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Advisory Circular

Subject: Maintainer Fatigue Risk Management

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1 **PURPOSE.** This advisory circular (AC):

1. Describes the basic concepts of human fatigue and how it relates to safety for aviation maintenance organizations and individual maintainers.
2. Provides information on Fatigue Risk Management (FRM) in terms of fatigue hazards and mitigation strategies specific to aviation maintainers.
3. Describes the benefits of implementing FRM methods within aviation maintenance organizations.
4. Identifies methods for integrating FRM within a Safety Management System (SMS) (if applicable).

Note: This AC is informational and is not mandatory. It does not constitute a regulation.

2 **RELATED READING MATERIAL.** Additional information about this topic can be found in the current editions of the following documents:

- AC 117-2, Fatigue Education and Awareness Training Program.
- AC 117-3, Fitness for Duty.
- AC 120-100, Basics of Aviation Fatigue.
- AC 120-103, Fatigue Risk Management Systems for Aviation Safety.
- The Federal Aviation Administration (FAA) Maintenance Fatigue Web site, www.mxfatigue.com.
- International Civil Aviation Organization (ICAO). Fatigue Risk Management Systems: Implementation Guide for Operators. 2011.
- Avers, K., and W.B. Johnson. "Applying Fundamental Sleep Science to the Aviation Workplace: A Review of FAA Fatigue Research." *The Journal of Aviation Psychology and Applied Human Factors*. Winter, 2012.
- Hobbs, A., K.B. Avers, J.J. Hiles. Fatigue Risk Management in Aviation Maintenance: Current Best Practices and Potential Future Countermeasures. Technical Report DOT/FAA/AM-11/10. Washington, D.C.: Federal Aviation Administration, Office of Aerospace Medicine, 2011.

Note: This document summarizes and does not reproduce the scientific references in the documents listed above. This list is not all-inclusive.

3 BACKGROUND. We are a nation of sleep-deprived workers. It is estimated that adults attempt to function on 1 to 1.5 hours less sleep than the generally recommended 8 hours per night. Human fatigue costs U.S. businesses over $136 billion in lost productivity each year. The losses do not include cost estimates associated with workplace injury, insurance claims, or rework. Of concern to Aviation Safety (AVS) is the finding that maintenance personnel tend to get 3 hours less sleep per night than is recommended. That is a sleep debt twice the national average. Sleepiness and fatigue associated with sleep debt is cumulative. This means that losing even an hour of sleep every other night over the course of a week will produce conditions that negatively affect performance. Some of the most critical performance errors associated with worker fatigue include, but are not limited to:

- Impaired judgment and decision making;
- Impaired communication skills;
- Decreased attention span and ability to recall information;
- Irritability;
- Slower reaction times; and
- Increased risk-taking.

3.1 Critical Issue. Personnel fatigue was first identified as a critical issue in aviation maintenance by the National Transportation Safety Board (NTSB) in 1996, stemming from the ValuJet accident in Florida. Since then, it continued to gain attention as a maintenance safety risk:

1. In 2000, an FAA field study that collected 50,000 hours of ActiGraph data from maintenance personnel across multiple organizations found that maintainers were typically getting about 5 hours of sleep;
2. In 2006, an FAA survey of international human factors (HF) programs in maintenance organizations revealed that over 80 percent of those responding indicated that human fatigue was an issue;
3. In 2008, an FAA conference on human fatigue revealed that scientists, regulators, company management, and labor representatives all agreed that human fatigue poses a safety hazard in the aviation maintenance industry and that individuals, and government and civilian organizations, need to take appropriate action; and
4. In 2010, the FAA Administrator publicly committed to review all aspects of FAA regulations that address human fatigue.

4 INTRODUCTION. The importance of managing human fatigue risk in the aviation maintenance industry cannot be overemphasized. This AC will provide maintenance organizations and the individual maintainer with the information necessary to detect fatigue symptoms, to identify fatigue hazards, to assess the associated safety and health risks, and to implement fatigue countermeasures. It will provide the necessary information to determine acceptable approaches/tools for mitigating fatigue-related risks and to create science-based business practices for managing fatigue risks.

4.1 Causes of Human Fatigue. The causes of fatigue in aviation maintenance are shared by the employer and by the individual maintainer. Causes of fatigue can be categorized related to the most responsible entity.

4.1.1 Factors primarily under the control of the individual maintainer may include:

1. Amount of sleep in previous 72 hours;
2. Quality of sleep;
3. Continuous hours awake;
4. Emotional, physical, or medical issues that interfere with restorative sleep (i.e., sleep quality); and
5. Underutilizing and overlooking the importance of sleep opportunities.

4.1.2 Factors primarily under the control of the employer may include:

1. The start time and duration of the shift;
2. Work and work/life schedule changes;
3. Sub-optimal rotation of shift schedules;
4. Not having a routine work schedule;
5. Work schedules that overlap with time periods when the body is biologically programmed to sleep (known as circadian rhythm);
6. Working too long at the same task; and
7. Working under suboptimal conditions, such as low staffing levels, insufficient breaks, poor lighting, noise, extreme temperatures, and so on.

4.2 Fatigue Hazards. Human fatigue is a safety hazard in performing any and all maintenance tasks because, at a minimum, it can impair judgment, make it difficult to get and stay focused, cause forgetfulness, affect mood, and reduce motivation. Fatigue hazards not only affect the safety of the flying public, but also pose risks to the safety and health of the maintainer, the maintenance organization, and the industry as a whole.

4.2.1 <u>Safety Risk</u>. Fatigue affects worker safety on and off the job. Fatigue in the workplace can be a serious safety hazard and is repeatedly linked to errors that lead to incidents and accidents.

- The relative risk of work-related injuries increases approximately 15 percent on afternoon shifts and 28 percent on night shifts, as compared to morning shifts.
- A large U.S. air carrier found that injury risk increases dramatically after a worker has been on the job for 8 hours. Workers on a 12-hour shift had more than double the risk of suffering an injury than workers on an 8-hour shift. Workers on a 16-hour shift had more than 4 times the risk of suffering an injury than workers on an 8-hour shift.
- The NTSB estimates that fatigue causes at least 100,000 crashes, 40,000 injuries, and 1,550 deaths on U.S. roadways per year.

