveillance devices, as well as the specialized facility environments that house them. They work variable 24/7 schedules that can include on-call and extended duty days. A cooperative FAA management and labor workgroup was formed in 2008 to assess the impact that fatigue might have on the TechOps workforce. Area and facility-specific shift schedules were identified as potential hazards that might contribute to a fatigued workforce. The initial workgroup included a CAMI scientist, five operations management personnel, and a union representative. That workgroup expanded to nearly 20 individuals with additional science representation and oversight by the Fatigue Risk Management Program Office within the Air Traffic Organization. To develop a baseline assessment of fatigue in technical operations, a major survey and field study,

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similar to that of the ATC research effort, was begun by researchers at the FAA William J. Hughes Technical Center. The workgroup also initiated research into operationally relevant fatigue countermeasures and is addressing five action items:
(1) assessing watch schedules with modeling tools,
(2) improving and incorporating fatigue-related incident reporting procedures,
(3) developing educational/training materials to raise fatigue awareness and provide countermeasure strategies,
(4) investigating the feasibility of integrating a fatigue risk management system, and
(5) appraising duty time regulations for possible adjustments (Nesthus & Avers, 2009).

This research is currently ongoing, and results are not yet available.

Pilots

The diversity of equipment and schedules that flight crews operate is immense. From small helicopters to 800-passenger airliners, flight crews transport approximately 500,000 international passengers every hour of the day. Given the complexity of schedules and continuously evolving technology, it is not surprising that pilot fatigue remains under the microscope of not only scientists but also of regulators. One recent flight-deck fatigue research initiative began in 2006, when a US carrier proposed to the FAA a city-pair flight operation exceeding 16 hours of flight time, now known as ultra-long-range (ULR) flight operations. Title 14 of the Code of Federal Regulations (CFR) Part 121 Flag Operation Regulations did not address flight times in excess of 16 hours. The FAA issued an operational specification (A332) that required carriers flying ULR flights to collect data and evaluate fatigue risk. The CAMI assisted the FAA's Air Transportation Division and the carrier in the evaluation of the first proposed ULR operation. The researchers designed a study to examine fatigue levels and mitigation strategies for the entire ULR operation (pre-duty, in-flight, layover, and return-to-base rest for both flight crew and cabin crew). The study examined crewing requirements, training, scheduling, maximum schedule deviations, sleep/rest facilities, and in-flight rest breaks. Data were collected for pilots on six trips and for cabin crew on four trips. Both objective and subjective measures were used to assess sleep duration, sleep quality, performance, fatigue symptoms, and mood. Using the sleep, activity, task effectiveness (SAFTE) model and Fatigue Avoidance Scheduling Tool (FAST) (Hursh et al., 2004), the analysis revealed that onboard and layover sleep patterns impacted sleep duration/quality and subjective reports. The trends indicated that elevated fatigue and diminished cognitive alertness were associated with decrements in Psychomotor Vigilance Test (PVT) performance (Lamond, Dawson, & Roach, 2005; Thorne et al., 2005) and FAST™ effectiveness predictions. The results indicated that pilots flying the proposed ULR schedule were not excessively fatigued with countermeasures in place for extended layovers, on-board sleep opportunities, on-board duty rotations, etc. Cabin crew did not receive equivalent countermeasures, and the results indicated they did experience excessive fatigue. Scheduling changes were made to cabin crew schedules to optimize alertness and minimize fatigue. This study revealed the strategic role that data collection and scientific modeling tools can have in developing crew schedules to optimize alertness and minimize fatigue flight operations not covered under existing regulations (Nesthus, 2011; Nesthus & Avers, 2009).

