Fatigue Management Guide for General Aviation Operators of Large and Turbojet Aeroplanes

First Edition, 2016

EXECUTIVE LETTER

Dear Colleagues,

It is widely recognized that aviation is the world's safest form of transport. This fact represents years of combined effort from across the industry and a shared focus on the continuous improvement of our already safe system. In that spirit, the International Civil Aviation Organization (ICAO), International Business Aviation Council (IBAC), and Flight Safety Foundation (FSF) are pleased to present this manual, which aims to familiarize general aviation operators with contemporary concepts of fatigue management and provide guidance for their implementation in day to day operations.

IBAC, as the representative of the business aviation community, has a long established and abiding interest in the role of fatigue management to improve flight safety. The FSF has a long history of providing the aviation industry with fatigue-related guidance, much of it used by IBAC in the development of business aviation best practices. The ICAO/IBAC/FSF collaboration is a reflection of a mutual commitment to fatigue management and a common understanding of its implementation within the general aviation environment.

The material presented here is based on the work of the ICAO Fatigue Risk Management Systems Task Force with specific input provided by expert contributors with hands-on experience in general aviation operations. The result is a document that presents approaches widely accessible to the general aviation operators and pilots who will be using them.

We are extremely proud to jointly introduce this document, which will contribute to the improved management of fatigue risk and help us achieve our common goal of improving aviation safety worldwide.

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USE OF THIS MANUAL

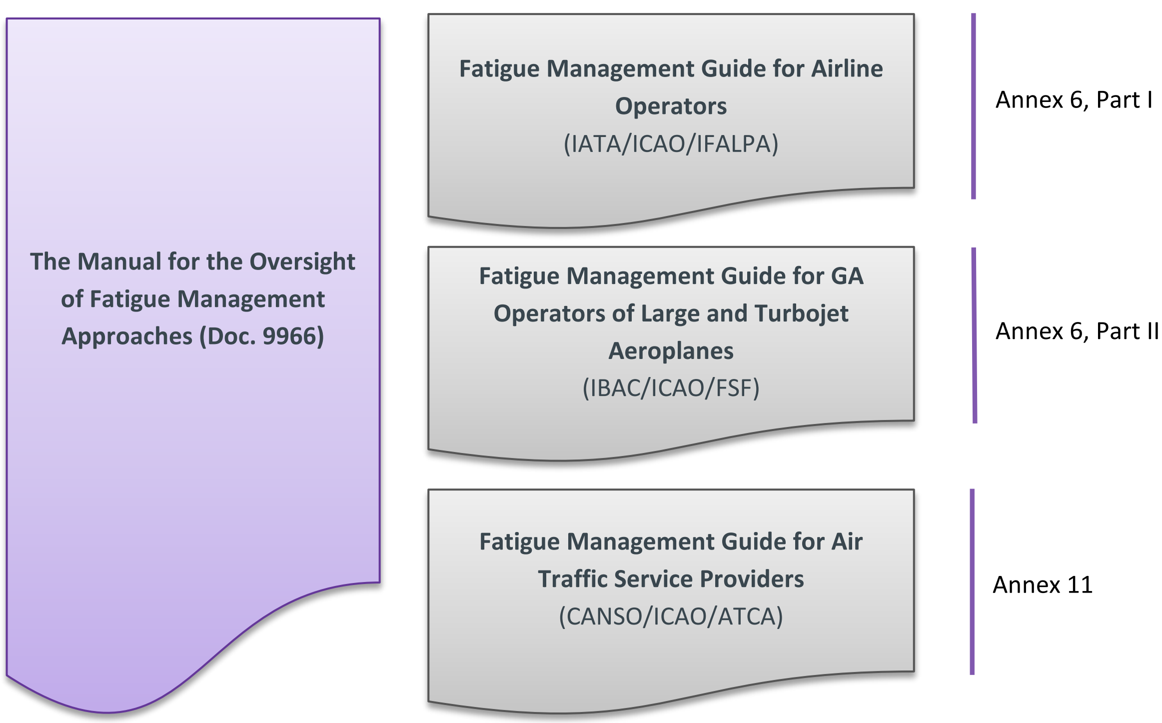
This Fatigue Management Guide for General Aviation Operators is one in a suite of manuals produced by ICAO and industry partners on fatigue management. It was developed by the International Civil Aviation Organization (ICAO), the International Business Aviation Council (IBAC) and the Flight Safety Foundation (FSF), to provide general aviation (GA) aeroplane operators with information on the nature of fatigue and guidance on managing the risks related to this hazard within a general aviation operator's safety management system. The National Business Aviation Association (NBAA) Safety Committee also played a vital role in the development of this document.

The suite of fatigue management manuals includes other implementation manuals developed to assist specific professional groups to effectively manage their fatigue risks, as well as the *Manual for the Oversight of Fatigue Management Approaches* (Doc 9966), which has been developed to assist regulators to establish regulations for, and provide oversight of, fatigue management approaches.

The *Manual for the Oversight of Fatigue Management Approaches* (Doc 9966) has been designed to be read in association with any of the relevant Implementation Manuals.

The content of all of these manuals is based on the work of the ICAO FRMS Task Force. They follow a similar structure to facilitate their use.

The suite of Fatigue Management Manuals[1], and their corresponding Annexes, is as follows:



[1] All manuals are downloadable at http://www.icao.int/safety/fatiguemanagement/Pages/default.aspx

The following diagram provides an overview of the Fatigue Management Guidance Manual for General Aviation Operators and is presented to assist readers in navigating its contents. Major topics addressed in each of the Chapters are identified.

Chapter 1 Introduction to Fatigue Management	•Fatigue management approaches •Fatigue management in GA operations •Associated ICAO SARPs
Chapter 2 Scientific Principles for Fatigue Management	•The need for sleep •Sleep loss and recovery •Circadian effects on sleep and performance •The influence of workload on fatigue
Chapter 3 Operational Knowledge and Experience	•Factors in GA flight operations that influence fatigue •Organizational factors that can influence fatigue management •GA operator and individual crew member responsibilities
Chapter 4 Implementing a Fatigue Management Programme	•Establishing operator-identified flight and duty limits •Using SMS processes to manage fatigue risks
Appendix A Subjective Measures of Fatigue	•Ratings of fatigue Levels •Assessment of sleep duration
Appendix B Evaluation the Contribution of Fatigue to Safety Events	•Establishing whether the crew member(s) was in a fatigued state •Establishing whether behaviours and decisions were consistent with the actions of a fatigued person or crew
Appendix C Excerpts from Flight Safety Foundation – NBAA Duty/Rest Guidelines for Business Aviation	•GA industry-developed guidelines for duty and flight time limits, rest requirements and crew scheduling practices for adaption by individual GA operators

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GLOSSARY

**denotes an ICAO definition.*

Actigraph. A wristwatch-like device containing an accelerometer to detect movement. Activity counts are recorded per unit time, for example every minute. The patterns of movement can be analyzed using purpose-built software to estimate when the wearer of the actiwatch was asleep, and to provide some indication of how restless a sleep period was (i.e., sleep quality). Actigraphs are designed to record continuously for several weeks so they are valuable tools for monitoring sleep patterns, for example before, during, and after a trip or work pattern.

Actigraphy. Use of actiwatches to monitor sleep patterns. For actigraphy to be a reliable measure of sleep, the computer algorithm that estimates sleep from activity counts must have been validated against polysomnography, which is the gold standard technology for measuring sleep duration and quality. The main weakness of actigraphy is that an actigraph cannot differentiate between sleep and still wakefulness (since it measures movement).

Afternoon Nap Window. A time of increased sleepiness in the middle of the afternoon. The precise timing varies, but for most people it is usually around 15:00-17:00. This is a good time to try to nap. On the other hand, it is also a time when it is more difficult to stay awake, so unintentional micro-sleeps are more likely, especially if recent sleep has been restricted.

Augmented Flight Crew**.** A flight crew that comprises more than the minimum number required to operate the aeroplane so that each crewmember can leave his or her assigned post to obtain in-flight rest and be replaced by another appropriately qualified crewmember.

Bio-mathematical Model. A computer programme designed to predict aspects of a schedule that might generate an increased fatigue risk for the average person, based on scientific understanding of the factors contributing to fatigue. Bio-mathematical models are an optional tool (not a requirement) for predictive fatigue hazard identification within an FRMS. All bio-mathematical models have limitations that need to be understood for their appropriate use.

Circadian Body Clock. A neural pacemaker in the brain that monitors the day/night cycle (via a special light input pathway from the eyes) and determines our preference for sleeping at night. Shift work is problematic because it requires a shift in the sleep/wake pattern that is resisted by the circadian body clock, which remains 'locked on' to the day/night cycle. Jet lag is problematic because it involves a sudden shift in the day/night cycle to which the circadian body clock will eventually adapt, given enough time in the new time zone.

Countermeasures. Personal mitigation strategies that individuals can use to reduce their own fatigue risk. Sometimes divided into strategic countermeasures (for use at home, for example good sleep habits, napping before night duty), and operational countermeasures, for example controlled napping and strategic use of caffeine.

Crew member**.** A person assigned by an Operator to a duty on an aircraft during a flight duty period.

Cumulative sleep debt. Sleep loss accumulated when sleep is insufficient for multiple nights (or 24-hr days) in a row. As cumulative sleep debt builds up, performance impairment and objective sleepiness increase progressively, and people tend to become less reliable at assessing their own level of impairment.

****Duty*****.** Any task that flight or cabin crew members are required by the operator to perform, including, for example, flight duty, administrative work, training, positioning and standby when it is likely to induce fatigue.

***Duty period.** A period which starts when a flight or cabin crew member is required by an operator to report for or to commence a duty and ends when that person is free from all duties.

Evening Wake Maintenance Zone. A period of several hours in the circadian body clock cycle, just before usual bedtime, when it is very difficult to fall asleep. Consequently, going to bed extra early usually results in taking a longer time to fall asleep, rather than getting extra sleep. Can cause restricted sleep and increased fatigue risk with early duty start times.

****Fatigue.*** A physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties.

****Fatigue Risk Management System (FRMS).*** A data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles, knowledge and operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.

****Flight duty period.*** A period which commences when a flight or cabin crew member is required to report for duty that includes a flight or a series of flights and which finishes when the aeroplane finally comes to rest and the engines are shut down at the end of the last flight on which he is a crew member.

****Flight time — aeroplanes.*** The total time from the moment an aeroplane first moves for the purpose of taking off until the moment it finally comes to rest at the end of the flight.

****Hazard.*** A condition or an object with the potential to cause or contribute to an aircraft incident or accident.

Internal Alarm Clock. A time in the circadian body clock cycle when there is a very strong drive for waking and it is difficult to fall asleep or stay asleep. Occurs about 6 hours after the **Window of Circadian Low** in the late morning to early afternoon and can cause restricted sleep and increased fatigue risk after night duty.

Jet Lag. Desynchronization between the circadian body clock and the day/night cycle caused by transmeridian flight (experienced as a sudden shift in the day/night cycle). Also results in internal desynchronization between rhythms in different body functions. Resolves when sufficient time is spent in the new time zone for the circadian body clock to become fully adapted to local time.

Micro-sleep. A short period of time (seconds) when the brain disengages from the environment (it stops processing visual information and sounds) and slips uncontrollably into light non-REM sleep. Micro-sleeps are a sign of extreme physiological sleepiness.

Mitigations. Interventions designed to reduce a specific identified fatigue risk.

Non-Rapid Eye Movement Sleep (Non-REM Sleep). A type of sleep associated with gradual slowing of electrical activity in the brain (seen as brain waves measured by electrodes stuck to the scalp, known as EEG). As the brain waves slow down in non-REM sleep, they also increase in amplitude, with the activity of large groups of brain cells (neurons) becoming synchronized. Non-REM sleep is usually divided into 4 stages, based on the characteristics of the brainwaves. Stages 1 and 2 represent lighter sleep. Stages 3 and 4 represent deeper sleep and are also known as ***slow-wave sleep***.

Non-REM/REM Cycle. Regular alternation of non-REM sleep and REM sleep across a sleep period, in a cycle lasting approximately 90 minutes.

On-call. A defined period of time, during which an individual is required by the service provider to be available to receive an assignment for a specific duty. Synonymous with ***standby.***

Pairing. A scheduling expression describing the time from when a flight crewmember initially reports for duty until he/she returns home from the sequence of flights and is released from duty. (See ***Trip***)

Rapid Eye Movement Sleep (REM Sleep). A type of sleep during which electrical activity of the brain resembles that during waking. However, from time to time the eyes move around under the closed eyelids – the 'rapid eye movements' – and this is often accompanied by muscle twitches and irregular heart rate and breathing. People woken from REM sleep can typically recall vivid dreaming. At the same time, the body cannot move in response to signals from the brain, so dreams cannot be 'acted out'. The state of paralysis during REM sleep is sometimes known as the 'REM block'.

Recovery Sleep. Sleep required for recovery from the effects of acute sleep loss (in one 24-hour period) or cumulative sleep debt (over multiple consecutive 24-hour periods).

****Rest period.*** A continuous and defined period of time, subsequent to and/or prior to duty, during which personnel are free of all duties.