4.2.2 Health Risk. Fatigue is related to increases in health issues, doctor visits, use of sick leave, impaired driving, and difficulty dealing with home and social life. Health issues include, but are not limited to:

- Heart disease and high blood pressure;
- Depression, anxiety, and stress;
- Gastrointestinal disorders (peptic ulcers, indigestion, heartburn, flatulence, upset stomach, or constipation);
- Overeating;
- Higher alcohol and drug use; and
- A lower sense of overall well-being.

4.3 **Duty-Time Limitations.** Historically, the FAA has managed fatigue in aviation maintenance with personnel duty-time limitations. Title 14 of the Code of Federal Regulations (14 CFR) part 121, § 121.377 states that, "Within the United States, each certificate holder (or person performing maintenance or preventive maintenance functions for it) shall relieve each person performing maintenance or preventive maintenance from duty for a period of at least 24 consecutive hours during any seven consecutive days, or the equivalent thereof within any one calendar month." Eventually, an enhanced application of fatigue modelling with use of wearable technologies (e.g., Fitbit devices) will help workers and employers assess fatigue risk and adjust schedules accordingly. SMS and Fatigue Risk Management Systems (FRMS) will help ensure that schedules need not be based on "one-size-fits-all" duty-time limitations.

4.3.1 Scientific Evidence. Scientific evidence indicates that duty time interacts with sleep loss, time of day, time since last sleep, time on task, environmental conditions, type of work schedule, schedule rotation/changes, and other causes of fatigue, and that each should be considered when developing work schedules. An effective approach to managing fatigue risk should take the same data/information into consideration, regardless of the size of the operation.

4.4 **FRM.** Conceptually, FRM serves to help make informed decisions regarding how to identify, mitigate, and prevent fatigue-related risk. In practice, FRM, be it a plan, policy, program, or system, contains the processes/procedures (i.e., reactive, proactive, and predictive) used for purposes of maximizing personnel alertness. FRM also minimizes fatigue-related performance errors that create safety hazards and risk for the maintainer, team/crew members, the public, and aircraft/equipment.

4.4.1 Promotion of FRM Techniques. Along with the FAA, the ICAO, the European Aviation Safety Agency (EASA), Transport Canada (TC), the Civil Aviation Safety Authority of Australia, and worldwide agencies in the aviation, road, and rail transport industries have been promoting, and in some cases requiring, use of FRM techniques. Most notably, Public Law (PL) 111-216, Airline Safety and Federal Aviation Administration Extension Act of 2010, Section 212(b), established a requirement for part 121 air carriers to develop, implement, and maintain a Fatigue Risk Management Plan (FRMP) for the air carrier's pilots that is acceptable to the Administrator.

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

- Fewer on-the-job accidents and injuries;
- Fewer physical illnesses;
- Reduced absenteeism;
- Reduced turnover;
- Reduced morale problems;
- Reduced insurance claims and premiums;
- Reduced damage to equipment and aircraft;
- Increased average sleep time and sleep quality; and
- An improved quality of life.

4.4.3 SMS. FRM should be part of an SMS. The integration provides a comprehensive approach in identifying hazards and managing risks that extends beyond regulatory compliance. Below are underlying principles of effective FRM as it applies to an SMS:

1. It requires a systemic approach involving, at a minimum, company policies; incident reporting and analysis systems; and reactive, proactive, and predictive risk assessment that define responsibilities, authority, input, procedures and processes, and outputs, which are basic elements of safety management.
2. It requires a partnership between the employer and the employee, as each can contribute uniquely to solutions.
3. It identifies an organization's hazards related to worker fatigue. Thus, requirements of an effective SMS minimize the need for additional fatigue-specific regulations.

4. It ensures that the hazards and any associated risks are identified and mitigated, and that the level of risk is continuously monitored. Thus, risks are as low as reasonably practical, as it is unrealistic to aim for "zero fatigue."

5 DEFINITIONS.

5.1 Acute Fatigue. Acute fatigue is a somewhat sudden onset of physical or mental exhaustion. It is closely related to recent sleep (last 24 hours), time since last sleep, and current time of day. Less than 8 hours of sleep in the last 24 hours, being awake longer than 17 hours, and working between midnight and 6:00 a.m. are associated with acute fatigue in the average person.

5.2 Biomarkers. Biomarkers are characteristic biological properties that can be detected and measured in the body, such as in the blood or tissue. Biomarkers may indicate either normal, abnormal, or diseased processes in the body. Currently, there are no easily obtainable biomarkers of fatigue. However, several biomarkers of the circadian rhythm exist, such as core body temperature and melatonin levels. In the absence of biomarkers to identify fatigue, we can directly measure fatigue effects in performance variables, or indirectly by using measures of sleep and time of day, and by modeling the effects of these conditions on performance.

5.3 Chronic Fatigue. The average adult needs about 8 hours of sleep per day. If the average person gets less than the required amount of sleep each day for multiple days, then a state of chronic fatigue can occur. With chronic fatigue, performance is degraded and recovery tends to be relatively slow. A person can hasten recovery by attempting to sleep longer than the normal amount for several days. Chronic fatigue is often the result of a physical condition or psychological condition.

5.4 Circadian Rhythm. The body's internal clock, the circadian rhythm, tells your body when to be awake and when to go to sleep. The circadian rhythm is closely aligned with day and night and is sensitive to light exposure. Humans are preprogrammed to be awake when it is light and sleep when it is dark. Twice during the day, the body slows down. It happens mid- to late afternoon, between 3:00 p.m. and 5:00 p.m., so expect to experience drowsiness during the lull. If one is awake after midnight and into the early morning hours between 2:00 a.m. and 6:00 a.m., which is counter to the body's natural rhythm, then one should also expect to experience drowsiness.

5.5 Fatigue. Fatigue refers to a physiological state in which there is a decreased capacity to perform cognitive tasks and an increased variability in performance as a function of time on task. Fatigue is also associated with tiredness, weakness, lack of energy, lethargy, depression, lack of motivation, and sleepiness.

5.6 Fatigue Risk Management (FRM). A management program used to mitigate the effects of fatigue.

5.7 Fatigue Risk Management System (FRMS). A nonprescriptive fatigue mitigation system that minimizes the acute and chronic sources of fatigue.