Cabin Crew

Cabin crew/flight attendants perform a number of preflight, during-flight, and postflight checks to ensure passenger safety. The regulations are less restrictive for flight attendants, and as a result they work more extreme schedules than pilots (Nesthus et al., 2007). Flight attendants are sensitive to extended schedules, time zone changes, night schedules, and on-demand calls. In 2005, Congress directed CAMI to investigate fatigue in cabin crew operations. CAMI teamed with the NASA Ames Research Center's Fatigue Countermeasure Group to conduct a preliminary study of fatigue and found that flight attendant fatigue was a salient issue that warranted further evaluation. The findings of that study (Nesthus, Schroeder, Connors, Rentmeister-Bryant, & DeRoshia, 2007) led to a series of congressionally mandated follow-on studies in 2008, including a survey of field operations, a field study on the effects of fatigue, validation of models for assessing fatigue, a focused study of incident reports, a review of international policies and practices, and a review of the benefits of training for fatigue risk management. On average, flight attendants reported sleeping 5.7 hours per night on workdays (Roma, Mallis, Hursh, Mead, & Nesthus, 2010). Flight attendants often worked in a fatigued state. These fatigue levels are influenced by type of operation, duty duration, continuous-duty overnights, reserve practices, reduced rest, lack of breaks, restricted rest periods, and duty report times (Avers et al., 2009; Roma et al., 2010). Some of the key conclusions resulting from these studies indicated that the industry needs to:
(1) identify ways to improve schedules from a science-based approach to maximize alertness and minimize fatigue while meeting operational and economic constraints of the industry;
(2) develop an adaptive fatigue mitigation safety system such as a fatigue risk management system (FRMS) that combines scientific principles and knowledge with operational support and constraints;
(3) apply scientific modeling tools to maximize alertness and minimize fatigue while meeting operational and economic constraints;
(4) develop and administer a comprehensive, science-based fatigue countermeasure training program; and
(5) establish a flight attendant fatigue workgroup of subject matter experts, aviation stakeholders, medical and research scientists, and aviation safety

management system (SMS) experts to evaluate 14 CFR sections 121.467 and 135.273 for possible revision (Avers, Hauck, Blackwell, & Nesthus, 2009; Avers, King, Nesthus, Thomas, & Banks, 2009; Banks, Avers, Nesthus, & Hauck, 2009; Holcomb et al., 2009; Nesthus et al., 2007; Roma et al., 2010).

Maintenance and Engineering

Maintenance technicians/engineers work 24/7 schedules with a substantial amount of work occurring on the midnight shift. In the late 1990s and early 2000s, the FAA conducted a series of studies examining the physical work conditions and operational schedules of aviation maintenance technicians (Hall, Johnson, & Watson, 2001; Johnson, Hall, & Watson, 2002; Johnson, Mason, Hall, & Watson, 2001; Sian & Watson, 1999). Researchers collected more than 50,000 hours of actigraph data in two field studies. The results revealed that the average daily sleep duration for maintenance personnel was 5 hours and 5 minutes.

In the late 2000s, a series of human factor surveys were administered to examine the issue of fatigue management and education in domestic and international operations. An international survey of human factors issues revealed that fatigue is a major challenge in the maintenance workforce, but few organizations had a fatigue management system (24.9%) or provided training on fatigue management (35.9%) (Hackworth et al., 2007). A subsequent survey of FAA aviation safety inspectors (ASIs) indicated that nearly 40% of ASIs believed that fatigue is a safety issue for the operators that they oversee. This position was reinforced by the fact that 48% responded that their operators do not have policies that address fatigue, and further, 22% of ASIs did not know if they had fatigue policies. When asked about fatigue management training, 51% of ASIs responded that their operators do not provide fatigue awareness training (Johnson & Hackworth, 2008).

A recent report (Hobbs, Avers, & Hiles, 2011) examined international best practices in fatigue risk management for aviation maintenance and focused on researching and identifying interventions associated with scheduling, policies and practices, education, organizational strategies, raising awareness, healthy sleep, vehicle and environmental strategies, and research and evaluation. The results of these reports clearly identified the need to transition basic scientific knowledge into aviation maintenance operations in the form of a FRMS.