Roster. ***(noun)*** a list of planned shifts or work periods within a defined period of time***;***

(verb) assignment of individuals to a schedule or pattern of work. Synonymous with ***Schedule.***

****Safety.*** The state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level.

****Safety management system (SMS).*** A systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures.

****Safety performance indicator.*** A data-based parameter used for monitoring and assessing safety performance.

****Safety performance target.*** The planned or intended objective for safety performance indicator(s) over a given period.

****Safety risk.*** The predicted probability and severity of the consequences or outcomes of a hazard.

Schedule. ***(noun)*** a list of planned shifts or work periods within a defined period of time***;***

(verb) assignment of individuals to a roster or pattern of work. Synonymous with ***Roster***.

Shift Work. Any work pattern that requires an individual to be awake at a time in the circadian body clock cycle that they would normally be asleep.

Sleep. A reversible state in which conscious control of the brain is absent and processing of sensory information from the environment is minimal. The brain goes "off-line" to sort and store the day's experiences and replenish essential systems depleted by waking activities.

Sleep Debt. See ***Cumulative sleep debt.***

Sleep Disorders. A range of problems that make it impossible to obtain restorative sleep, even when enough time is spent trying to sleep. Examples include obstructive sleep apnea, the insomnias, narcolepsy, and periodic limb movements during sleep.

Sleep Homeostatic Process. The body's need for ***slow-wave sleep*** (non-REM stages 3 and 4), that builds up across waking and discharges exponentially across sleep.

Sleep Inertia. Transient disorientation, grogginess and performance impairment that can occur after wakening. The length and intensity of sleep inertia is greatest when the individual has not had enough sleep, is woken from **slow-wave sleep** (non-REM stages 3 and 4) or woken during the WOCL.

Sleep Need. The amount of sleep that is required on a regular basis to maintain optimal levels of waking alertness and performance. Sleep need is very difficult to measure in practice because of individual differences. In addition, because many people live with chronic sleep restriction, when they have the opportunity for unrestricted sleep, their sleep may be longer than their theoretical 'sleep need' due to recovery sleep.

Sleep Quality. Capacity of sleep to restore waking function. Good quality sleep has minimal disruption to the non-REM/REM cycle. Fragmentation of the non-REM/REM cycle by waking up, or by brief arousals that move the brain to a lighter stage of sleep without actually waking up, decreases the restorative value of sleep.

Sleep Restriction. Obtaining less sleep than needed. The effects of sleep restriction accumulate, with performance impairment and objective sleepiness increasing progressively. The need for sleep will eventually build to the point where people fall asleep uncontrollably (see ***micro-sleep***).

Slow-Wave Sleep. The two deepest stages of non-REM sleep (stages 3 and 4), characterized by high amplitude slow brainwaves.

Standby. A defined period of time, during which an individual is required by the service provider to be available to receive an assignment for a specific duty. Synonymous with ***on call***.

Transient fatigue. Impairment accumulated across a single duty period, from which complete recovery is possible during the next rest period.

Trip. A scheduling expression describing the time from when a flight crewmember initially reports for duty until he/she returns home from the sequence of flights and is released from duty. A trip may include multiple flights and many days of travel (see ***Pairing***).

Unforeseen operational circumstance**.** Unexpected conditions that could not reasonably have been predicted and accommodated, such as bad weather or equipment malfunction, which may result in necessary on-the-day operational adjustments.

Unrestricted sleep. Sleep which is not restricted by any demands. Sleep can begin when an individual feels sleepy, and does not have to be delayed for any reason. In addition, the individual can wake up spontaneously and does not have to set the alarm.

Window of Circadian Low (WOCL) Time in the circadian body clock cycle when fatigue and sleepiness are greatest and people are least able to do mental or physical work. The WOCL occurs around the time of the daily low point in core body temperature - usually around 0200-0600 when a person is fully adapted to the local time zone. However, there is individual variability in the exact timing of the WOCL.

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CHAPTER 1. INTRODUCTION TO FATIGUE MANAGEMENT

The aviation industry provides one of the safest modes of transportation in the world. Nevertheless, a safety critical industry must actively manage hazards with the potential to impact safety. Fatigue is now acknowledged as a hazard that predictably degrades various types of human performance and can contribute to aviation accidents or incidents. Fatigue is inevitable in a 24/7 industry because the human brain and body function optimally with unrestricted sleep at night. As fatigue cannot be eliminated, it must be managed.

1.1. FATIGUE MANAGEMENT APPROACHES IN AVIATION

Fatigue management refers to the methods by which aviation Service Providers and individuals address the safety implications of fatigue. In general, ICAO Standards and Recommended Practices (SARPs) in various Annexes support two distinct approaches for managing fatigue of personnel:

1. a more prescriptive approach that requires the Service Provider to comply with duty time limits defined by the regulator, while managing fatigue hazards using the SMS processes that are in place for managing safety hazards in general ; and
2. a more performance-based approach that requires the Service Provider to implement a Fatigue Risk Management System (FRMS) that is approved by the regulator.

These approaches share two important basic features. First, they are based on scientific principles and operational knowledge and experience. Both should take into account:

- the need for adequate sleep (not just resting while awake) to restore and maintain all aspects of waking function (including alertness, physical and mental performance, and mood); and
- daily rhythms in the ability to perform mental and physical work, and in sleep propensity (the ability to fall asleep and stay asleep), that are driven by the circadian biological clock in the brain; and
- interactions between fatigue and workload in their effects on physical and mental performance; and
- the operational context and the safety-risk that a fatigue-impaired individual represents in that context.

Second, because fatigue is affected by all waking activities and not only work-related demands, fatigue management must be shared between the regulators, service providers and individuals:

- the regulator is responsible for providing a regulatory framework that enables adequate fatigue management and ensuring that the service provider is managing their fatigue-related risks to an acceptable level of safety;
- service providers are responsible for providing fatigue management education and implementing work schedules that enable individuals to perform their duties safely, and having processes for monitoring and managing fatigue hazards;
- individuals are responsible for arriving fit for duty, including making appropriate use of off-duty periods to obtain sleep and for reporting fatigue hazards.

1.2. FATIGUE MANAGEMENT IN GENERAL AVIATION AEROPLANE OPERATIONS

In commercial air transport operations, the two approaches to fatigue management require separate regulations. In general aviation operations, the situation is different. As is noted in the Foreword to Annex 6 — *Operation of Aircraft,* Part II — *International General Aviation — Aeroplanes*, it is not expected that general aviation should be regulated to the same level as commercial air transport. In general, the Annex 6 Part II SARPS do not require States to issue specific approvals. Approvals are specified only in a few instances.

Therefore, Annex 6, Part II Fatigue Management SARPs vary from those in other Annexes in that they do not mandate regulations for prescriptive limits for GA (aeroplane) flight crew or other operator personnel. Nor do they require GA operators to be subject to the same FRMS regulations, including an approval process, that a State may choose to offer.

Instead, an operator conducting international general aviation operations with large and turbojet aeroplanes is required to establish a fatigue management programme to ensure that operator personnel involved in the operations and maintenance of aircraft are performing at an adequate level of alertness. To do so, a GA operator conducting international operations with large and turbojet aeroplanes is required to establish flight and duty time limitations for aircraft crew members and duty time rules for other employees involved in the operation and maintenance of aircraft where fatigue may be an issue. These limitations are to be documented in their operations manual. Such limitations should be based on scientific principles (see Chapter 2) and used to implement informed scheduling practices (see Chapters 2 and 3).

GA operators conducting international general aviation operations with large and turbojet aeroplanes are also required by ICAO, as referenced in Annex 19, Section 4.2, to have a Safety Management System (SMS) that is commensurate with the size and complexity of the operation. An effective SMS should ensure management of all known risks, including those related to fatigue. For international GA aeroplane operations, the use of SMS processes, together with the development of scientifically-based flight and duty time limitations and informed scheduling practices, forms the basis of a fatigue management programme, as required in Annex 6, Part II, Section 3.4.2.8. This manual contains information to help international GA aeroplane operators to implement such a programme. In addition, GA aeroplane operators conducting domestic operations who have decided to use an SMS in their operations may also find this document helpful[2].

An FRMS, or some of the more rigorous FRMS Risk Management processes, should be considered when the fatigue-related risks associated with particular GA operations are considered high.

In an SMS, fatigue is only one of the possible safety risks considered. In contrast, an FRMS is a specialized system that focuses only on the management of fatigue risks. The structure of an FRMS is modeled on the SMS framework but has particular requirements (e.g. an increased reliance on specific types of data collection and analysis, enhanced processes specifically established to address fatigue risks, and more comprehensive fatigue management training) and an associated management structure. Therefore, the resources and methods dedicated to managing fatigue using SMS processes as described in this document are less complex and onerous than those required in an FRMS. However, GA operators are not precluded from using an FRMS approach and some of the methods more commonly associated with an FRMS may need to be considered when the fatigue-related risks in particular GA operations are considered high.

[2] It should be noted that this manual is directed specifically at GA *aeroplane* operators and not GA *helicopter* operators, whose organisational and operational context can differ significantly. For the purposes of this document, GA aeroplane operators will be referred to simply as "GA operators".

Further information that may assist GA operators in using FRMS methods is contained in another manual in the Fatigue Management suite - *The Fatigue Management Guide for Airline Operators.* It can be downloaded from the ICAO web site http://www.icao.int.

1.3. ICAO SARPS FOR FATIGUE MANAGEMENT IN GA OPERATIONS

The two fatigue management SARPs in Annex 6, Part II are presented in different Sections:

- Section 2 is primarily focused on the pilot-in-command in any international general aviation aeroplane operation. Paragraph 2.2.5.2 of this section (Duties of pilot-in-command) presents a Standard which outlines the responsibilities of the pilot-in-command with regards to managing fatigue risks.
- Section 3 applies to operators of large and turbojet aeroplanes conducting international general aviation operations. Paragraph 3.4.2.8 of this section (Fatigue Management Programme) outlines the fatigue management responsibilities of such operators.

The Annex 6 Part II Fatigue Management SARPs are presented below.

1.3.1. ANNEX 6, PART II, SECTION 2.2.5 – DUTIES OF PILOT-IN-COMMAND

2.2.5.2 *The pilot-in-command shall be responsible for ensuring that a flight:*

a) will not be commenced if any flight crew member is incapacitated from performing duties by any cause such as injury, sickness, fatigue, the effects of any psychoactive substance; and

b) will not be continued beyond the nearest suitable aerodrome when flight crew members' capacity to perform functions is significantly reduced by impairment of faculties from causes such as fatigue, sickness or lack of oxygen.

Intent: This performance-based Standard specifies the broad responsibility of the pilot-in-command to ensure that flight crew members are not fatigued at the commencement of a flight or are not suffering the effects of fatigue to a degree that would significantly impair their capacity to perform their functions during a flight. International GA operators should provide guidance to pilots in their operations manual on meeting these responsibilities.

Chapter 2 contains information which will help operators and pilots to understand fatigue and its effects on human performance.

1.3.2. ANNEX 6, PART II, SECTION 3.4.2 – OPERATIONAL MANAGEMENT

3.4.2.8 *Fatigue management programme*

An operator shall establish and implement a fatigue management programme that ensures that all operator personnel involved in the operation and maintenance of aircraft do not carry out their duties when fatigued. The programme shall address flight and duty times and be included in the operations manual.

Intent: Operators conducting international general aviation operations with large and turbojet aeroplanes are responsible for establishing a fatigue management programme to ensure personnel are performing at an adequate level of alertness. To do so, international GA operators must:

- establish flight and duty time limitations for aircraft crew members and duty time rules for other employees involved in the operation and maintenance of aircraft where fatigue may be an issue. These limitations are to be documented in their operations manual; and
- manage their risks (including those related to fatigue) using their existing SMS processes (as per Annex 19, Section 4.2).

It should be noted that this Standard refers to "operator personnel". It is intended to include personnel directly employed by the international GA operator and is not intended to include personnel employed by organizations that the operator has contracted with to perform operational and maintenance functions. However, operators are responsible for managing risks to their operations, and may address the issue of fatigue of contractor personnel, as part of their normal SMS activities.

CHAPTER 2. SCIENTIFIC PRINCIPLES FOR FATIGUE MANAGEMENT

The operational demands on crewmembers continue to change in response to changes in technology and commercial pressures, but human physiology remains unchanged. Advances in scientific understanding of human physiology can help GA operators to manage fatigue risk and increase operational safety and sometimes increase operational flexibility.

Fatigue results in a reduced capability to carry out operational duties. It can be considered an imbalance between:

- the physical and mental demands of all waking activities (not only duty demands); and
- recovery from those demands, which (except for recovery from muscle fatigue) requires sleep.

Following this line of thinking, to reduce fatigue in operations, strategies are required to manage the demands of waking activities and to improve sleep. Two areas of science are central to this and are the focus of this chapter.

1. Sleep science — particularly the effects of not getting enough sleep (on one night or across multiple nights), and how to recover from sleep loss; and
2. Circadian rhythms — daily cycles in physiology and behaviour that are driven by the circadian body clock (a pacemaker in the brain). Circadian rhythms include:
    - rhythms in subjective feelings of fatigue and sleepiness;
    - rhythms in the ability to perform mental and physical work; and
    - rhythms in the ability to fall asleep and stay asleep (sleep propensity).