5.8 Safety Management System (SMS). An SMS is a structured management system to control risk in operations. It is an integrated network of people and other resources performing activities that accomplish the safety mission and reach safety goals in the aviation environment. Management of the system's activities involves planning, organizing, directing, and controlling assets to meet the organization's safety goals. The safety management process starts with design, and implementing organizational processes and procedures to control risk in aviation operations. Once controls are in place, quality management techniques can be used to provide a structured process for ensuring that the controls achieve their intended objectives, and to improve them where they fall short. SMS relies on reliable and valid organizational data that fosters decision making based on risk assessment (i.e., Risk-Based Decision Making).

5.9 Window of Circadian Low (WOCL). Individuals living on a regular 24-hour routine with sleep at night have two periods of maximum sleepiness. These are known as WOCLs. One WOCL occurs at night, roughly from 2:00 a.m. to 6:00 a.m., a time when physiological sleepiness is greatest and performance capabilities are lowest. The other WOCL is in the afternoon, roughly from 3:00 p.m. to 5:00 p.m., and is less severe than the nighttime WOCL.

6 FATIGUE BASICS. Complex around-the-clock aviation maintenance operations heighten the challenge of fatigue among maintainers. Incident/event reports from maintainers reveal that fatigue is a clear concern. The value of understanding fatigue basics in regard to personal and flight safety cannot be overemphasized. There is evidence that, more often than not, individually we are unaware when we start showing signs of fatigue and unaware of the extent to which fatigue has impaired our performance. This makes it very important that members of the maintenance workforce are able to recognize signs of personal and others' fatigue as soon as possible. Understanding the fundamentals of fatigue and how it affects job performance, decision making, and life in general will improve the ability to identify and manage associated safety risks.

6.1 Warning Signs of Fatigue. Be familiar with the following common symptoms of fatigue that could put individuals, co-workers, and the public at risk (Rosekind et al., 1996) listed in Figure 1, Signs of Fatigue, below. These are observable indicators of fatigue. Some signs are more noticeable than others, such as yawning, slowed reactions, and limited communication versus lack of concentration, forgetfulness, and irritability. It is important to note that these are the most common examples of symptoms, not an exhaustive list. Also, these symptoms do not necessarily indicate fatigue; rather, a collection of symptoms signifies that a person is experiencing at least some level of fatigue.

Figure 1. Signs of Fatigue

Physical Signs	Mental Signs	Emotional Signs
• Yawning repeatedly • Heavy eyelids or microsleeps • Eye-rubbing • Nodding off or head drooping • Headaches, nausea, or upset stomach • Slowed reaction time • Lack of energy, weakness, or light headedness	• 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

6.2 Fatigue and Performance. The factors listed in Figure 1, above, are direct causes of fatigue and actually make fatigue unavoidable. Consider this: after 16 hours of being awake, our mental ability to perform work-related tasks decreases to a level consistent with having a blood alcohol concentration of 0.05 percent. After 24 hours of no sleep, mental impairment is consistent with performance deficits observed at roughly 0.10 percent blood alcohol concentration. Similarly, individuals operating on a 2-hour sleep debt over 2 weeks (i.e., 6 hours of sleep, instead of the needed 8 hours, for 2 weeks straight) perform similarly to an individual that has been awake for 16 hours or longer. Despite increased effort to do the job right, as fatigue levels increase, poor performance is inevitable. As a point of reference, most states and countries consider a 0.08 percent or higher blood alcohol concentration a legal level of impairment for driving a motor vehicle.

6.2.1 <u>Operational Data</u>. Operational data collected by a large U.S. air carrier maintenance organization revealed that individuals working 16-hour days or longer were 4 times more likely to be involved in a personnel injury incident/accident than an individual working an 8-hour day. Individuals working 12-hour days were 2 times more likely to be involved in a personnel injury incident/accident than an individual working an 8-hour day. The work-related fatigue symptoms listed in paragraph 6.1 (e.g., reduced reaction time, forgetfulness, and being withdrawn) clearly illustrate the level of risk associated with fatigued maintainers remaining on duty. Numerous field and laboratory studies have clearly shown that cognitive and psychomotor performance decreases with hours of wakefulness.

6.3 Fatigue and Your Brain. When deprived of sleep, the brain generates the response of sleepiness. If deprived of sleep for long enough, the brain can spontaneously shift from wakefulness to sleep in an uncontrolled fashion. The more fatigued you are, the more rapid and frequent the nodding off. You can nod off for short periods (e.g., microsleeps, which last only seconds), or as long as several minutes. Most everyone has unintentionally nodded off at one time or another. The potential safety risk of it happening at the wrong time and place reinforces our personal and organizational responsibilities to manage fatigue risk. The bottom line is that working fatigued not only puts an individual at risk, but also his or her colleagues, and ultimately the flying public.

6.4 Causes of Fatigue. Causes of fatigue are discussed in terms of those that actually make fatigue unavoidable, referred to as primary factors, and those that might lead to fatigue. Fatigue is the direct result of the following:

6.4.1 Disrupted Sleep and Sleep Loss. Just like food, water, and air, sleep is a basic biological need that is critical to survival. Sleep is necessary for the mind and body to restore itself; without it your performance will begin to suffer. You may not be getting a sufficient amount of sleep and/or the sleep that you do get is of poor quality. For example, if a barking dog periodically wakes you multiple times throughout the night, you are more likely to wake up without being fully rested and restored. It makes a big difference when your daily routine includes, as a rule, between 7 and 9 hours of deep and undisturbed sleep. If your daily routine lacks sufficient sleep, then you can expect to experience fatigue symptoms due to sleep debt. Sleep debt is the difference between the amount of sleep a person gets and the amount of sleep that they need. This debt must be repaid in order for you to perform daily activities without feeling fatigue. Be aware that countering a sleep deficit is not as easy as simply extending the time you sleep the next time. Rather, it requires uninterrupted sleep along with sleeping longer. More extended periods of sleep deprivation require more extended periods of sleep recovery.

6.4.2 Prolonged Wakefulness. The amount of time since you last woke up, which is your sleep history, determines how long you have been continuously awake. As the length of time since you were last asleep increases, your level of alertness decreases. This happens regardless of how much or little sleep you got the previous night. There is no way to "stockpile" sleep. You cannot sleep for 12 hours in an attempt to remain alert for the next 24 hours.