Summary

The basic underlying factors that contribute to fatigue remain consistent across transportation modes and present a significant challenge in aviation. The basic scientific research has established a solid understanding of fatigue. Since fatigue is a hazard in 24/7 operations, employees and their work are at risk if they are subjected to extended duty days, night shifts, rotating shifts, or sleep restrictions. The recent FAA research has clearly demonstrated that these conditions exist, and there are countermeasures that can be used to manage fatigue risk (e.g., Caldwell, 1997; Caldwell, 2005; Johnson, 2011a; Nesthus & Avers, 2009; Rosekind, 2011).

Transitioning Science to Industry

To fully capitalize on the available fatigue research, there must be a transition of basic sleep science to applied applications for industry. Industry leaders must be willing to change the status quo, and scientists must be willing to speak in plain language and recognize the utility of a partial solution for industry (Avers, 2011b; Johnson, 2011b). However, the transition from sleep laboratories to operational aviation applications requires joint responsibility among industry leaders, individual workers, scientists, and international aviation authorities (see Figure 1) (Rosekind, Neri, & Dinges, 1997). A number of strategies are being pursued to facilitate the practical application of scientific findings. Worldwide the aviation industry has taken a slightly different approach to fatigue risk management and has progressed at different rates.

Industry Involvement

Across research programs, one strategy has consistently emerged. Industry involvement is critical to successfully apply research and implement findings. The research involving pilots, air traffic controllers, technical operations personnel, flight attendants, and maintenance technicians all involved company leaders, labor leaders, scientists, and

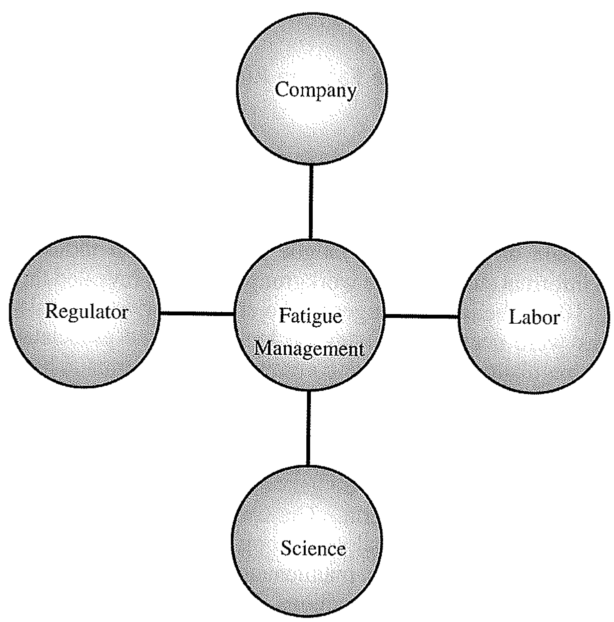

Figure 1. Shared responsibility for fatigue management in aviation.

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regulators in study design, data collection, implementation of findings, and development of products. Some success stories include the air traffic control Article 55 Workgroup, the Aviation Maintenance Fatigue Risk Management Group, and the Pilot Rulemaking Group.

Article 55 Workgroup

In 1999, the first Article 55 Workgroup was established with members from FAA headquarters, field managers, union leaders, supervisor committee members, and CAMI scientists. The workgroup was established to identify key shiftwork issues in air traffic control and develop recommendations for countermeasures to reduce the risk of fatigue-related problems. The workgroup recommended the use of fatigue countermeasure education, controlled rest as a fatigue countermeasure, and schedule evaluation and adaptation to reduce fatigue risk (Della Rocco & Nesthus, 2005). The first Article 55 recommendations were not implemented. A subsequent workgroup was established in 2009. The second Article 55 Workgroup was established to identify and mitigate workplace fatigue concerns, develop recommendations to mitigate fatigue in the workplace, and establish a FRMS. The fatigue recommendations are based on available scientific literature. Some of the recommendations include designing and implementing an FRMS; providing schedule adjustments for minimum hours between evening and day shifts; developing policy and education for employees; using scheduling optimization for fatigue risk management, fatigue countermeasures education, and effective use of relief periods. A Memorandum of Understanding (MOU) has been established for some of these recommendations, and further ad hoc workgroup activities are underway toward implementation (Gimbrere, 2011; Huss, 2010; "Memorandum of Understanding," 2009; Nesthus, 2011).