This chapter summarizes the science under four key principles:

1. Periods of wake need to be limited. Getting enough sleep (both quantity and quality) on a regular basis is essential for restoring the brain and body,.
2. Reducing the amount or the quality of sleep, even for a single night, decreases the ability to function and increases sleepiness the next day.
3. The circadian body clock affects the timing and quality of sleep and produces daily highs and lows in performance capacity on various tasks.
4. Workload can contribute to crewmember fatigue. Low workload may unmask physiological sleepiness while high workload may exceed the capability of a fatigued individual.

2.1. SCIENTIFIC PRINCIPLE 1: THE NEED FOR SLEEP

Have you ever wondered what happens from the time you fall asleep at night to when you wake up in the morning? If you have slept well, you will wake up feeling physically and mentally refreshed. Your experiences of the previous day will have been sorted, stored, and linked to your existing memories so that you wake up with a seamless sense of who you are. If you have not slept well, you know that the coming day will not be easy.

SCIENTIFIC PRINCIPLE 1

PERIODS OF WAKE NEED TO BE LIMITED. GETTING ENOUGH SLEEP (BOTH QUANTITY AND QUALITY) ON A REGULAR BASIS IS ESSENTIAL FOR RESTORING THE BRAIN AND BODY.

We are meant to spend about a third of our lives asleep. The optimal amount of sleep per night varies between individuals, but most adults require between 7 and 9 hours. There is a widespread belief that sleep time can be traded off to increase the amount of time available for waking activities in a busy lifestyle. However, sleep science makes it very clear that sleep cannot be sacrificed without consequences. Sleep has multiple functions – the list keeps growing - but it is clear that it has vital roles in memory and learning, in maintaining alertness, performance, and mood, and in overall health and well-being.

2.1.1. TYPES OF SLEEP

A complex series of processes is taking place in the brain during sleep. Various methods have been used to look at these processes, from reflecting on dreams to using advanced medical imaging techniques. Sleep scientists have traditionally looked at sleep by monitoring electrical patterns in brain wave activity, eye movements, and muscle tone. These measures indicate that there are two very different types of sleep:

- Non-rapid eye movement (Non-REM) sleep; and
- Rapid eye movement (REM) sleep.

NON-RAPID EYE MOVEMENT SLEEP (NON-REM SLEEP)

During non-rapid eye movement sleep (non-REM sleep), brainwave activity gradually slows compared to waking brainwave activity. The body is being restored through muscle growth and repair of tissue damage. Non-REM sleep is sometimes described as "a quiet brain and quiet body." Across a normal night of sleep, most adults normally spend about three quarters of their sleep time in non-REM sleep.

Non-REM sleep is divided into three stages, based on the characteristics of the brainwaves. Stages 1 and 2 represent lighter sleep (it is not very difficult to wake someone up). It is usual to enter sleep through Stage 1 and then Stage 2 non-REM.

Sleep is a complex series of processes that has multiple functions.

Stage 3 non-REM sleep is also known as slow-wave sleep (SWS) or deep sleep. Basically, in SWS the brain stops processing information from the outside world and huge numbers of brain cells (neurons) start firing in synchrony, generating big, slow electrical waves. More stimulation is needed to wake someone up than from non-

REM Stages 1 and 2. During SWS, consolidation of certain types of memory is occurring, so SWS is necessary for learning. Waking up from SWS, various parts of the brain have to reactivate in sequence.

The longer you are awake and the more physically active you are, the more slow-wave activity your brain will show in your next sleep period. Thus SWS fits the traditional idea that sleep somehow restores you from the demands of waking activities. This is sometimes described as the 'sleep homeostatic process'.

RAPID EYE MOVEMENT SLEEP (REM SLEEP)

During non-rapid eye movement sleep (non-REM sleep) brainwave activity looks similar to waking brainwave activity. However in REM sleep, from time to time the eyes move around under the closed eyelids — the so-called "rapid eye movements" — and this is often accompanied by muscle twitches and irregular heart rate and breathing. Most adults normally spend about a quarter of their sleep time in REM sleep.

There are two different types of sleep: non-REM and REM (rapid eye movement) sleep.

During REM sleep, the brain is repairing itself and information from the previous day is being sorted and related to stored memories. People awakened from REM can typically recall vivid dreaming. During REM sleep, the body cannot move in response to signals from the brain, so dreams cannot be acted out. (The signals effectively get blocked in the brain stem and cannot get through to the spinal cord.) People sometimes experience brief paralysis when they wake up out of a dream, when reversal of this "REM block" is slightly delayed. Because of these features, REM sleep is sometimes described as a "busy brain and paralyzed body".

Figure 2.1 summarizes the proportion of night time sleep that a young adult typically spends in each of the types of sleep.

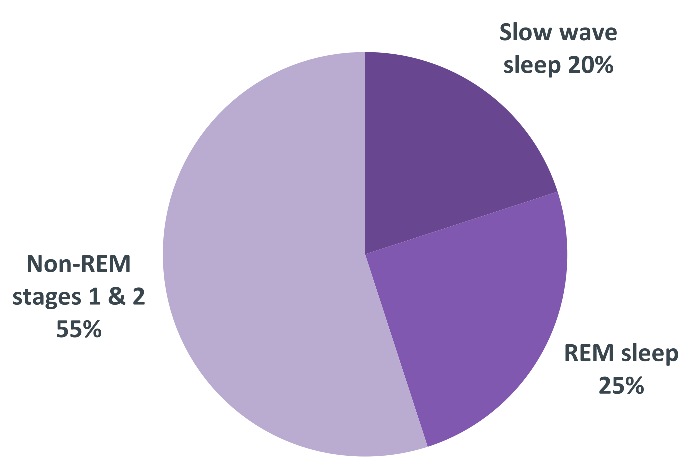

Figure2-1. Proportion of the night spent in each types of sleep, for a young adult

2.1.2. THE NON-REM/REM CYCLE

Across a normal night of sleep, non-REM sleep and REM sleep alternate in a cycle that lasts roughly 90 minutes (but is very variable in length, depending on a number of factors). Figure 2-2 is a diagram summarizing the non-REM/REM cycle across the night in a healthy young adult who goes to bed at 11:00 pm and wakes around 07:30am. Real sleep is not as tidy as this — it includes more arousals (transitions to lighter sleep) and brief awakenings. Sleep stages are indicated on the vertical axis and time is represented across the horizontal axis.

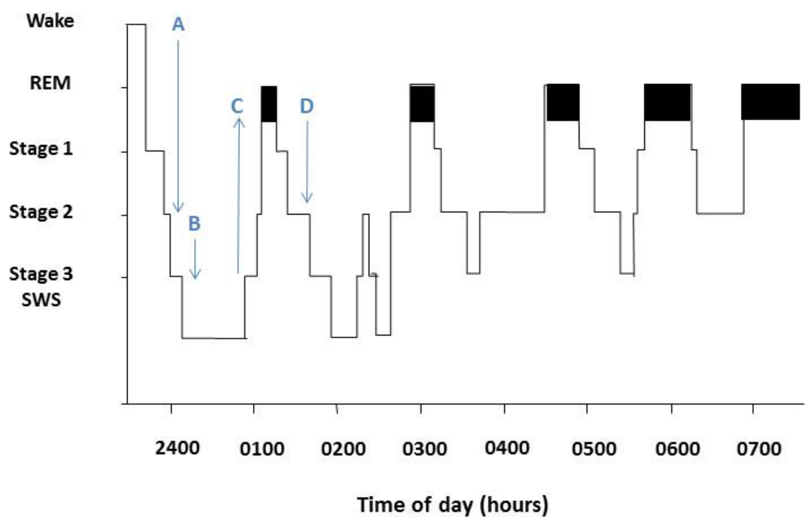

Figure 2-2. The non-REM/REM cycle across the night, for a healthy young adult

Sleep is entered through Stage 1 non-REM and then progresses through Stage 2 non-REM (see 'A' in Figure 2-2) and eventually into slow-wave sleep (see 'B' in Figure 2-2). About 80-90 minutes into sleep, there is a shift out of slow-wave sleep (see 'C' in Figure 2-2). This shift is often marked by body movements, as the sleeper transitions briefly through Stage 2 non-REM and into the first REM period of the night (REM periods are indicated as shaded boxes in Figure 2-2). After a fairly short period of REM, the sleeper progresses back down again through lighter non-REM sleep (see 'D' in Figure 2-2) and into slow-wave sleep, and so the cycle repeats. In the morning, the sleeper in Figure 2.2 wakes up out of REM sleep and is likely to be able to remember dreaming.

In each non-REM/REM cycle across a normal night of sleep:

- the amount of slow-wave sleep decreases (there may be none at all in later cycles); and
- in contrast, the amount of REM sleep increases.

People sometimes experience grogginess or disorientation when they first wake from sleep. This is known as sleep inertia. It can occur when waking from any stage of sleep but may be worse after longer periods of sleep.

OPERATIONAL IMPLICATION 1.
MITIGATION STRATEGIES FOR SLEEP INERTIA

For GA Operators providing quick response services, sleep inertia can pose a significant risk. The risk of sleep inertia can be reduced by having a protocol for returning to active duty that limits the duration of sleep or allows time for sleep inertia to wear off (see *Operational Implication 5: Napping as a Fatigue Mitigation)*. It is suggested that at least 10-15 minutes should be allowed before recommencing safety-related duties.

Sometimes, however, crew can be woken unexpectedly, for example by an alarm or a phone call from dispatch, and need to respond or operate almost immediately. Below are some examples of effective strategies used by operators to manage the adverse effects that sleep inertia can have on performance,

- When dispatch call to wake up a night standby crew, they ask crew to get in uniform and to then call dispatch back to receive the mission details. This strategy has helped to reduce misunderstandings that were being caused by sleep inertia.
- Missions at night are classified as time critical and non-time critical. When crew are woken to operate a non-time critical mission at night, the response time is extended by 20 minutes. While they prepare for the mission some crew have a cup of coffee, as this has been shown to help alleviate sleep inertia. The crew do not takeoff until sleep inertia has dissipated.
- Driving performance is particularly susceptible to sleep inertia. Therefore, one operator has expanded their office to include a bedroom for each crew member working a night standby duty. The bedrooms are temperature controlled, dark, quiet and comfortable.

2.1.3. FACTORS THAT AFFECT SLEEP QUALITY

Sleep quality (its restorative value) depends on going through unbroken non-REM/REM cycles (which suggests that both types of sleep are necessary and one is not more important than the other). The more the non-REM/REM cycle is fragmented by waking up, or by arousals that move the brain to a lighter stage of sleep without actually waking up, the less restorative value sleep has in terms of how you feel and function the next day.

For sleep to be fully restorative, it must contain unbroken cycles of non-REM and REM sleep.

OPERATIONAL IMPLICATION 2.
PROCEDURES FOR MINIMISING SLEEP INTERRUPTIONS

Uninterrupted non-REM/REM cycles are the key to good quality sleep, so operators should develop procedures that minimize interruptions to crewmembers' sleep.

Rest periods (in flight or on layovers) should include protected blocks of time (sleep opportunities) during which crewmembers are not contacted except in emergencies. These protected sleep opportunities need to be known to crewmembers and all other relevant personnel. For example, calls from crew scheduling should not occur during a rest period as they can be extremely disruptive.

Operators should also develop procedures to protect crewmember sleep at layover and napping facilities. For example, if a rest period occurs during the day at a layover hotel, the operator should make arrangements with the hotel to restrict access to the section of the hotel where crewmembers are trying to sleep (such as no children, crewmembers only) and instruct their staff to honor the necessary quiet periods (for example, no maintenance work or routine cleaning).

SLEEP QUALITY AND AGING

Across adulthood, the proportion of sleep time spent in slow-wave sleep declines, particularly among men. In addition sleep generally becomes more fragmented after about age 50-60 years. These age-related trends are seen in the sleep of flight crewmembers, both on the ground and in the air[3]. A study of in-flight sleep on delivery flights of B-777 aircraft (from Seattle to Singapore or Kuala Lumpur) found that older pilots took longer to fall asleep, obtained less sleep overall, and had more fragmented sleep than their younger colleagues.

It is not yet clear whether these age-related changes in sleep reduce its effectiveness for restoring waking function. Laboratory studies that experimentally fragment sleep are typically conducted with young adults. On the flight deck, experience (both in terms of flying skills and knowing how to manage sleep on trips) could help reduce potential fatigue risk associated with age-related changes in sleep. From both practical and scientific perspectives, age is not considered to be a specific factor to be addressed in order to manage fatigue.

Sleep quality declines as a normal part of aging.

[3] Signal TL, Gander PH, van den Berg M. Sleep in flight during long rest opportunities. Internal Medicine Journal 34(3): A38, 2004.

SLEEP DISORDERS

The quality of sleep can also be disrupted by a wide variety of sleep disorders, which make it impossible to obtain restorative sleep, even when people spend enough time trying to sleep. Sleep disorders pose a particular risk for crewmembers because, in addition, they often have restricted time available for sleep. As part of an FRMS, training should include basic information on sleep disorders and their treatment, where to seek help if needed, and any requirements relating to fitness to fly.