6.4.3 Circadian Rhythm. Your body's internal clock, the circadian rhythm, tells your body when to be awake and when to go to sleep. The circadian rhythm is closely aligned with day and night and is sensitive to light exposure. Our bodies are preprogrammed to be awake when it is light and asleep when it is dark. Twice during a day, the body slows down. It happens mid- to late afternoon, between 3:00 p.m. and 5:00 p.m., so expect to experience drowsiness during the lull. If you are awake after midnight and into the early morning hours between 2:00 a.m. and 6:00 a.m., which is counter to your body's natural rhythm, you should expect to experience drowsiness.

6.4.3.1 Below are work-related situations and personal choices that minimize opportunities for exposure to light and/or sleep and disrupt your body's internal clock, making it difficult to get adequate sleep.

- Overtime/back-to-back shifts;
- Early morning and night shifts;
- A rotating schedule;

- No work breaks;
- Long commutes to and from work;
- Travel that crosses time zones;
- Use of sleep aids or other medications that can result in drowsiness or keep people awake;
- Misuse of alcohol; and/or
- Use of caffeine before going to bed.

6.5 Multiple Secondary Factors of Fatigue. Secondary factors do not necessarily result in fatigue; however, they are very likely to contribute to fatigue, especially if you experience more than one factor or if they occur in combination with one or more primary contributors.

6.5.1 Work Schedules. Work schedules that require reporting for duty before 7:00 a.m., after 6:00 p.m., and rotating shifts that do not align with our body's natural wake and sleep cycle, which results in too little or poor quality sleep. Rotating shifts and overtime can also lead to fatigue based on the previous hours or days worked.

6.5.2 Work Environment. Work environments that put excessive demands on the body may worsen fatigue levels. Examples of excessive demands are: vibration, loud or continuous noise, excessive heat or cold, poor air quality, and poor lighting.

6.5.3 Work Demands. The physical, cognitive, and emotional demands of a job that create relatively high workload contribute to fatigue.

6.5.4 Travel. Travel across time zones creates a mismatch between the body's internal clock (natural wake and sleep cycle) and the time change. Because the body has no time to adjust, we end up going to sleep later than normal or waking up earlier than necessary, so we do not get enough sleep and, in turn, we experience some level of daytime sleepiness.

6.5.5 Illness. Ongoing illnesses, such as allergies, colds, flu, muscle spasms, etc., can create a level of discomfort that will keep you from getting restful sleep.

6.5.6 Sleep Disorders. Undiagnosed and untreated sleep disorders, such as sleep apnea, restless leg syndrome, and insomnia can keep you from getting to sleep and staying asleep. If you experience disrupted sleep, proper medical care may be necessary.

6.5.7 Lifestyle Choices. Lifestyle choices related to unhealthy habits in general, such as not eating well-balanced meals, not exercising regularly, not staying hydrated, as well as poor sleep habits in particular, such as watching TV in bed, and either smoking, rigorously exercising, or overeating right before bedtime, have a profound negative impact on sleep quality and duration.

6.5.8 Use of Substances. Substances used too close to bedtime, such as caffeine and alcohol, or used too close to waking up, such as sleep aids and medications, can contribute to fatigue.

6.5.9 Stress and Anxiety. Stress and anxiety often will keep you from falling asleep, even when feeling very tired.

7 FATIGUE RISK MANAGEMENT (FRM). Aviation maintenance personnel face a particular risk of fatigue due to night shift work, the potential for long and unregulated duty times, and the sleep disruption that can result from these working conditions (Hackworth et al., 2007; Johnson et al., 2001).

7.1 FRM in Aviation Maintenance. Most of the FRM approaches in industry have been designed for continuous control tasks, such as driving a vehicle or operating an aircraft. In such tasks, one of the major fatigue-related threats is an unwanted sleep episode, in the form of either an extended period of sleep or a microsleep. In maintenance, falling asleep at work is not the main hazard created by fatigue. Rather, a fatigued maintainer is at increased risk of maintenance errors due to impaired mental functioning. Maintenance organizations face a unique set of fatigue-related challenges; however, they also have access to a unique set of potential solutions. As a result, FRM in maintenance can involve a wider range of countermeasures than comparable systems developed for flightcrews or vehicle drivers.

7.2 Characteristics of Maintenance Work. Although maintenance personnel must contend with significant fatigue risks, some characteristics of aircraft maintenance provide opportunities to mitigate the hazards presented by fatigue.

7.2.1 Maintenance Tasks. Maintenance tasks tend to be self-paced rather than externally paced. Although much maintenance work is performed under time pressure, a maintainer conscious of impaired performance may be able to pause a task, trade speed for accuracy, or repeat a step as necessary.

7.2.2 Performance Modification. In some cases, there are opportunities to modify methods of task performance in maintenance. In many cases, task cards can be modified and error-capturing barriers can be added and introduced, such as secondary inspections or operational/functional checks.

7.2.3 Flexibility. Maintenance organizations sometimes have flexibility to choose the time at which certain tasks are performed. In such cases, it may be possible to schedule the most safety-critical tasks, or those most susceptible to fatigue, at times when fatigue will have the least impact.

7.2.4 Travel. Most maintainers are not required to travel across time zones while on duty. Consequently, jet lag and travel-related circadian rhythm disruption, which are major considerations for flightcrew FRMS, are not usually relevant in the maintenance environment. The exception is when maintainers must travel to a remote work site to perform a task.

7.3 Employer and Employee Responsibilities. The conditions that produce fatigue originate not only in the workplace but also in the employee's personal life. Effective FRM requires a partnership with shared responsibility between the employee and the employer.

7.3.1 Workplace Factors. Workplace factors include working hours, staffing levels, environment, and the availability of break periods.

7.3.2 Personal Factors. Personal factors leading to fatigue can include social and family commitments, commute time, second jobs, and medical conditions that may reduce the quality or quantity of sleep. The employee has a responsibility to ensure, as much as possible, that he or she is rested and "fit for duty" before reporting for work.

7.4 **Objectives of FRM.** FRM interventions can be characterized not only in terms of the activities that comprise the approach, such as Hours of Service (HOS) limits and incident reporting systems, but also the intended objectives of these activities. An approach common to many risk management systems is a distinction between controls aimed at hazard prevention, and controls directed at risk mitigation (Murphy and Yates, 2009; Reason and Hobbs, 2003). Consistent with this distinction, the three potential objectives of FRM should be considered as layers of defense.