Aviation Maintenance Fatigue Risk Management Workgroup

In 2009, CAMI scientists invited 25 individuals to be part of a multidisciplinary workgroup that would develop integrated, scientifically based, practical solutions to address the issue of maintenance fatigue in the aviation industry. An informal survey of the workgroup members revealed that all (100%) believed changes in the current duty/rest regulations were necessary. Given the length of time associated with regulatory change, the committee voted to pursue both short-term and long-term solutions. The committee members worked together to develop a number of science-based, fatigue risk management tools to improve fatigue risk assessment, incident investigation, scheduling decisions, awareness, and education. The workgroup is currently developing an operational guidebook on how to implement a FRMS in the aviation maintenance industry. The handbook provides both instructions for implementation and the tools necessary for a successful fatigue risk management program. The workgroup has focused on research and development of interventions associated with scheduling, policies and practices, education, organizational strategies, raising awareness, healthy sleep, vehicle and environmental strategies, and research and evaluation (Avers, 2011b; Avers, Johnson, Banks, & Nei, 2011; Johnson, 2011a, 2011b).

Pilot Flight/Duty/Rest Rulemaking

In 2009, an aviation rulemaking committee (ARC) was established to review existing flight, rest, and duty time limitations. The ARC involved scientists, regulators, pilots, labor leaders, and airline management and was commissioned to discuss current approaches to mitigating fatigue and develop practical, science-based recommendations for regulatory change. The efforts of the ARC contributed to the publication of Public Law (PL) 111-216, 212 (b) which requires the FAA to specify limitations on the hours of flight and duty time allowed for pilots, to address problems relating to fatigue (Nesthus & Mallis, 2011).

Rulemaking

Rulemaking efforts have been considered by each mode of operation and remain on the horizon for most. The pilot community has seen the most traction in rulemaking, and the FAA has recently released AC 120-103 with guidance on how to develop and implement a fatigue management plan, as a supplement to PL 111-216, 212 (b). The current law directs the FAA to issue new regulations specifying flight/duty time limitations and rest requirements and to consider other factors affecting pilot alertness, including time of day, number of takeoffs and landings, multiple time zone crossings, and the effects of commuting. Under the rule, an FRMS can be implemented as a means of monitoring and mitigating fatigue for operators that wish to run operations outside of the standard flight/duty time limits. For the deviation to be approved, the operator must demonstrate that it is equivalently safe to the regulated flight/duty time limits. Existing research has provided critical evidence and justification for the current rulemaking efforts, but the regulatory process has been expedited by US congressional demand for revised pilot hours rules after the 2009 Colgan Airlines Flight 3407 accident in New York State where pilot fatigue was believed to be a contributing factor (NTSB, AAR-10-01, 2010) Accidents and other high-visibility events seem to be the impetus for transitioning science to the workplace in the form of regulations (Johnson, 2011a; Nesthus, 2011).

Workshops

Some aviation modes have elected to use workshops as forums to enhance public awareness of fatigue, identify challenges, develop solutions, and educate the industry. In 2010 and 2011, this approach went international and was pursued by the FAA Office of Chief Scientific Advisors, the Civil Aerospace Medical Institute, and the European Human Factors Advisory Group (see, e.g., Avers et al., 2011; Johnson, 2011b).