Sleep disorders can reduce the amount and quality of sleep a person can obtain, even when they spend enough time trying to sleep.

CAFFEINE, NICOTINE, AND ALCOHOL

Caffeine (in coffee, tea, energy drinks, colas and chocolate) stimulates the brain, making it harder to fall asleep and disrupting the quality of sleep. Some people are more sensitive to effects of caffeine than others, but even heavy coffee drinkers will have lighter and more disturbed sleep if they drink coffee close to bedtime (although they may not even notice this). Nicotine in cigarettes is also a stimulant and affects sleep in a similar way. Alcohol on the other hand makes us feel sleepy but it also disturbs sleep. While the body is processing alcohol (at the rate of about one standard drink per hour), the brain cannot obtain REM sleep. Pressure for REM sleep builds up, and sleep later in the night often contains more intense REM periods and is more disturbed as a consequence.

Caffeine, nicotine, and alcohol can disrupt sleep quality.

OPERATIONAL IMPLICATION 3.
STRATEGIC USE OF CAFFEINE

Caffeine can be useful to temporarily reduce sleepiness on duty because it blocks a chemical in the brain (adenosine) that increases sleepiness. It can also be used in advance of a period that is likely to be associated with higher fatigue (e.g. the early hours of the morning). Caffeine takes approximately 30 minutes to have an effect and can last for up to 5 hours, (but people differ widely in how sensitive they are to caffeine and how long the effects last). It is important to remember that caffeine does not remove the need for sleep and it should only be used as a short term strategy. For maximum benefit, caffeine should be avoided when alertness is high, such as at the beginning of a duty period, and instead used at times when sleepiness is expected to be high, e.g. towards the end of a long duty period or at the times in the circadian body clock cycle when sleepiness is greater.

ENVIRONMENTAL FACTORS

The sleep environment can affect sleep quality.

Environmental factors can also disturb sleep. Bright light increases alertness (and can be a short-term countermeasure to temporarily relieve fatigue in the work environment). It is much easier to sleep in a dark room. Heavy curtains or a mask can be used to block out light. Sudden sounds also disturb sleep. Masking them using white noise can help, for example tuning the radio in the hotel room between stations. Falling asleep requires being able to lower core body temperature (by losing heat through the extremities), so it is easier to fall asleep if the room is cooler rather than hotter. For most people (18-20 °C/ 64-68 °F) is an ideal room temperature for sleep. A comfortable sleep surface is also important.

QUALITY OF IN-FLIGHT SLEEP

Sleep obtained at work is often not as good quality as sleep under normal conditions at home.

Studies using polysomnography show that crewmembers' sleep in onboard crew rest facilities is lighter and more fragmented than their sleep on the ground[4]. Sleep during flight deck naps is also lighter and more fragmented than would be predicted from laboratory studies[5]. Nevertheless, there is good evidence that in-flight sleep improves subsequent alertness and reaction speed and is a valuable mitigation strategy in fatigue management. Interestingly, the fragmented quality of in-flight sleep is not seen in studies in hypobaric chambers at cabin pressures (6,000-8,000 feet), so it cannot be due to altitude[6]. The factors most commonly identified by crewmembers as disturbing their in-flight sleep are random noise, thoughts, not feeling tired, turbulence, ambient aircraft noise, inadequate bedding, low humidity, and going to the toilet.

QUALITY OF SLEEP WHEN ON STANDBY

Sleep may also be disturbed if there is an expectation of being woken and called back to work. A laboratory study compared the sleep of people who were told on one night that they may be woken and required to respond to a noise, to their sleep on another night when they received no instructions[7]. The findings showed that it took people longer to fall asleep and they spent longer awake during the night when they expected to be woken. In this study the noise never occurred so sleep was not disturbed by external factors.

Sleep obtained when on call may be poorer quality.

A limited number of field studies have looked at the effects on sleep quality of being on-call. For example, an older polysomnographic study of the sleep of ships engineers found that sleep during on-call nights (with an average of two

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[4] Signal TL, Gale J, Gander PH. Sleep Measurement in Flight Crew: Comparing actigraphic and subjective estimates of sleep with polysomnography. Aviation Space and Environmental Medicine 76(11):1058-1063, 2005.

[5] Rosekind MR, Graeber RC, Dinges DF, et al. Crew Factors in Flight Operations IX: Effects of planned cockpit rest on crew performance and alertness in long haul operations. NASA Technical Memorandum 108839, Moffett Field: NASA Ames Research Center, 1994.

[6] Mumm JM, Signal TL, Rock PB, Jones SP, O'Keeffe KM, Weaver MR, Zhu S, Gander PH, Belenky G. Sleep at simulated 2438 m: effects on oxygenation, sleep quality, and post-sleep performance. Aviation, Space, and Environmental Medicine 80 (8):691-697, 2009.

[7] Wuyts, J., De Valck, E., Vandekerchove, M., Pattyn, N., Exadaktylos, V. Haex, B., Verbraecken, J. and Cluydts, R. (2012) Effects of pre-sleep simulated on-call instructions on subsequent sleep. *Biological Psychology*, 91:383-388.

alarms) was shorter and contained more light non-REM sleep, less slow-wave sleep, and less REM sleep, and higher heart rate than sleep on nights when engineers were not on call[8]. Many of these effects were observable before any alarms had occurred on on-call nights. In addition, engineers rated their sleep quality as lower on on-call nights and their sleepiness as higher on the day following an on-call night. These findings and subsequent studies with junior doctors support the idea that the anticipation of being called for duty somehow interferes with sleep quality.

2.1.4. THE IMPACT OF CONTINUOUS TIME AWAKE

Scientific evidence shows that the longer a crewmember remains awake, the worse their alertness and performance become. This is due to an increasing homeostatic pressure for sleep associated with the longer period of wakefulness. . Sleep is the only way to reverse this.

The US National Transportation Safety Board has examined the relationship between time since awakening (TSA) and errors in 37 aircraft accidents (1978-1990) in which flight crew actions or inactions were causal or contributing factors[9]. The median TSA at the time of the accident was 12 hours for captains and 11 hours for first officers. Six crews were classified as low TSA (both the captain and the first officer were below the median) and six crews were classified as high TSA (both the captain and the first officer were above the median). For low TSA crews, the median time awake was 5.3 hours for captains and 5.2 hours for first officers. For high TSA crews the median time awake was 13.8 hours for captains and 13.4 hours for first officers. Overall, high TSA crews made about 40% more errors than low TSA crews (12.2 versus 8.7 errors), primarily due to making more errors of omission (5.5 versus 2.0 errors). In terms of error types, high TSA crews made significantly more procedural errors and tactical decision errors than low TSA crews.

Research supports the benefits of napping as a mitigation in flight operations. For two-pilot crews on long range flights, planned 40-minute nap opportunities on the flight deck seat have been shown to provide an average of 23 minutes of sleep and to improve alertness and performance at top of descent, with no apparent effect on subsequent layover sleep[10]. Note that not all regulators permit flight deck napping.

A short nap can improve alertness and performance and is a valuable mitigation strategy in fatigue management.

[8] Torsvall L, Akerstedt T. Disturbed sleep while being on-call: an EEG study of ships' engineers. Sleep, 11: 35-38, 1998.
[9] National Transportation Safety Board Safety Study 94/01.
[10] Rosekind MR, Graeber RC, Dinges DF, et al. Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations. NASA Technical Memorandum 108839, 1994.

OPERATIONAL IMPLICATION 4.
PROTOCOLS FOR STANDBY, RESERVE AND ON-CALL DUTIES

Although standby, reserve and on-call duties lack the certainty associated with scheduled shifts, the same scientific principles still apply. It is important to establish protocols for assigning unscheduled duties that aim to:

- *Minimize interruptions during circadian times when sleep is more likely*. *(*Circadian influences are further discussed in *Section 2.3: Circadian Effects on Sleep and Performance)*

  During periods of being on standby, reserve or on-call, there will be times when an individual is more likely to be able to sleep. Therefore, interruptions (such as non-urgent phone calls from work) during those times should be minimised as much as possible.

- *Minimize continuous hours of wakefulness before and during duty periods that are unscheduled.*

  When being called-in is highly likely, establishing minimal notification periods before the individual can be asked to report for duty allows some the opportunity for some sleep. If minimal notification periods are not operationally feasible, an extended duty is required or a call-back occurs late in the day or during the night, naps will reduce increasing sleep pressure over extended waking hours. Consideration should be given to appropriate napping facilities and the establishment of napping protocols (See *Operational Implication 5: Napping as a Fatigue Mitigation*.

- *Build in some level of schedule predictability*.

  Being on call, even when you are not called out, involves being in a state of constant readiness and may affect the quantity and quality of sleep obtained. . Therefore, the time of day for potential duty should be predictable and consistent, and the number of consecutive days that an individual may be subject to being assigned unscheduled duties should be limited. . This provides some level of consistency in the timing of duty periods and allows for individuals to plan and manage their sleep periods.

Further information on assigning unscheduled duties ins provided in Section 4.1.3 *Principles for Designing and Managing Pairings and Rosters – Assigning Unscheduled Duties*

OPERATIONAL IMPLICATION 5.
NAPPING AS A FATIGUE MITIGATION

When a person has been awake for a long period of time or if they have not had enough sleep over one or more days, some sleep is always better than none. Napping is a mitigation that can help maintain performance and alertness in the short term, until a more substantial sleep opportunity becomes available. Napping should not be used as a means of extending a duty period, which requires the opportunity for longer sleep periods with the provision of appropriate facilities.

Napping before work: When a duty period starts later in the day (e.g. in the evening or at night) a nap prior to commencing work will reduce the period of wakefulness and help maintain performance and alertness during the work period. It has been shown that napping prior to work does not reduce the amount of sleep obtained during an in-flight rest period.

Napping during a duty period: Napping during a duty period (e.g. on the ground while the aircraft is being loaded and unloaded or in-flight under certain conditions), can help maintain performance during extended work periods or during duty periods at night. How such naps are managed will depend on the context in which they occur and where they can be taken (e.g. in the cockpit versus in the cabin; in specially appointed sleeping facilities versus in makeshift conditions). The length of the nap will depend largely on the available time away from duties but it should allow enough time for individuals to fall asleep (it may take people longer than usual to fall asleep in these circumstances) and enough time after waking before recommencing duties to ensure that any sleep inertia has dissipated (see Operational Implication 1: Mitigation Strategies for Sleep Inertia). It is also critical that individuals are educated to not reduce their sleep time in anticipation of an nap during a flight or duty period. If they sleep less before work because they assume they will get a nap at work, then the overall benefit of allowing napping may be negated.

Controlled rest on the flight deck:: These types of naps are taken by pilots in response to unexpected fatigue experienced during operations. If these are allowed, they need to be supported by specific guidance material and policies to ensure operational integrity and continued safe operations when this fatigue mitigation measure is necessary (see Section 4.2.9 for further information on controlled rest on the flight deck).

2.2. SCIENTIFIC PRINCIPLE 2: SLEEP LOSS AND RECOVERY

Even for people who have good quality sleep, the amount of sleep they obtain is very important for restoring their waking function.

SCIENTIFIC PRINCIPLE 2

REDUCING THE AMOUNT OR THE QUALITY OF SLEEP, EVEN FOR A SINGLE NIGHT, DECREASES THE ABILITY TO FUNCTION AND INCREASES SLEEPINESS THE NEXT DAY.

2.2.1. SLEEP RESTRICTION IN THE LABORATORY

Numerous laboratory studies have looked at the effects of 'trimming' sleep at night by an hour or two (known as sleep restriction). Losing as little as two hours of sleep on one night will reduce alertness the next day and degrade performance on many types of tasks. Studies that have restricted sleep on multiple nights in a row have key findings that are important for fatigue management.

EFFECTS OF SLEEP RESTRICTION ACCUMULATE AND ARE DOSE-DEPENDENT

The effects of restricting sleep night after night accumulate, so that people become progressively less alert and less functional each subsequent day. This is sometimes described as *accumulating a sleep debt*. This is a common occurrence for crewmembers .

The shorter the time allowed for sleep each night, the faster alertness and performance decline. For example, one laboratory study found that spending 7 hours in bed for 7 consecutive nights was not enough to prevent a progressive slowing down in reaction time[11]. The decline was more rapid for a group of participants who spent only 5 hours in bed each night, and even more rapid for a group who spent only 3 hours in bed each night. This is described as a dose-dependent effect of sleep restriction.

The effects of restricting sleep night after night accumulate. Less sleep per day = more rapid performance degradation.

SOME TYPES OF TASKS ARE MORE AFFECTED THAN OTHERS

Insufficient sleep impacts many facets of cognitive functioning with the most consistent and largest effects found when measuring processing speed and attention. However, brain imaging studies suggest that the brain regions involved in more complex mental tasks (for example anticipating events, planning and determining relevant courses of action -particularly under novel situations) are the most affected by sleep loss and have the greatest need for sleep to recover their normal function. Studies using more complex cognitive tasks do show changes in short-term memory, mental arithmetic, executive

[11] Belenky G, Wesensten NJ, Thorne DR, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. Journal of Sleep Research 12:1-12, 2003.

functions and language with sleep loss but the findings are less consistent and the change in performance smaller than in studies using attention and reaction time tasks.