1. The first and most obvious objective of fatigue countermeasures is to reduce the level of fatigue experienced by personnel at work. This is the approach most commonly referred to when considering FRM. Worker education, HOS limits, and the redesign of shift schedules are examples of interventions intended to meet this objective.
2. The second class of interventions is designed to break the link between fatigue and performance decrements. This can be achieved by reducing the probability that a fatigued maintainer will make an error, or capturing fatigue-related errors once they have occurred. Work breaks and additional task steps designed to capture errors are examples of such interventions.
3. A final approach to manage the risks presented by maintainer fatigue is to minimize, where possible, the operational consequences of errors, including fatigue-related. An example is § 121.374(c), a regulation that prevents a possibly fatigued maintainer from performing the same task on both engines of a twin-engine aircraft used in Extended Operations (ETOPS). The rule is not intended to reduce fatigue or reduce the probability of error. Rather, it tends to minimize the criticality of an error should one occur. This AC acknowledges that manufacturers and operators must conduct appropriate analyses to identify "critical tasks." For example, fatigued cabin cleaning crew may spill liquids, or loosen connections that could result in subsequent hazard and risk. Sometimes the most basic activity can be critical, so the best alternative is to assume that fatigued workers present hazards, regardless of their position.

8 **HOW TO REDUCE FATIGUE.** Fatigue reduction interventions are intended to minimize fatigue in the workplace, while recognizing that its complete elimination is not always practical. Interventions include HOS limits (whether voluntary or mandatory), scientific scheduling, napping strategies, education, excused absences, and in certain cases, medical treatment. These interventions are described in detail in the following paragraphs.

8.1 HOS Limits. In the United States, the only regulatory HOS limit that currently applies to aviation maintenance is § 121.377. HOS limits are also instituted by non-government agencies (including airlines, certified repair stations (CRS) and other maintenance, repair, and overall companies). These limits are primarily used to restrict the length of duty days as well as provide designated sleep or break opportunities to reduce fatigue.

8.2 Scientific Scheduling Models. In recent years, software modelling systems have been incorporated into many FRMS. Software models have advantages over HOS limits as they can take into account circadian variations in alertness and sleep obtained to produce an estimate of the fatigue level that may result from a particular shift pattern. When used as scheduling tools, software models have the advantage of offering greater flexibility than hard HOS limits. However, they can also be implemented in conjunction with hard limits. To utilize scheduling models, the user inputs an employee's work and break times over a 7-day period. The system then produces fatigue scores which express the level of fatigue likely to be experienced by the person. Thresholds are set to inform whether the fatigue level represents an unacceptable risk. Software modelling can be a useful tool as part of a comprehensive FRMS, but must be used cautiously, with an awareness of the capabilities and limitations of computerized models (Independent Transport Safety Regulator, 2010). For a comprehensive review of fatigue modelling systems, refer to Mallis et al. (2004). There can be a reasonable, scientific scheduling agreement between management and labor. It is a good situation for all.

8.3 Napping Strategies. Naps can be helpful either as a preventative measure, as when taken before reporting for a night of shift work, or as a way of improving alertness during a night shift. Controlled studies have shown that even a brief sleep episode can result in performance improvements. For instance, Purnell, Feyer, and Herbison (2002) found that the vigilance performance of aircraft maintenance personnel on the first of 2 consecutive 12-hour night shifts (7:00 p.m. to 7:00 a.m.) was improved by a 20-minute nap taken at around 3:00 a.m. No improvement was found on the second of the two night shifts. The reason for this is unclear. Other studies have found that brief, controlled sleeps of less than 40-minute duration have been shown to significantly increase the alertness of airline pilots, resulting in reduced lapses and reduced response time to stimuli (Rosekind et al., 1994). Similar benefits have been found for air traffic controllers (Della Rocco, Comperatore, Caldwell, and Cruz, 2000) and truck drivers (Macchi, Boulos, Ranney, Simmons, and Campbell, 2002).

8.4 Training and Educational Material. The provision of educational material to employees is one of the few steps the organization can take to address the personal lifestyle factors that contribute to fatigue. The FAA provides extensive educational material on fatigue for maintenance personnel, including training material, video material, and posters. This material can be accessed at http://www.faa.gov/about/initiatives/maintenance_hf/. Aviation Maintenance Technicians (AMT), inspectors, maintenance planners, task schedulers, and the families of shift workers will benefit from information on fatigue issues and steps they can take to help the shift worker obtain sleep. It is important to note that time worked, time awake, time asleep, and time of day are critical in considering fatigue risk. It is also important to consider all factors associated with sleep quality. The FAA training material addresses these factors.

8.5 Excused Absences. Some FRMS enable employees to take unplanned leave if they believe their level of fatigue would prevent them from performing their duties (Cook, 2008). While sick leave is a generally accepted aspect of personnel management, "fatigue leave" may be less readily accepted. Organizations need to weigh the potential disruption caused by an unplanned absence against the potential harm that could result when an employee reports for duty impaired.

8.6 Medical Treatment. In some cases, a maintainer's fatigue at work may be a consequence of an underlying medical condition, such as insomnia or sleep apnea (Kryger, Roth, and Dement, 2005). In these situations, medical attention will be required to address the root cause of the problem. A comprehensive FRMS must include measures to ensure that at-risk employees receive appropriate medical treatment.

9 HOW TO 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 completely eliminate fatigue from the workplace. Therefore, it is appropriate to have a second line of defense with the objective of reducing the probability of error among fatigued workers. The plain language slogan of this approach could be: "We know that people are going to be fatigued. How can we manage the risk when a fatigued maintainer is at work?" These interventions can involve one of two approaches: measures directed towards individuals, or measures directed towards tasks.

9.1 Measures Directed Towards Individuals. Several methods are available to help fatigued individuals recognize their level of fatigue and take steps to obtain temporary relief.

9.1.1 Self-Assessment. The most obvious way to detect fatigue is self-assessment by the employee. Several quick assessment guides are available to assist with this judgment, although they should be used with caution as individuals are not always accurate judges of their own level of fatigue (Dinges, Mallis, Maislin, and Powell, 1998).