In maintenance operations, groups from both North America and Europe conducted workshops to prioritize human factor challenges and solutions. The groups operated independently but generated similar results. Both workshops identified the issue of fatigue risk management as one of the top five human factor challenges (Avers et al., 2011; Johnson, 2011b). In 2011, another workshop prioritized fatigue challenges and created a list of industry action items. The workshop had the expressed goal to identify specific actions to transition fatigue science to the workplace. The prioritized solutions for fatigue challenges included the following:

(1) increase the promotion of fatigue risk management,
(2) deliver fatigue education,
(3) implement hours of service limits,
(4) require fatigue risk management programs,
(5) apply fatigue assessment tools,
(6) assess and cultivate a fatigue-sensitive culture,
(7) measure fatigue return-on-investment, and
(8) integrate fatigue into safety management systems (Johnson, 2011a).

In cabin crew operations, scientists used existing cabin safety workshops as a forum for fatigue awareness and education. Since 2010, CAMI scientists have hosted approximately 10 mini-workshops for flight attendant trainers to increase their awareness of fatigue hazards and the fatigue countermeasures that can be applied to proactively and reactively reduce fatigue risk while at home and at work. The workshops were based on guidance from CAMI fatigue countermeasure training research (Avers et al., 2009) and have received positive reviews from attendees.