HOW YOU FUNCTION VERSUS HOW YOU FEEL

For the first few days of severe sleep restriction (for example, 3 hours in bed), people are aware that they are getting progressively sleepier. However, after several days they no longer notice any difference in themselves, even though their alertness and performance continues to decline. In other words, as sleep restriction continues, people become increasingly unreliable at assessing their own functional status. Therefore, both objective and subjective tests are useful in fatigue management. Objective ratings of fatigue and sleepiness are often considered more reliable for measuring fatigue-related impairment (see Appendix A of this guidance).

People are not very accurate at judging their alertness and performance after sleep has been restricted for several days.

SLEEPINESS CAN BECOME UNCONTROLLABLE

The pressure for sleep increases progressively across successive days of sleep restriction. Eventually, it becomes overwhelming and people begin falling asleep uncontrollably for brief periods, known as micro-sleeps. During a micro-sleep, the brain disengages from the environment (it stops processing visual information and sounds). In the laboratory, this can result in missing a stimulus in a performance test. Driving a motor vehicle, it can result in failing to take a corner. Similar events have been recorded on the flight deck during descent into major airports.

Sleepiness eventually becomes overwhelming and results in uncontrollable micro-sleeps.

SOME PEOPLE ARE MORE AFFECTED THAN OTHERS

Individuals vary widely in their ability to tolerate sleep loss.

At least in the laboratory, some people are more resilient to the effects of sleep restriction than others. Currently, there is a lot of research effort aimed at trying to understand why this is, but it is still too early for this to be applied in fatigue management (for example, by recommending different personal mitigation strategies for people who are more or less affected by sleep restriction).

LIMITATIONS OF LABORATORY SLEEP RESTRICTION STUDIES

Laboratory studies are currently the main source of information on the effects of sleep restriction, but they have some obvious limitations. Laboratory studies usually look at the effects of restricting sleep at night and participants sleep in a dark, quiet bedroom. More research is needed on the effects of restricting sleep during the day, and on the combination of restricted sleep and poor quality sleep. This limitation may mean that current understanding of the effects of sleep restriction is based on a 'best case scenario'.

When examining performance effects, laboratory studies have also focused on the performance of individuals, not people working together as a crew. More research is needed to improve understanding of how the fatigue levels of individual crewmembers affect the flight deck performance of two-pilot crews. For example, one simulation study with 67 experienced B747-400 crews found that sleep loss in the last 24 hours increased the total number of errors made by the crew (the captain was always the pilot flying)[12]. Paradoxically, greater sleep loss among first officers improved the rate of error detection, but greater sleep loss among captains led to a higher likelihood of failure to resolve errors that had been detected. Greater sleep loss was also associated with changes in decision making, including for some crews, a tendency to choose lower risk options, which would help mitigate fatigue risk.

2.2.2. SLEEP RESTRICTION IN FLIGHT OPERATIONS

Table 2.1 summarizes data on sleep restriction across different flight operations that were monitored by the NASA Fatigue Programme in the 1980s[13]. In these studies, crewmembers completed sleep and duty diaries before, during, and after a scheduled commercial trip. For each crewmember, his average sleep duration per 24 hours at home before the trip was compared with his average sleep duration per 24 hours on the study trip. During night cargo and long-haul trips, crewmembers often had split sleep (slept more than once in 24 hours).

Scheduling has undoubtedly changed since these studies, so in many cases the data in Table 2-1 are likely to be unrepresentative of the current situation. However, they indicate that sleep restriction is very common across different types of flight operations.

[12] Thomas MJW, Petrilli RM, Lamond NA, et al. Australian long haul fatigue study. In: Enhancing Safety Worldwide: Proceedings of the 59th Annual International Air Safety Seminar. Alexandria, USA, Flight Safety Foundation, 2006..

[13] Gander PH, Rosekind MR, Gregory KB. Flight crew fatigue VI: an integrated overview. Aviation, Space, and Environmental Medicine 69: B49-B60, 1998.

Table 2-1. Sleep restriction during commercial flight operations

	Short-haul	Night Cargo	Long-haul
crewmembers averaging at least 1 hour of sleep restriction per trip day	67%	54%	43%
crewmembers averaging at least 2 hours of sleep restriction per trip day	30%	29%	21%
length of trip	3-4 days	8 days	4-9 days
time zones crossed per day	0-1	0-1	0-8
number of crewmembers studied	44	34	28

Note: The night cargo trips included a 1-2 night break in the sequence of night shifts.

Splitting long-haul trips into 24 hours days is rather arbitrary, because the average duty day lasted 10.2 hours and the average layover lasted 24.3 hours.

2.2.3. RECOVERY FROM THE EFFECTS OF SLEEP RESTRICTION

Prolonged sleep restriction may have effects on the brain that can continue to affect alertness and performance days to weeks later [14]. Available laboratory studies do not yet give a clear answer to the question of how long it takes to fully recover from these effects. However, the following findings are reliable.

- Lost sleep is not recovered hour-for-hour, although recovery sleep may be slightly longer than normal sleep at night.
- At least two consecutive nights of unrestricted sleep are required for the non-REM/REM sleep cycle to return to normal.
  - Typically, on the first night of recovery, more SWS will occur, but this can limit the time available for REM sleep.
  - On the second night of recovery, the brain catches up on REM sleep.
  - Recovery of a normal non-REM/REM cycle may take longer if recovery sleep is not at night, or if a crewmember is not adapted to the local time zone.

Recovery of a normal sleep pattern after an accumulated sleep debt takes at least two nights of unrestricted sleep.

- If sleep restriction continues over multiple nights, then the recovery of waking alertness and performance will normally require more than two consecutive nights of unrestricted sleep.
  - One 10-hour sleep opportunity at night is not enough to recover from the cumulative effects of 5 nights of sleep restricted to 4 hours per night[15].

[14] Rupp TL, Wesensten NJ, Bliese PD, et al. Banking sleep: realization of benefits during subsequent sleep restriction and recovery. Sleep 32:311-321, 2009

- Three 8-hour sleep opportunities at night are not enough to recover from 7 nights of sleep restricted to 7 hours per night[16].

During prolonged low-level sleep restriction, it may be that the brain somehow reconfigures the way it manages tasks, so that we adapt by settling at a stable but sub-optimal level of alertness and performance. However, the prolonged recovery times seen in laboratory sleep restriction studies suggest that return to optimal performance may be a slow process. Longer periods of time off, such as blocks of annual leave, may be important for full recovery.

Recovery of waking alertness and performance after accumulating a sleep debt may take longer than two nights of unrestricted sleep.

OPERATIONAL IMPLICATION 6. ALLOWING FOR SLEEP RECOVERY

Because the effects of sleep restriction are cumulative, schedules must be designed to allow periodic extended opportunities for recovery. Recovery opportunities need to occur more frequently when daily sleep restriction is greater, because of the more rapid accumulation of fatigue.

The usual recommendation for a recovery opportunity is a minimum of two consecutive nights of unrestricted sleep. This is not necessarily 48 hours off duty. A 48-hour break starting at midnight will not allow most people two consecutive nights of unrestricted sleep (most people go to sleep before midnight). Conversely, a 40-hour break starting at 20:00 will allow most people two consecutive nights of unrestricted sleep.

Especially in irregular operations, procedures that allow a crewmember to continue sleeping until needed can reduce the rate of accumulation of sleep debt. For example, if on a short layover with a probable early departure the possible 0600h departure is delayed until 1000h, then a reliable procedure that allows the crew member to continue sleeping would be beneficial.

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[15] Banks S, Van Dongen HPA, Maislin G, et al. Neurobehavioral dynamics following chronic sleep restriction: dose-response effects of one night for recovery. Sleep 33:1013-26, 2010.

[16] Belenky G, Wesensten NJ, Thorne DR, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. Journal of Sleep Research 12: 1-12, 2003.

THE RECOVERY VALUE OF SPLIT SLEEP

The laboratory studies referenced earlier allowed participants a single sleep opportunity at night. However, split sleep is common during different types of flight operations. For example, in-flight sleep on long flights results in split sleep (either by the use of controlled rest or where augmented crews enable scheduled in-flight rest breaks). Layovers after transmeridian flights also commonly include split sleep, as do daytime layovers between night duty periods without transmeridian flights.

Laboratory studies suggest that having a restricted sleep period at night plus a daytime nap has equivalent recovery value to an identical total amount of sleep taken in one consolidated block at night.[17] However, these are short-term studies that take place in dark, quiet laboratory environments with no distractions, and participants are fully adapted to the local time zone. These conditions do not always apply in 24/7 flight operations, so careful consideration is needed before applying the findings to crewmembers.

An important advantage of split sleep is that it reduces the length of time that a crewmember is continuously awake (see *Section 2.1.4 The Impact of Continuous Time Awake, page 13*).

2.2.4. LONG-TERM SLEEP RESTRICTION AND HEALTH

Evidence from laboratory studies and from epidemiological studies that track the sleep and health of large numbers of people across time, indicates that chronic short sleep may have negative effects on health in the long term. This research suggests that people who report averaging less than 7 hours of sleep per night are at greater risk of becoming obese and developing type-2 diabetes and cardiovascular disease. There is still debate about whether habitual short sleep actually contributes to these health problems, or is just associated with them. In addition, flight crewmembers as a group are exceptionally healthy compared to the general population. What is clear is that good health depends not only on good diet and regular exercise, but also on getting enough sleep on a regular basis. Sleep cannot be sacrificed without consequences..

[17] Mollicone DJ, Van Dongen H, Rogers NL, et al. Response surface mapping of neurobehavioral performance: Testing the feasibility of split sleep schedules for space operations. Acta Astronautica 63: 833-40, 2008.

2.3. SCIENTIFIC PRINCIPLE 3: CIRCADIAN EFFECTS ON SLEEP AND PERFORMANCE

Sleeping at night is not just a social convention. It is programmed by the circadian clock - an ancient adaptation to life on our 24-hour rotating planet.

SCIENTIFIC PRINCIPLE 3

THE CIRCADIAN BODY CLOCK AFFECTS THE TIMING AND QUALITY OF SLEEP AND PRODUCES DAILY HIGHS AND LOWS IN PERFORMANCE ON VARIOUS TASKS.

Like other mammals, we have a circadian master clock located in a small cluster of cells (neurons) deep in the brain. The cells that make up the master clock are intrinsically rhythmic, generating electrical signals faster during the day than during the night. However, they have a tendency to produce an overall cycle that is a bit slow – for most people the 'biological day' generated by the master clock is slightly longer than 24 hours.

This master clock, also known as the circadian body clock, receives information about light intensity through a direct connection to special cells in the retina of the eye (this special light input pathway is not involved in vision). Being light sensitive enables the circadian body clock to stay in step with the day/night cycle. However, it also creates problems for crewmembers who have to sleep out of step with the day/night cycle (for example on domestic night cargo operations), or who have to fly across time zones and experience sudden shifts in the day/night cycle. The effects of light on the circadian body clock are considered in more detail later in this chapter.

The circadian body clock is a pacemaker in the brain that is sensitive to light through a specialized input pathway from the eyes (separate from vision).

Other parts of the brain and some other organs including the liver, kidneys, and gut, contain peripheral oscillators that generate their own local circadian rhythms. (Indeed, every cell in the body contains the 'clock genes' that are the basic molecular machinery for generating circadian rhythms.) The circadian body clock in the suprachiasmatic nucleus is at the top of a hierarchy, keeping the rhythms in other parts of the brain and body in step with the day/night cycle and with each other.

The circadian body clock programs humans for daytime wakefulness and night time sleepiness.

2.3.1. EXAMPLES OF CIRCADIAN RHYTHMS

It is not possible to directly measure the electrical activity of the circadian body clock in the SCN of human beings. However, many circadian rhythms in physiology and behaviour can be measured as a way of indirectly tracking the cycle of the circadian body clock. Figure 2.3 shows an example of some circadian rhythms of a 46-year old short-haul pilot monitored before, during, and after a 3-day pattern of flying on the east coast of the USA (staying in the same time zone[18]. The black horizontal bars indicate when he was on duty.

[18] Gander PH, Graeber RC, ,Foushee HC, Lauber JK, Connell LJ. Crew Factors in Flight Operations II: Psychophysiological Responses to Short-Haul Air Transport Operations. NASA Technical Memorandum #108856. Moffett Field: NASA Ames Research Center, 1994.

- He kept a daily diary of his activities, including when he slept (the shaded vertical bars in Figure 2-3).
- His core body temperature was monitored continuously (shown in the upper panel in Figure 2-3).
- In his logbook, he also rated his fatigue every 2 hours while he was awake, on a scale from 0 = most alert to 100 = most drowsy (shown in the lower panel in Figure 2-3).

His core temperature fluctuated by about 1 degree Celsius across the 24-hour day. Notice that his temperature started to rise each morning *before* he woke up. In effect, his body was preparing ahead of time for the greater energy demands of being more physically active. (If body temperature only began to rise after he started to be more physically active, it would be a lot harder to get up in the morning).