9.1.2 Technologies. Several technologies offer the possibility of detecting a dangerous level of fatigue at the start of a shift, or continuously throughout task performance. For the most part, psychomotor performance tests have been used widely in research studies and have been shown to be effective indicators of a person's vigilance performance when fatigued. Such tests require a period of performance monitoring to establish a baseline for each individual. Changes in that baseline performance can be indicative of fatigue. The tests are usually installed on a handheld device or even a smartphone, and typically measure the person's speed of response to a stimulus (Dinges and Powell, 1985; Thorne et al., 2005). It must be understood that one-time use of a Psychomotor Vigilance Test (PVT) and other such tests are not a tactical means to establish a fatigue level. However, organized, established integration of PVT, and like devices/tests, can be a strategic tool for an FRMS. Other technologies, such as eye movements, blink rate, performance measures, and voice analysis, also show promise as methods to detect fatigue in operational personnel. Again, such devices are a strategic part of an FRMS. Alertness monitoring systems are not likely to be adopted in maintenance in the near future; it is conceivable that they may eventually play a part in an overall FRMS.

9.1.3 Exercise. Research shows that a period of exercise, such as a brief walk, can increase alertness and temporarily reverse the impact of fatigue on some psychomotor tasks (Bonnet, 2005; Bonnet and Arand, 1998; Wilkinson, 1965). However, the results appear to be temporary, only lasting a matter of minutes. A maintenance technician experiencing extreme fatigue may be able to call "time out" and put down their tools for a moment, or perform a part of a task that requires physical activity, such as walking to a storeroom. However, such breaks provide only temporary relief lasting a matter of minutes, and are not feasible strategies for managing fatigue over long periods of time.

9.1.4 Environment. Certain aspects of the work environment can exacerbate or mask the effects of fatigue. In some cases, improvements to the work environment may help maintainers cope with fatigue. There is evidence that bright light can increase attentiveness and reduce errors among otherwise fatigued individuals (Cajochen, 2007; Caldwell et al., 2009; Campbell and Dawson, 1990; Dawson, Encel, and Lushington, 1995; Moore-Ede, 1993). These findings are a reminder that tasks performed in a dark environment, such as fluorescent penetrant inspections, will be particularly challenging for a fatigued individual. Exposure to fresh air or cool, dry air may also provide relief from fatigue, although the benefit is temporary and may be slight (Bonnet, 2005; Moore-Ede, 1993). Posture may also have an impact on fatigue susceptibility. An activity that is carried out while standing or walking is less likely to be affected by fatigue than an activity performed in a prone or seated position (Bonnet, 2005).

9.1.5 Caffeine. Caffeine is one of the most widely used stimulants, and if used carefully and in moderation, can be part of an overall FRM strategy in maintenance. Caffeine has a half-life in the body of around 5 hours, and shift workers should be careful to avoid caffeine in the hours leading up to sleep. An exception is where caffeine is intentionally taken immediately prior to a brief nap. The alertness-enhancing effects of caffeine do not occur until approximately 30 minutes after the caffeine has been consumed, leaving a brief window in which a useful nap may be taken. This combination of caffeine followed immediately by a brief nap has been shown to significantly reduce fatigue during the 2 hours following the nap (Reyner and Horne, 1997). When caffeine is used as a fatigue countermeasure, it is generally recommended that the person avoids the routine consumption of caffeinated drinks, as caffeine is less effective as an alerting agent for people who have developed caffeine dependence (Mitler and O'Malley, 2007).

9.2 **Measures Directed Towards At-Risk Tasks.** In addition to managing fatigue at the level of the individual, it is also possible to break the link between fatigue and maintenance error by changing aspects of the task assigned to the maintainer. Because much of the worldwide work on FRM has been directed at pilots or vehicle operators, the task-based approach has received relatively little attention. The task-based approach is based on the idea that maintenance tasks vary along a continuum, from tasks that are highly susceptible to fatigue, to those that are less susceptible. This approach is based upon the probability that an error will occur on a task, not necessarily the severity of the consequences of the error. Task-based approaches to harm minimization can involve two complimentary approaches: changing when the task is performed, and changing how it is performed.

9.2.1 Scheduling Tasks. Even if the task steps involved in a maintenance procedure cannot be modified, it may still be possible to reduce the susceptibility of a task to fatigue through careful task scheduling. Most maintenance organizations do not appear to take the fatigue susceptibility of a procedure into account when scheduling tasks. In some cases, individual maintainers have informal norms concerning the time of day at which tasks are performed. For example, when AMTs have discretion about the timing of tasks, they sometimes choose to perform the most challenging tasks at the beginning of their shift, leaving less complex tasks until the end of the shift, when they expect to be less alert. In most large organizations, AMTs have limited control over the timing of tasks throughout their shift, yet crew leads, foremen, or in some cases planning personnel may have some discretion in task scheduling to minimize the impact of fatigue. Therefore, it is critical that such personnel have an awareness of the impact of fatigue on human performance. The following types of tasks have been identified as being most susceptible to fatigue-related errors:

- Inter-trade communications;
- In-depth supervision;
- Training;
- Troubleshooting;
- Testing;
- Calibration;
- Inspection;
- Job planning; and
- Documenting of work.

9.2.2 Modifying Tasks. In some cases, it is possible to modify task procedures to reduce the task's susceptibility to fatigue-related errors, or to detect the presence of an error. Such task-based interventions are sometimes referred to as "fatigue proofing." Task-based approaches to risk mitigation in maintenance can include:

- Close supervision;
- Working in pairs or teams, depending on the task;
- Task rotation;
- Checklists;
- Support for new personnel by experienced personnel;

- Communication/briefings at shift handover;
- Breaking lengthy repetitive tasks into smaller tasks with breaks in between;
- Independent inspections; and
- Operational, functional, or formalized self-checks.

10 HOW TO MINIMIZE IMPACT OF FATIGUE-RELATED ERRORS. After efforts have been made to reduce fatigue and to prevent or capture fatigue-related errors, a final line of defense is to minimize the operational consequences of fatigue-related errors. Tasks vary along a continuum from the most safety-critical to tasks having limited or unlikely safety effect. Hazard prevention/reduction differs from the interventions described in the preceding sections, as the focus is on the severity of fatigue-related errors, rather than their probability. The plain language slogan of this approach could be: "Despite our best efforts, fatigue-related errors will happen from time to time. How can we make sure these errors do not have serious consequences?"