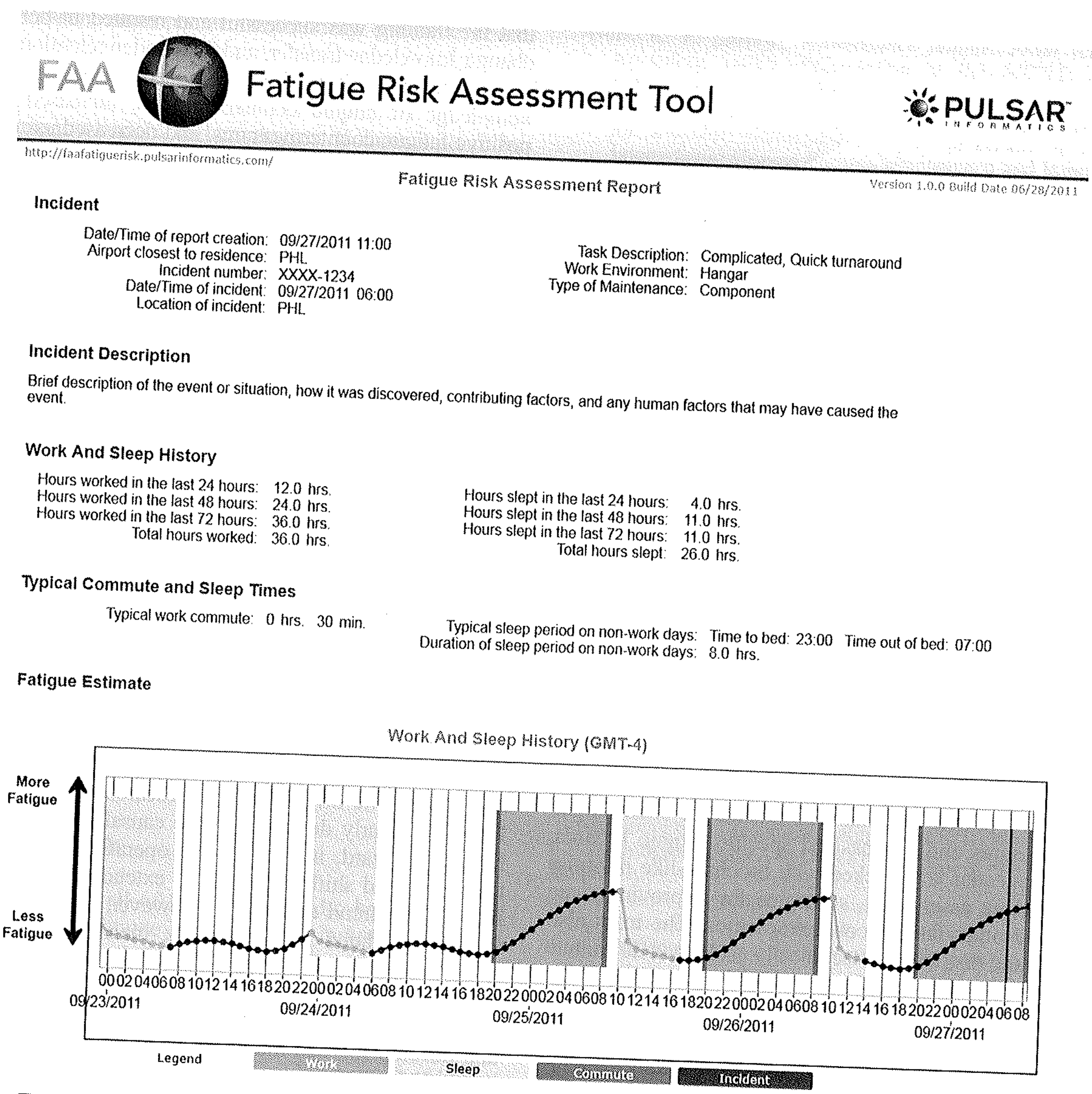

Figure 2. Example output for automated fatigue risk assessment tool.

Products

Scheduling

Fatigue models simulate the physiological conditions that affect performance and alertness (homeostasis and circadian rhythm). Using these models, researchers have developed scheduling tools to estimate performance declines and provide an estimate of schedule-induced fatigue risk. These tools can be used proactively to predict future risk and postanalytically in accident investigations to analyze whether fatigue was a potential contributor.

In maintenance operations, the FAA has teamed with Pulsar Informatics, Inc., to develop a science-based but easy-to-use scheduling tool for predictive and postanalytic fatigue assessments. The basic version of the tool is currently being beta tested and is available as freeware for mechanics and accident investigators to assess fatigue risk. See Figure 2 for the fatigue risk assessment output (Avers, 2011a; Johnson, 2011a).

Incident Forms

To obtain a true baseline of fatigue accidents and incidents, fatigue reporting must be improved. Past tools have asked one fatigue-related question on the form: "Fatigued, yes or no?" Available research demonstrates that people are poor assessors of their own fatigue levels (e.g., Roma et al., 2010). The questions asked following an incident must be objective. Across modes, efforts have been made to improve the documentation of incidents and the assessment of fatigue as a contributing factor. The new forms include, but are not limited to, time of incident, time zones, sleep history, and work history. This data can be used in combination with a fatigue model to estimate fatigue risk and the likelihood it was a contributing factor to the incident (Johnson & Avers, 2010; Nesthus, 2011).

Fatigue Awareness

Fatigue awareness is one of the most basic but necessary short-term solutions for fatigue risk management. The maintenance fatigue working group developed a series of fatigue-awareness tools that could be adopted immediately to inform the workforce, including posters and a fatigue risk management toolbox pocket calendar. The posters included fatigue countermeasures and emphasized specific fatigue hazards. A pocket calendar was packed with brochure-like information on fatigue assessment, strategies for improving sleep quality, and other fatigue countermeasures. The team also developed and distributed a technically acclaimed 20-minute education video titled *Grounded* (see www.mxfatigue.com). Teaming with the FAA safety team, more than 150,000 aviation industry personnel have been exposed to information on fatigue hazards and potential mitigation strategies. Today, these awareness materials are being adopted on other continents and in other industries (Avers et al., 2011).