This crewmember did not feel at his best first thing in the morning. He tended to feel least fatigued about 2-4 hours after he woke up, after which his fatigue climbed steadily across the day. (He was not asked to wake up every 2 hours across the night to rate his fatigue).

Core body temperature is often used as a marker rhythm to track the cycle of the circadian body clock because it is relatively stable and easy to monitor. However, no measurable rhythm is a perfect marker of the circadian body clock cycle. For example, changes in the level of physical activity also cause changes in core temperature, which explains the small peaks and dips in temperature in Figure 2-3.

The circadian body clock affects every aspect of human functioning resulting in cycles of high performance and low performance.

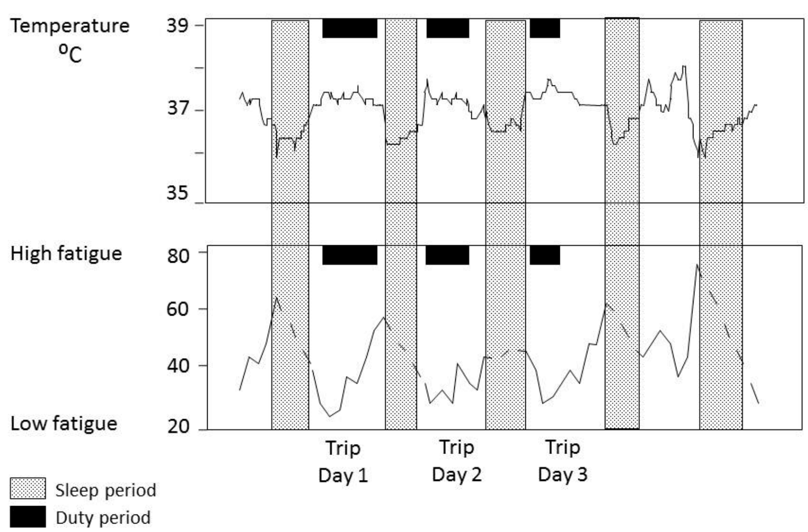

Figure2-3. Circadian rhythms of a short-haul pilot

2.3.2. SLEEP REGULATION: THE CIRCADIAN BODY CLOCK AND THE SLEEP HOMEOSTATIC PROCESS

The circadian body clock is one of two key processes that regulate sleep timing and quality (the other is the sleep homeostatic process, which is described in more detail below). The circadian body clock has connections to sleep-promoting and wake-promoting centres in the brain, which it modulates to control the sleep/wake cycle. It also influences the timing and amount of REM sleep. Just after the minimum in core body temperature, the brain goes more quickly into REM sleep and stays in REM for longer than at any other time in the circadian body clock cycle. This is sometimes described as a circadian rhythm in 'REM sleep propensity'. Thus, during a normal night of sleep, the longest bouts of REM sleep occur in the last non-REM cycles towards morning (see Figure 2-2).

Figure 2-4 is a diagram that summarises the relationships between sleep and the circadian body clock cycle (tracked here by the circadian rhythm in core body temperature). The figure is based on data collected from 18 night cargo pilots on their days off, i.e., when they were sleeping at night[19]. Their core body temperature was monitored continuously and they recorded their sleep and duty times in a daily diary. Their average core body temperature rhythm has been simplified (the continuous curve). The dot represents the average time of the temperature minimum, which is used as a reference point for describing the other rhythms.

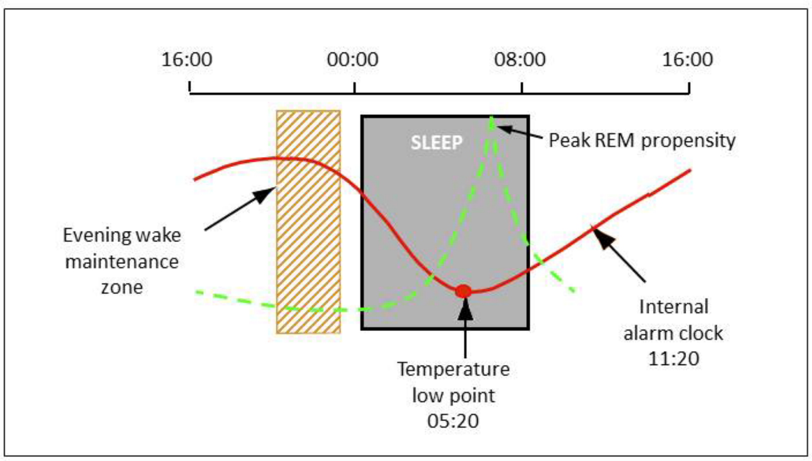

Figure 2-4. Relationships between normal sleep at night and the circadian body clock cycle[20]

[19] Gander PH, Rosekind MR, Gregory KB. Flight crew fatigue VI: an integrated overview. Aviation, Space, and Environmental Medicine 69: B49-B60, 1998.

[20] Figure provided by Prof. P. H. Gander, adapted from Gander PH et al (1998) Gregory, K.B., Connell, L.J., Graeber, R.C., Miller, D.L., and Rosekind, M.A. Flight crew fatigue IV: overnight cargo operations. *Aviation, Space, and Environmental Medicine 69:*B26-B36.

Figure2-4 highlights the following relationships:

The circadian clock exerts strong influence over sleep, creating windows when sleep is promoted and windows when sleep is opposed.

- Sleep normally begins about 5 hours before the minimum in core body temperature.
- Wakeup normally occurs about 3 hours after the minimum in core body temperature.
- REM sleep propensity (the dashed curve) peaks just after the minimum in core body temperature.
- As core body temperature begins to rise, the circadian body clock sends an increasingly strong signal to the brain centres that promote wakefulness, sometimes called the 'circadian alerting signal'. About 3 hours after waking up, homeostatic pressure for sleep is low (see below) and the circadian alerting signal is strong enough to make it very hard to fall asleep or stay asleep. This is sometimes referred to as the *internal alarm clock*.
- The circadian alerting signal is strongest just before usual bedtime. This makes it very difficult to fall asleep a few hours earlier than usual, and this part of the circadian body clock cycle is known as the *evening wake maintenance zone*.

The time around the daily minimum in core body temperature is the part of the circadian body clock cycle when people generally feel most sleepy and are least able to perform mental and physical tasks. This is sometimes described as the *Window of Circadian Low (WOCL).*

The Window of Circadian Low (WOCL), which occurs around the time of the daily minimum in core body temperature, corresponds to the time of day when people feel most sleepy and are least able to perform.

The second key process regulating sleep timing and quality is the sleep homeostatic process (see Principle 1, Section 2.1). This can be summarized as: your brain's need for sleep builds up while you are awake and the only way to discharge this pressure is to sleep. The homeostatic process can be tracked by the amount of slow-wave sleep.

- Across time awake, the pressure for slow-wave sleep builds up. The longer you are awake, the more slow-wave sleep you will have in the first few non-REM/REM cycles when you next sleep.
- Across sleep, the amount of slow-wave decreases in each subsequent non-REM/REM cycle. In other words, the pressure for slow-wave sleep is discharged across the sleep period.

Discharging the homeostatic pressure for sleep seems to take priority - slow-wave sleep is always greatest in the first non-REM/REM cycles, regardless of when that sleep occurs in the circadian body clock cycle.

The circadian body clock and the sleep homeostatic process interact to produce two times of peak sleepiness in 24 hours.

1. Sleepiness is greatest when people are awake during the *WOCL*, which occurs around 3-5 am for most people on a normal routine with sleep at night.
2. Sleepiness increases again in the early afternoon - sometimes called the afternoon nap window (around 3-5 pm for most people). Restricted or disturbed sleep at night makes it harder to stay awake during the next afternoon nap window.

The precise timing of the two peaks in sleepiness is different in people who are *morning types* (whose circadian rhythms and preferred sleep times are earlier than average) and *evening types* (whose circadian rhythms and preferred sleep times are later than average). Across the teenage years, most people become more evening-type. Across adulthood, most people become more morning-type. This progressive change towards becoming more morning-type has been documented in flight crewmembers across the age range 20-60 years.

The combined effects of the sleep homoeostatic pressure and the circadian body clock can be thought of as defining 'windows' when sleep is promoted (the early morning and afternoon times of peak sleepiness) and 'windows' when sleep is opposed (the time of the internal alarm clock in the late morning, and the evening wake maintenance zone).

2.3.3. HOW LIGHT SYNCHRONIZES THE CIRCADIAN BODY CLOCK

The cells (neurons) in the circadian body clock spontaneously generate electrical signals faster during the day than at night (usually described as 'firing' faster during the day than at night). Light exposure effectively increases the firing rate of the clock cells. Depending on when in the body clock cycle light is received, there are three possible outcomes:

1. Light in the morning shortens the body clock cycle in that cycle (known as a phase advance);
2. Light in the middle of the day does not change the body clock cycle length (no phase change); or
3. Light in the evening lengthens the body clock cycle in that cycle (known as a phase delay).

Figure2-5 shows graphically how these different responses are possible. The solid line in each panel represents the circadian rhythm in firing rate of the circadian body clock cells.

- In the left hand panel, light speeds up the rising part of the body clock cycle, leading to a phase advance.
- In the middle panel, light causes no phase change.
- In the right hand panel, light slows down the falling part of the body clock cycle, leading to a phase delay.

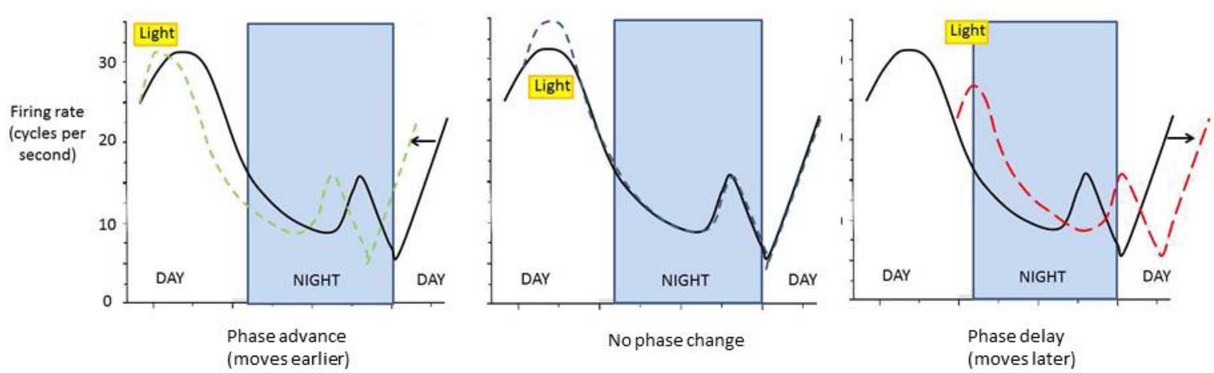

Figure2-5 Effects of light on the circadian body clock at different times in its cycle

Bright light causes bigger shifts in the circadian body clock cycle than dim light, and the clock is particularly sensitive to blue light.

In summary, for a crewmember fully adapted to the local time zone and sleeping regularly at night:

- light exposure after the circadian temperature low point in the morning will result in a phase advance of the body clock cycle;
- light exposure in the middle of the day will have minimal effect on the body clock cycle;
- light exposure in the evening before the circadian temperature low point will result in phase delay of the body clock cycle.

Light in the morning shortens the circadian body clock cycle and light in the evening lengthens the body clock cycle.

In theory, this means that just the right amount of light exposure at the same time every morning would speed up a slightly slow circadian body clock cycle just enough to synchronize it to exactly 24 hours (most of us have an innate body clock cycle slightly longer than 24 hours). In practice, staying in step with the day/night cycle is more complex than this. In modern industrialized societies, people have very haphazard exposures to light, particularly bright outdoor light. In addition, the circadian body clock is sensitive to other time cues from the environment, for example it can also be moved backwards or forwards in its cycle by bouts of physical activity.

The ability of the circadian clock to "lock on" to the 24-hour day/night cycle is a key feature of its usefulness for most species, enabling them to be diurnal or nocturnal as needed to enhance their survival. However, it can create challenges for crewmembers involved in 24/7 operations because it causes the circadian body clock to resist adaptation to any pattern other than sleep at night.

Figure 2-6 below shows data from 14 factory workers who worked 3 morning shifts (0700-1400), 3 evening shifts (1400-2200), had 26 hours off and then worked 3 night shifts (2200-0700). Work times are shown by the unshaded bars and free time is shown by the shaded sections. The black dots represent the average peak in the circadian rhythm of melatonin (a hormone the body normally produces at night that is also used as a marker of the circadian clock – like core body temperature). As can be seen from the graph below, the peak in the melatonin rhythm does not change across the 9 days despite the change in the pattern of sleep and work.