10.1 Harm Minimization. Harm minimization in the context of maintenance fatigue involves keeping the most safety-critical tasks out of the hands of the most fatigued people. This approach does not prevent the maintainer from making a fatigue-related error, but reduces the likely consequences of the error. For example, if an overnight task involves a disassembly stage followed by an assembly stage, it may be appropriate, when feasible, to schedule the disassembly for the time of maximum fatigue, and the assembly for a time at which fatigue is less likely. This arrangement is based on the assumption that an error during assembly is likely to be more serious than an error during disassembly.

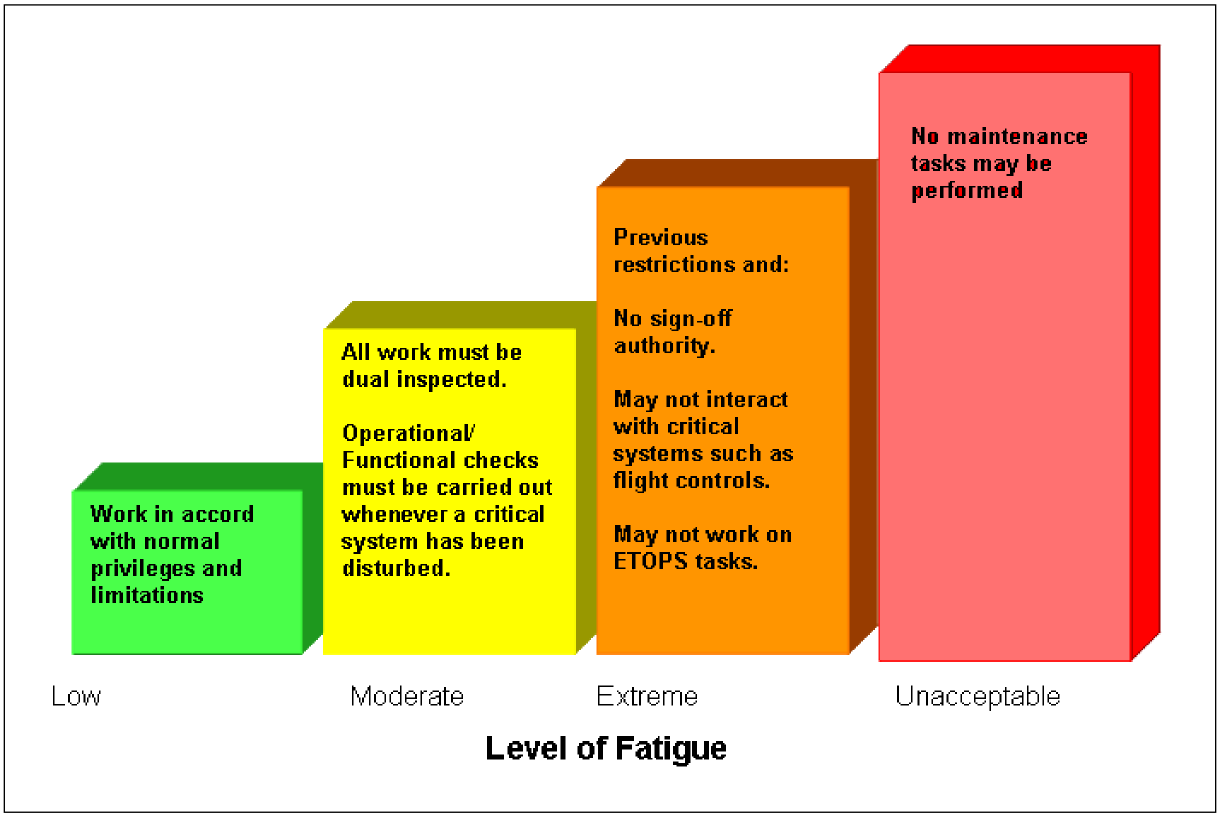
11 PROGRESSIVE RESTRICTIONS. The concept of progressive restrictions on work responsibilities has been proposed as a fatigue countermeasure. This involves progressively limiting the involvement of the individual in critical task steps as their level of fatigue increases. Some propose that the certification and inspection authority of maintenance personnel should be limited when they have been on duty for longer than 12 hours (Jauregui and Hosey, 2005). For example, a technician may be judged to be at "moderate" risk of fatigue once their shift has passed beyond 12 hours (if a day shift), or 8 hours (if a night shift), or when more than 48 hours have been worked in a 7-day period. These staff members are prohibited from carrying out secondary independent inspections, detailed inspections, or involvement with structurally significant items and critical systems. Technicians are judged to be at "extreme" risk of fatigue when a day shift is extended beyond 14 hours (beyond 12 hours for a night shift), or when they have worked more than 60 hours in a 7-day period. In addition to the above limitations, personnel at "extreme" risk of fatigue are not allowed to perform any critical tasks (including the performance or verification of Airworthiness Directives (AD)), are not permitted to be in charge of engine runs, must not be responsible for functional and operational checks on critical systems, and are not permitted to taxi aircraft. "Unacceptable" fatigue risk is judged to commence when a person has been on duty for 16 hours (if their duty period started as a day shift) or 14 hours (if their duty period started as a night shift) or when they have worked more than 72 hours in a 7-day period.

A staff member with an "unacceptable" fatigue risk is not considered safe to perform any work activities.

11.1 Determination of Activity Complexity. This AC is not suggesting that every maintenance-related task must be assigned a level or risk, to include task complexity, with associated rating of probability and severity of an error. While such a large effort could be part of an FRMS, instead one could establish what a "reasonable person" would consider to be a complex activity requiring a rested maintenance worker.

11.2 Assessments. Fatigue's most common assessments, as mentioned above, include amount of rest, number of hours awake, and time of day. However, organizations must be cognizant of factors such as type of physical/mental strain, environmental conditionals, industrial challenges, and more. Thus, HOS cannot be the sole determination of potential fatigue.

Figure 2. Work Responsibility Restriction—Example



Example of the progressive restriction of work responsibilities as fatigue risk increases.

11.3 Implementation of Defensive Barriers for Fatigue. The concept of defensive barriers was developed to prevent human errors from becoming critical events. Organizations that are aware of fatigue and understand that personnel are fallible are then cognizant of fatigue as a latent organizational weakness. "About 80% of all events are attributed to human error. When the 80% human error is broken down further, it reveals that the majority of errors associated with events stem from latent organizational weaknesses."