Education Programs

The development of fatigue education programs has pursued multiple aviation modes, including maintenance, air traffic, and flight attendants. The FAA's research studies have resulted in the development of targeted education programs. More than 23,000 air traffic controllers have received an educational CD titled *Shiftwork Coping Strategies* (Della Rocco & Nesthus, 2005). This CD was also revised and distributed to address the educational needs of the TechOps workforce. The FAA safety team is currently requiring all aviation maintenance technicians involved in the Aviation Maintenance Technician (AMT) awards program to complete a core course on fatigue countermeasures. To date, more than 9,000 technicians have completed the course, at a rate of 1,000 per month during 2011. CAMI continues to receive requests for fatigue education materials and has shared more than 5,000 copies of the fatigue countermeasure workshop for maintainers and flight attendants (Avers, 2011a; Avers, Johnson, & Hauck, 2010). Recent study findings indicate that the training was successful and resulted in behavioral change, knowledge transfer, and knowledge retention. Training participants show improved sleep times, improved knowledge of fatigue countermeasures, increased use of positive fatigue countermeasures, and decreased use of negative fatigue countermeasures (Banks & Avers, 2011).

Fatigue Assessment

Real-time fatigue assessment continues to be a challenge in operational work environments. Although no assessment is better than a physiological test, the maintenance fatigue workgroup has developed a list of indicators to help individuals identify when they are fatigued or when someone they work with is fatigued. Although the strategy is not foolproof, it provides some simple, observable guidelines framed in terms of behavioral symptoms of fatigue. The symptom checklist is currently available online at www.mxfatigue.com. Additional tools available on the website include a sleep diary and answers to frequently asked questions.

Conclusions

The disruptive effect of fatigue on personnel and the safety of aviation operations is well-established across modes of operations. The original fatigue research conducted by the FAA has clearly documented the causal factors that make fatigue a hazard, including 24/7 operations, early reports, time zone and shift changes, and extended duty days. The more recent trend of research, however, is directed toward fatigue mitigation or fatigue risk management strategies. Even though there may be some differences across operations, there are many similarities. The evidence demonstrates that all aviation modes should focus on research and develop focused interventions associated with scheduling, policies and practices, education, organizational strategies, raising awareness, healthy sleep, vehicle driving and environmental strategies, and research and evaluation. When possible, each mode should capitalize and build on existing research and best practices learned across the industry. As the FAA continues to conduct fatigue research, it is important to consider the next step in transitioning critical results to the industry. The available FAA R&D, which has been described here, will serve as the foundation for transferring scientific findings into real-world applications.

The transition from science to applied operations has progressed slowly in the aviation industry over the last 50 years. However, in the last 10 years, there has been substantial progress on multiple fronts. Fatigue countermeasure training is freely available, guidance on fatigue risk management systems is published, tools for fatigue assessment and investigation are accessible, current duty rest regulations are under review, and rules regarding FRMSs are being published.

Limitations/Challenges

Despite recent attempts at transitioning scientific results to the industry, there remain some challenges to fatigue risk management. Most notably, the effective transition of scientific results requires active commitment from regulators, company leaders, and employees. If there is no collective will to proceed with such programs, it will continue to be very challenging to transition scientific knowledge into practical operations (Johnson, 2011a).

It is difficult to develop a collective will if the problem is undefined in terms of personal and operational consequences. Currently, investigators of accidents and events are ill-equipped to determine if fatigue is a contributing factor. Fatigue is rarely listed as the cause of an event or an accident. This indicates that companies, individuals, and regulators may not fully understand the threat that fatigue poses to safety. Since we know that fatigue is the result of biological processes and affects everyone, we must, as an industry, improve root cause analysis and documentation of fatigue as a contributor to accidents or events (Avers et al., 2011).

Additional factors continue to influence fatigue research and the transition into the workplace. These factors include economic concerns, political climate, executive commitment, and fitness for duty, among others. None of these should stop the international aviation industry from taking the necessary action to address the threat of fatigued aviation workers. We must continue the commitment to move forward together in a cooperative and collaborative manner to improve aviation safety.