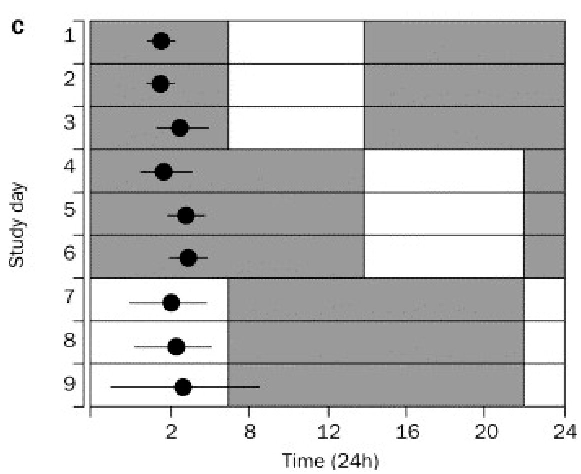

Figure 2-6. Timing of the peak in melatonin across 3 morning, 3 evening and 3 night shifts.

In extreme latitudes, where there are long periods of darkness in winter, the biological clock receives less light information to help keep in step with the 24-hour cycle. A small number of studies have looked at the effects on sleep and fatigue in the extreme latitudes and show that in the winter months people go to bed and get up later, have more difficulty falling asleep and may sleep for slightly longer (although other studies find no difference in sleep duration) compared to in summer. Although sleep may be slightly longer, fatigue levels are greater in the winter months at these extreme latitudes.

2.3.4. SHIFT WORK

From the perspective of human physiology, shift work can be defined as any duty pattern that requires a crewmember to be awake during the time in the circadian body clock cycle that they would normally be asleep if they were free to choose their own schedule (see Figure 2-4).

The further sleep is displaced from the optimum part of the circadian body clock cycle, the more difficult it becomes for crewmembers to get adequate sleep (i.e., the more likely they are to experience sleep restriction). For example, crewmembers flying domestic night cargo operations are typically on duty through most of the optimum time for sleep in the circadian body clock cycle. This happens because the circadian body clock is 'locked on' to the day/night cycle, and does not flip its orientation to promote sleep during the day when crewmembers are flying at night.

Figure 2-7 is a diagram that summarises what happened to the circadian biological clock and sleep when the night cargo crewmembers in Figure 2-4 were flying at night and trying to sleep in the morning. Again, their average core body temperature rhythm has been simplified (the continuous curve).

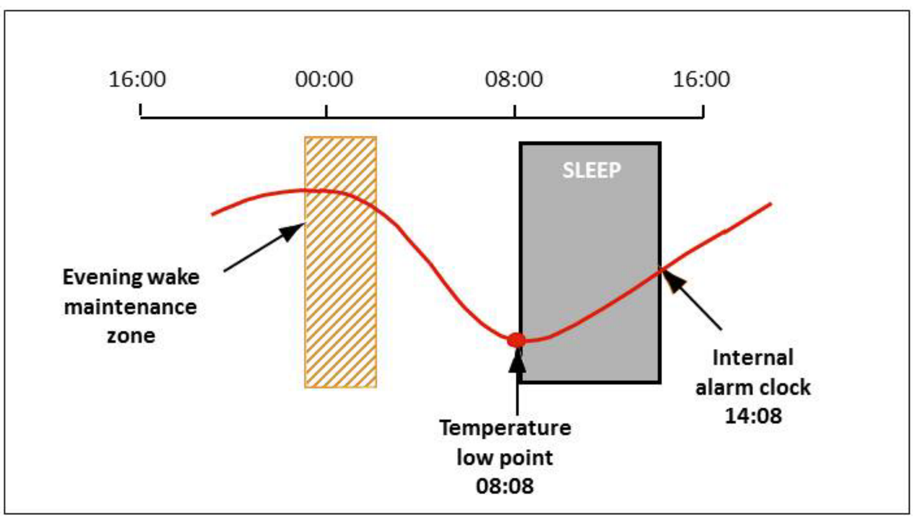

Figure 2-7. Relationships between sleep after night duty and the circadian body clock cycle[21]

[21] Figure provided by Prof. P. H. Gander, adapted from Gander PH et al (1998) Gregory, K.B., Connell, L.J., Graeber, R.C., Miller, D.L., and Rosekind, M.A. Flight crew fatigue IV: overnight cargo operations. *Aviation, Space, and Environmental Medicine 69:*B26-B36.

On off duty days, when these crewmembers were sleeping at night, the average time of the temperature minimum was 05:20 (Figure 2-4). When they were flying at night (Figure 2-7) this moved to 08:08, i.e., the average temperature minimum delayed by 2 hours 48 minutes. The circadian body clock did not adapt fully to night duty, which would have required a shift of about 12 hours. As a result, crewmembers had to sleep in a different part of the circadian body clock cycle after night duty.

- After night duty (Figure 2-7), they fell asleep close to the circadian temperature minimum. In contrast when they slept at night (Figure 2-4), they fell asleep about 5 hours before the temperature minimum.
- After night duty (Figure 2-7), crewmembers woke up about 6 hours after the circadian temperature minimum, within 5 minutes of the predicted time of the internal alarm clock. In contrast when they slept at night (Figure 2-4), they woke up about 3 hours after the temperature minimum.
- Crewmembers were not asked what woke them up from sleep episodes after night duty, but they rated themselves as not feeling well-rested after these restricted morning sleep episodes.

Another consequence of the incomplete adaptation of the circadian body clock to night duty was that crewmembers were often operating the last flight of the night in the window of circadian of (the WOCL) when they would be expected to be sleepy and having to make additional effort to maintain their performance. No fatigue-related incidents were observed on these flights (all crews were accompanied by a flight deck observer). However, all flights were routine, i.e., there were no operational events that tested the capacity of these crewmembers to respond to non-routine situations.

OPERATIONAL IMPLICATION 7.
SCHEDULING

The perfect schedule for the human body is daytime duties with unrestricted sleep at night. Anything else is a compromise. There are, however, general scheduling principles based on fatigue science that should be taken into account when designing a duty schedule:

- The circadian body clock does not adapt fully to altered schedules such as rotating shifts or night work. Some adaptation may occur on slow rotating schedules. There is no clear difference between forwards versus backwards rotating shift schedules.
- Whenever a duty period overlaps an individual's usual sleep time, it can be expected to restrict sleep. Examples include early duty start times, late duty end times, and night work.
- The more a duty period overlaps an individual's usual sleep time, the less sleep the individual is likely to obtain. Working right through the usual night-time sleep period is the worst-case scenario.
- Night duty also requires working through the time in the circadian body clock cycle when self-rated fatigue and mood are worst, and additional effort is required to maintain alertness and performance. Napping before and during a night duty period is a useful strategy (discussed above in *Operational Implication 5: Napping as a Fatigue Mitigation*).
- Night duty also forces an individual to sleep later than normal in their circadian body clock cycle, so they have a limited time to sleep before the circadian alerting signal wakes them up. This can cause restricted sleep following a night shift. To provide the longest sleep opportunity possible, night shifts should be scheduled to end as early as possible and individuals need to get to sleep as soon as possible after coming off duty.
- The evening wake maintenance zone occurs in the few hours before usual bedtime. This makes it very difficult to fall asleep earlier than usual, ahead of an early duty report time. Early report times have been identified as a cause of restricted sleep in aviation operations.
- Across consecutive duty periods that result in restricted sleep, individuals will accumulate a sleep debt and fatigue-related impairment will increase.
- To recover from a sleep debt, individuals need a minimum of two full nights of sleep in a row. The frequency of rest periods should be related to the rate of accumulation of sleep debt.

2.3.5. JET LAG

Flying across time zones exposes the circadian body clock to sudden shifts in the day/night cycle. Because of its sensitivity to light and (to a lesser extent) social time cues, the circadian body clock will eventually adapt to a new time zone. During the period of adaptation, common symptoms include wanting to eat and sleep at times that are out of step with the local routine, problems with digestion, degraded performance on mental and physical tasks, and mood changes.

Studies with participants flown as passengers have identified the following factors that affect the rate of adaptation to a new time zone.

- Adaptation generally takes longer when more time zones are crossed.
- Adaptation is usually faster after westward travel (phase delay) than after eastward travel (phase advance) across the same number of time zones. The fact that the innate cycle of the circadian body clock is slightly longer than 24 hours (for most people) probably contributes to this. It is easier to lengthen the cycle to adapt to a westward shift.
- After eastward flights across 6 or more time zones, the circadian body clock may adapt by shifting in the opposite direction, for example shifting 18 time zones west rather than 6 time zones east. When this happens, some rhythms shift eastward and others westward (known as resynchronization by partition) and adaptation can be particularly slow.
- Rhythms in different functions can adapt at different rates, depending on how strongly they are influenced by the circadian body clock. Thus, during adaptation, rhythms in different body functions can be out of step with each other, as well as out of step with the day/night cycle.
- Adaptation is faster when the circadian body clock is more exposed to local time cues, including outdoor light, and exercising and eating on local time.
- Beginning a trip with a sleep debt seems to increase the duration and severity of jet lag symptoms.

The circadian body clock is not able to adapt immediately to changes in time zones.

Crewmembers who operate transmeridian flights rarely have enough time in a destination to adapt fully to local time, with 1-2 day layovers being typical. However, different patterns of transmeridian flights can have different effects. For example, there appears to be very little circadian adaptation across flights leaving and returning to a crewmember's domicile time zone, with a 1-2 day layover in the destination city. On the other hand, longer sequences of back-to-back transmeridian flights can lead to the circadian body clock adopting a non-24-hour period that may be close to its innate period [22]. This presumably happens when repeated time zone crossings are combined with a non-24-hour sleep/wake pattern, so that there are no longer any 24-hour day/night cues to synchronize the circadian body clock.

Figure 2-9 depicts data from an early NASA study with B747 200/300 flight crews (3-person crews consisting of a captain, first officer, and flight engineer). Similar trip patterns are still being flown by some operators but with an additional pilot, not a flight engineer. Participants had their core body temperature monitored continuously and kept sleep and duty diaries before, during, and after this trip, which included 4 trans-Pacific flights plus one round trip within Asia (NRT-SIN-NRT). The dots indicate the average time of the temperature minimum (for 6 crewmembers per day).

By the end of this trip pattern, the temperature minimum had delayed by about 4.5 hours, giving an average drift rate of about 30 minutes per 24 hours (or an average cycle length of the circadian body clock of about 24.5 hours). The drift presumably was the result of the fact that the circadian body clock did not have any 24-hour time cues to lock on to, with the non-24 hr duty/rest cycle and every layover in a different time zone.

One consequence was that the temperature minimum (and the WOCL) sometimes occurred in flight, for example on the last flight from NRT to SFO. At these times, crewmembers would be expected to be sleepy and having to make additional effort to maintain their performance. This would be an ideal time to take an in-flight nap (crewmembers did not have in-flight sleep opportunities on this trip).

Another consequence was that when crewmembers returned home, their circadian body clocks were on average 4.5 hours delayed with respect to local time and took several days to readapt.

[22] Gander PH, Gregory KB, Miller DL, Rosekind MR, Connell LJ, Graeber RC. Flight crew fatigue V: long-haul air transport operations. Aviation, Space, and Environmental Medicine 69:B37-B48, 1998.

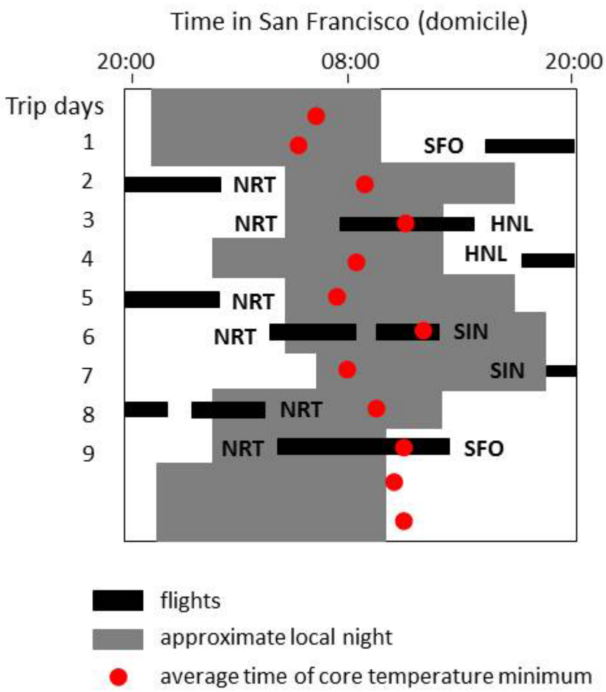

Figure 2-8. Study tracking the circadian body clock across multiple trans-Pacific flights

The fact that long-haul and ULR crewmembers seldom stay long enough in any destination time zone to become adapted to local time has effects on their layover sleep. Often, crewmembers split their sleep, having one sleep period on local night and another corresponding to local night in their home time zone, which overlaps the preferred part of the circadian body clock cycle for sleep (at least for the first 24-48 hours in a new time zone). Another factor affecting layover sleep, particularly for unaugmented crews who do not have the opportunity for in-flight sleep, is that long-haul duty days are often associated with extended periods of waking. For example, one study that monitored crewmembers on unaugmented long-haul trips found that the average duty day involved staying awake for 20.6 hours (the average duty period lasted 9.8 hours). [13]

There is some evidence that when crewmembers stay longer in the destination region, for example doing several days of local flying with minimal time zone changes before flying the long-haul trip home, their circadian body clocks begin to adapt to the destination time zone [23]. This may improve layover sleep. On the other hand, when they arrive back in their home time zone, they may need additional days to readapt to local time.