(DOE-HDBK-1028-2009, Human Performance Improvement Handbook, Volume 1, Concepts and Principles, pages 1-10, 1-15, 2-9.) Organizations should utilize human performance improvement tools to build defensive barriers into their administrative controls, policies, and procedures (DOE-HDBK-1028-2009, Volume 2, Human Performance Tools for Individuals, Work Teams, and Management). This can be done by identifying critical tasks associated with all disciplines and at all levels of the organization. Then, for each identified critical task, establish an administrative control that would halt the progression of human error into a critical event. In short, events will happen; however, those events will not become critical events unless a barrier has been side-stepped or is nonexsistent. Volumes 1 and 2 of the DOE-HDBK-1028-2009 can be found at http://energy.gov/sites/prod/files/2013/06/f1/doe-hdbk-1028-2009_volume1.pdf and http://energy.gov/sites/prod/files/2013/06/f1/doe-hdbk-1028-2009_volume2.pdf.

12 FRM WITHIN SMS.

12.1 Objectives. The trend towards formal FRMSs in transport has been slow to reach aviation maintenance. An overall approach to FRM in maintenance can include interventions directed at three objectives: reducing fatigue, reducing or capturing fatigue-related errors, and minimizing the harm caused by fatigue-related errors. Most fatigue countermeasures can actually address more than one of these objectives. Because the FRMS approach was originally developed for pilots and vehicle drivers, most existing FRMS focus on objective one, the reduction of fatigue. However, maintenance organizations have greater opportunities to alter the scheduling and method of task performance in response to the threat of fatigue. Therefore objectives two and three deserve special attention in maintenance operations.

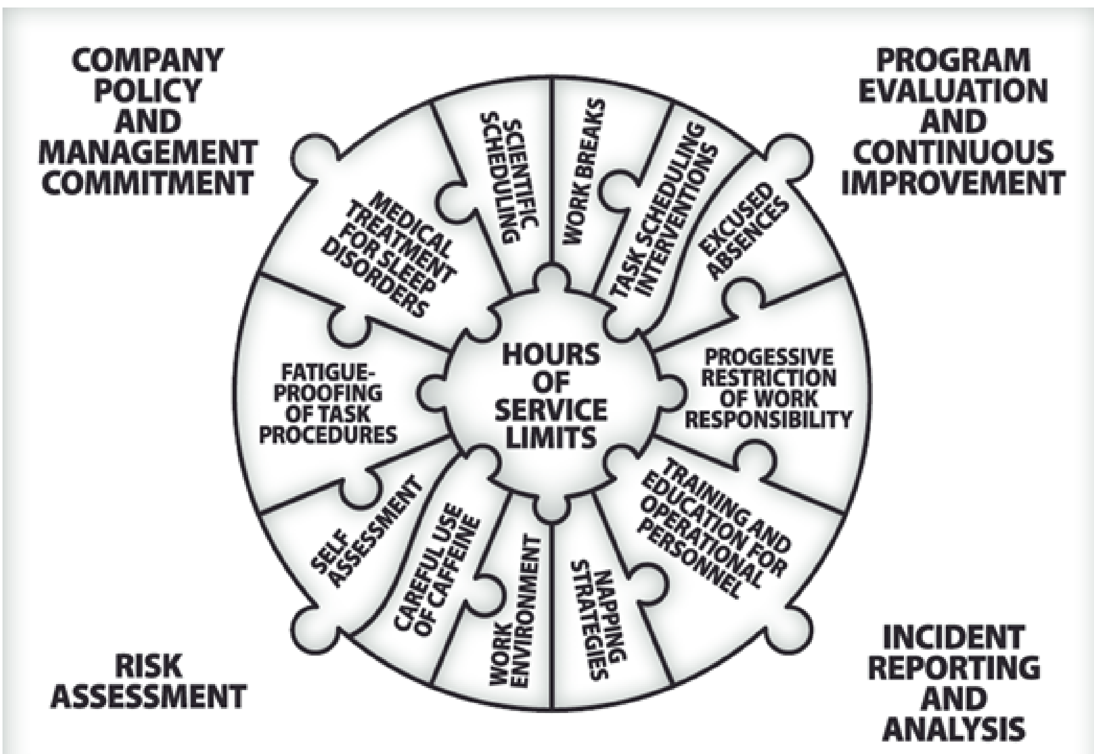
12.2 Guiding Principles. FRMS is an application of the SMS model, through which hazards are identified and risk is managed with a comprehensive approach that extends beyond regulatory compliance, as described in AC 120-103. FRMS can be integrated within an existing SMS, or can be developed as a standalone system. The following principles guide FRM development:

- An FRMS requires a systemic approach, involving company policies; incident reporting and analysis systems; reactive, proactive, and predictive risk assessment; and the other elements of a general SMS.
- Effective FRM requires a partnership between the employer and the employee, as each can contribute uniquely to solutions.
- It is unrealistic to aim for “zero fatigue” in all cases. An appropriate objective for FRM is to ensure that risks are managed to a level as low as reasonably practical.

12.3 Commitment. Whatever approach to FRM is applied, commitment from all levels of the organization is clearly essential. Upper management have a responsibility to state a clear policy on fatigue, including how fatigue-related incidents will be dealt with under a just safety culture. Supervisors and middle-level managers have a responsibility to ensure that the FRM policy is applied in day-to-day operations. Supervisors, crew leads, and planners have a critical role in ensuring that fatigue and circadian factors are taken into account in task assignment and planning. Finally, individual AMTs and inspectors are ultimately responsible for the quality of their work. They must have a good understanding of fatigue and its effects, must strive to arrive for duty well-rested, and must have access to strategies to deal with workplace fatigue when it arises.

12.4 HOS Limits. In accordance with international best practices, HOS limits should be a central part of any FRMS. In the absence of national HOS regulations, companies can develop their own science-based policies. In addition to HOS limits, an FRMS for maintenance will include a range of interventions addressing the task, the work environment, and the fitness for duty of personnel, including organizational-level elements such as company policies, reporting and incident analysis systems, risk assessment, and mechanisms to periodically evaluate and improve the system.

Figure 3. Fatigue Risk Management (FRM) Elements



Elements of an FRM for maintenance.

John Barbagallo
Deputy Director, Flight Standards Service

APPENDIX A. REFERENCES

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☐ An error (procedural or typographical) has been noted in paragraph ____________ on page _______.

☐ Recommend paragraph _____________ on page __________ be changed as follows:

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(Briefly describe what you want added.)

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