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Original Article

Appendix

Selected list of FAA sponsored publications on fatigue in aviation

Publication date	Title	Authors
1963	*A Central Factor in Pure Tone Auditory Fatigue*	Wernick et al.
1965	*Auditory Fatigue: Influence of Mental Factors*	Capps et al.
1965	*Effects of Several Mental Tasks on Auditory Fatigue*	Collins et al.
1965	*Fatigue in Aviation Activities*	Mohler
1965	*Pilot Fatigue: Intercontinental Jet Flight: OKC–Tokyo*	Hauty et al.
1966	*Physiological Stress and Fatigue in Aerial Missions for the Control of Forest Fires*	Balke et al.
1966	*Fatigue and Stress Studies*	Fiorica
1968	*Physiological Effects on Air Tanker Pilots Flying Forest Fire Retardant Missions*	Melton et al.
1978	*Cardiorespiratory Assessment of Decongestant-Antihistamine Effects on Altitude, +Gz and Fatigue Tolerances*	Lategola et al.
1981	*Cardiorespiratory Assessment of 24-Hour Crash-Diet Effects on Altitude, +Gz and Fatigue Tolerances*	Lategola et al.
1981	*Fatigue in Flight Inspection Field Office (FIFO) Flight Crews*	Melton et al.
1982	*Effects of Prior Physical Exertion on Tolerance to Hypoxia, Orthostatic Stress, and Physical Fatigue*	Lategola et al.
1982	*Effects of Physical Fatigue and Altitude on Physiological, Biochemical, and Performance Responses*	Higgins et al.
1994	*Blink Rate as a Measure of Fatigue: A Review*	*Stern et al*
1995	*Effect of Alcohol and Fatigue on an FAA Readiness-to-Perform Test*	NTI, Inc. (T. Nesthus, COTR)
1995	*Shift Work, Age, and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities. Part I: The sleep/wake cycle*	Della Rocco et al.
1999	*The Role of Shift Work and Fatigue on Air Traffic Control Operational Errors and Incidents*	Della Rocco et al.
1999	*Study of Fatigue Factors Affecting Human Performance in Aviation Maintenance*	Sian et al.
2001	*Fatigue Modeling*	Nesthus
2001	*Evaluation of Aviation Maintenance Working Environments, Fatigue, and Human Performance*	Johnson et al.
2001	Ocular Correlates of Fatigue	Nesthus et al.
2002	*A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules. Part III: Effects on Core Body Temperature and Neuroendocrine Measures*	Boquet et al.
2003	Neuroimaging Sleep Debt With fMRI in Short- and Long-Sleepers	Carr et al.
2003	Clockwise and Counterclockwise Rotating Shifts: Effects on Sleep Duration, Timing, and Quality	Cruz et al.
2003	Clockwise and Counterclockwise Rotating Shifts: Effects on Vigilance and Performance	Cruz et al.
2004	Clockwise and Counterclockwise Rotating Shifts: Effects on Temperature and Neuroendocrine Measures	Boquet et al.
2007	Predicting Fatigue Using Voice Analysis	Greely et al.
2007, July	*Flight Attendant Fatigue*	Nesthus et al.
2009	*Flight Attendant Fatigue. Part VI: Fatigue Countermeasure Training and Potential Benefits*	Avers et al.
2009	*Flight Attendant Fatigue. Part V: A Comparative Study of International Flight Attendant Fatigue Regulations and Collective Bargaining Agreements*	Banks et al.
2009	*Flight Attendant Fatigue. Part I: National Duty, Rest, and Fatigue Survey*	Avers et al.
2009	*Flight Attendant Fatigue. Part IV: Analysis of Incident Reports*	Holcomb et al.
2010	*Flight Attendant Fatigue Recommendation II: Flight Attendant Work/Rest Patterns, Alertness, and Performance Assessment*	Roma et al.
2011	*Fatigue Risk Management in Aviation Maintenance: Current Best Practices and Potential Future Countermeasures*	Hobbs et al.