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[23] Gander P, van den Berg M, Mulrine H, et al. Circadian adaptation of airline pilots during extended duration operations between the USA and Asia. Chronobiology International 30: 963-972, 2013

2.4. SCIENTIFIC PRINCIPLE 4: INFLUENCE OF WORKLOAD ON FATIGUE

The ICAO definition of fatigue describes workload as 'mental and/or physical activity' and includes it as a potential cause of fatigue. Three dimensions of workload are commonly identified:

1. The nature and amount of work to be done (including time on task, task difficulty and complexity, and work intensity).
2. Time constraints (including whether timing is driven by task demands, external factors, or by the crewmember).
3. Factors relating to the performance capacity of the crewmember (for example experience and skill level, sleep history, and circadian phase).

SCIENTIFIC PRINCIPLE 4

WORKLOAD CAN CONTRIBUTE TO AN INDIVIDUAL'S LEVEL OF FATIGUE. LOW WORKLOAD MAY UNMASK PHYSIOLOGICAL SLEEPINESS WHILE HIGH WORKLOAD MAY EXCEED THE CAPACITY OF A FATIGUED INDIVIDUAL.

At present, there is no clear operational definition of workload or agreed ways of measuring it for flight or cabin crewmembers, and it seems likely that its causes and consequences will vary in different operational contexts. There is fairly wide acceptance of the idea that intermediate levels of workload may contribute least to performance impairment. Low workload situations may lack stimulation, leading to monotony and boredom which could expose underlying physiological sleepiness and thus degrade performance. At the other end of the spectrum, high workload situations may exceed the capacity of a fatigued crewmember, again resulting in poorer performance.

High and low workload can contribute to fatigue

High workload may also have consequences for sleep, due to the time required to "wind down" after demanding work.

High workload may disturb sleep due to the time required to "wind down" after demanding work.

Compared to the research available on other causes of fatigue, there is only limited research addressing the effects of differing levels of workload on crewmember fatigue. One older European study used a 'hassle factor' as a measure of workload[24]. The amount of hassle increased significantly on flights into and out of Schiphol airport. It was also associated with duty periods that were unusually long, given the number of flights, possibly as a result of flight delays. A more recent European study examined the independent factors that predict the fatigue of short-haul pilots at the end of FDPs, using the 7-point Samn-Perelli fatigue scale[25]. The main predictors were time awake and duty duration, with a minor contribution from workload (measured with the NASA Task Load Index).

It is widely accepted that workload increases with the number of sectors in a flight duty period. This is reflected, for example, in the US Federal Aviation Administration's duty time limits for flight crew, which are shorter for duty days with

[24] Air crew fatigue: a review of research undertaken on behalf of the UK Civil Aviation Authority. CAA Paper 2005/4. https://www.caa.co.uk/docs/33/CAAPaper2005_04.pdf

[25] Vervodja M, Elmenhorst E-M, Pennig S, et al. Significance of time awake for predicting pilots' fatigue on short-haul flights: implications for flight and duty time regulations. Journal of Sleep Research 23(5):564-7. 2014.

more flight segments. A number of studies have confirmed that fatigue is higher at the end of short-haul FDPs with more flight segments[26].

Few studies have attempted to investigate the potential interactive effects between workload and other causes of fatigue. A field study of fatigue ratings made by air traffic controllers found some evidence for self-rated workload and time-on-task having interactive effects on fatigue.[27] When self-rated workload was low, fatigue ratings remained relatively stable for continuous work periods up to 4 hours. However when workload was high, there was a rapid increase in fatigue after 2 hours of continuous work. These effects of workload became more evident after controllers had been awake for at least 12 hours. The time-of-day variation in fatigue ratings was also influenced by workload, being more marked at low and high levels of workload than at intermediate levels.

The relationship between workload and fatigue has not been well researched

[26] Powell D, Spencer MB, Holland D, et al. Pilot fatigue in short haul operations: effects of number of sectors, duty length, and time of day. Aviation, Space, and Environmental Medicine 78:698-701, 2007.
Powell D, Spencer MB, Holland D, et al. Fatigue in two-pilot operations: implications for flight and duty time regulations. Aviation, Space, and Environmental Medicine 79:1047-1050, 2008.
Air crew fatigue: a review of research undertaken on behalf of the UK Civil Aviation Authority. CAA Paper 2005/4.
[27] Spencer MB, Rogers AS, Stone BM. A review of the current scheme for the regulation of air traffic controllers hours (SCRATCOH). Farnborough, England: Defense Evaluation and Research Agency, 1997.

CHAPTER 3. OPERATIONAL KNOWLEDGE AND EXPERIENCE

Effective fatigue management not only requires consideration of scientific principles and knowledge, but also needs to be based on operational experience, which is acquired through conducting specific operations over time and managing fatigue-related risks in those operations. These two sources of expertise are complimentary.

Science generally aims to develop principles that can be broadly applied. Many of the scientific studies that underpin the principles in Chapter 2 do not have flight operations as their primary focus, but the findings are applied in flight operations. This means that knowledge of the operational and organizational context, as well as understanding of the constraints and motivations of the workforce must be considered alongside the science to develop an appropriate fatigue management approach in specific flight operations.

In the following two sections, contextual factors are categorised as relating either to the flight operations context or to the broader organizational context. However it can be argued that some factors belong in both categories and clearly the two contexts interact in their effects on fatigue management.

3.1. GA FLIGHT OPERATIONS CONTEXT

Operational context covers factors that a crew member experiences on duty, such as local environmental factors, working conditions, and the influence of crew member qualifications and experience (both their own and that of the other crew members they are working with). Examples include the weather at the departure and arrival airports, traffic delays, airspace complexity, irregular operations, interactions with other aviation professionals (for example air traffic control), short-haul versus long-haul operations, and managing operational demands.

Table 3-1 identifies some of the factors in the flight operations context that can influence crew member fatigue. Some or all of these factors may be relevant, depending on the specific tasks to be completed by the crew member on the day.

Table 3-1. Examples of factors in the flight operations context that can influence fatigue

Factor in operational context	
Specific fleet attributes	• The availability and quality of on board rest facilities and policies for their use • Patterns and types of flying (e.g., long-haul versus short-haul)
Routes and destinations	• Airport traffic density • ATC behaviours • Time spent in ground transportation • Standard of layover accommodation • Availability of food and water • Social opportunities • Cultural differences
Experience in managing operational demands	• Experience level in aircraft type (of crew members and of the operator) • Experience on type and complexity of operations • Experience level of pilot in command and other crew members • Experience level of other flight department personnel
Staffing Levels	• Sufficient to be able to offer adequate sleep opportunities during and between flight assignments to avoid cumulative fatigue • Sufficient to cover sickness and other absences
Irregular operations	• Frequency of the need to use Captain's discretion/duty period extensions • Frequency of disruption to schedules and the assignment of unscheduled duties • Pressures to complete the "mission"
Specific aircraft aspects	• Level of noise on the flight deck • Temperature on the flight deck • Cabin altitude • Level of vibration on the flight deck • MEL impacts on the aircraft

The presence of these factors and others will depend on the nature of the operation. Table 3-2 summarizes findings of NASA field studies identifying the causes of fatigue associated with different types of operations in commercial air transport operations.

Table 3-2. Summary of identified work-related fatigue causes (from NASA field studies 18)

Cause of fatigue hazard	Type of operations		
	Short-haul	Night cargo	Long-haul
Restricted sleep due to short rest periods	X		
Restricted sleep due to early duty report times	X		
Multiple high workload periods across the duty day	X		
Multiple sectors	X	X	
High-density airspace	X		
Long duty days	X		X
Extended wakefulness on duty days			X
High workload during circadian low		X	X
Shorter sleep periods at wrong times in the circadian cycle		X	X
Circadian disruption (due to night work)		X	X
Split sleep patterns and short sleep episodes on layovers		X	X
Circadian disruption (due to crossing multiple time zones)			X
Circadian drift (changes in circadian pattern) following extended patterns			X
Note.- These causes of fatigue identified in these particular studies do not represent an exhaustive list.			

Within GA operations, the unpredictable nature of many operations, particularly within business aviation operations, represents a significant fatigue hazard. Trip requirements may come up with very little notice and may undergo significant change during the course of a flight or series of flights. This can make it very difficult for GA operator personnel to plan their non-work time in order for them to be adequately rested when they commence their duties. It may also indicate that during the course of undertaking unscheduled duties, operator personnel begin to experience a high sleep drive because they have not had the opportunity to sleep for a long period of time (see Scientific Principle 1 in Chapter 2).

Split duty days are another common feature of the schedules of business aviation personnel. However, the timing of the "split" may impact on an individual's ability to use this time to sleep because the ability to get to sleep and to obtain restful sleep varies significantly across the 24 hour day.

By having a clear understanding of causes of fatigue inherent in their operations, GA operators should be able to identify flight and duty limits and construct schedules that address their unique operational context as part of their fatigue management programme.

3.2. ORGANIZATIONAL CONTEXT

Knowledge of the context in which the organization operates can provide an understanding of the pressures it faces and the factors that affect how it is able to address fatigue issues. Table 3-3 identifies some of the ways in which the organizational context can influence fatigue management.

Table 3-3. Examples of factors in the organizational context that can influence fatigue management

Factor in organizational context	
Career stability	• Business and economic pressures • Changing employment arrangements (e.g., labour agreements, use of contract employees) • Significant changes in the parent organization
Level of autonomy of crew during a duty period	• Pressures (business and personal) to complete the "mission" • Geographic separation from the crew support team , i.e., immediate support and supervisory guidance is not always readily available • Crew members are the final link in the safety chain for every flight
Fatigue management structure	• Fatigue management is integrated into day-to-day risk management activities versus being the responsibility of an independent group or individual
Effective reporting practises	• Safety/hazard reporting system • Ease of reporting fatigue hazards • Implications for a crew member of submitting a report • Actions by management in response to fatigue reports

3.3. STAKEHOLDER RESPONSIBILITIES

Responsibility for fatigue management must be shared between the GA operator and the individual crew member. Aspects of the operational and organizational context will influence how individuals discharge their fatigue management responsibilities.

The GA operator is responsible for providing:

- adequate resourcing for fatigue management;
- a working environment that has appropriate emphasis on mitigations for fatigue-related risk;
- appropriate fatigue reporting mechanisms and promoting a positive organizational response to reporting fatigued;
- schedules that enable fatigue on duty to be maintained at an acceptable level, as well as providing adequate opportunities for rest and sleep; and
- education and awareness training for all stakeholders on fatigue and its effects, how the operator's fatigue management approach works and how individuals can better manage their own fatigue.

Individual crew members are responsible for:

- making optimum use of off-duty periods to get adequate sleep;
- coming to work fit for duty;
- managing their own fatigue levels; and
- responsible use of individual authority (e.g., captain's discretion);
- reporting fatigue issues

All stakeholders should play an active role in the development and dissemination of best practice and lessons learned, to ensure that these are embedded across the organization.

3.3.1. FATIGUE REPORTING

Fatigue management relies on identification of fatigue hazards and effective safety reporting. The operational and organizational context has particular influence on whether crew members consider the identification of fatigue hazards as part of their professional role and on whether they are prepared to report fatigue hazards. It must be acceptable for crew members to raise legitimate issues about fatigue without fear of retribution or punishment either from within or outside the organization. The issues associated with fatigue are difficult to detect if people are unwilling or unable to report them.

To encourage an ongoing commitment by crew members to reporting fatigue hazards, the GA operator should:

- have clear processes for reporting fatigue hazards.
- be clear that the organization expects crew members to report fatigue hazards;
- establish a process for what to do when a crew member considers that they are too fatigued to perform safety-critical tasks to an acceptable standard.
- identify the implications for crew members of submitting a fatigue hazard report.
- identify how the organization will respond to reports of fatigue hazards, including acknowledging receipt of reports and providing feedback to individuals who report.
- take appropriate actions in response to fatigue reports consistent with stated policy.
- maintain the integrity of the safety reporting system and reporter confidentiality.
- provide feedback on the analysis of reports and changes made in response to identified fatigue hazards.

CHAPTER 4. IMPLEMENTING A FATIGUE MANAGEMENT PROGRAMME

The objective of a GA operator's fatigue management programme is to manage, to an acceptable level, the risks associated with fatigue hazards that operator personnel involved in the operations and maintenance of aircraft are exposed to, and to ensure that such personnel are performing at an adequate level of alertness. To achieve this objective, GA operators should:

- establish flight and duty time limitations for aircraft crew members and duty time rules for other employees involved in the operation and maintenance of aircraft where fatigue may be an issue, and include those provisions in their operations manual; and
- use their SMS processes to manage their fatigue risks. This includes use of appropriate mitigations and raising awareness of fatigue issues as part of training.

4.1. ESTABLISHING LIMITS

From Chapter 3, when identifying flight and duty limits, a GA operator necessarily takes into account the variety of operations that they cover and the different conditions in which their operational personnel must work.

GA operator-identified limits based on the scientific principles discussed in Chapter 2 should be established for:

- flight times;
- fight duty periods;
- duty periods; and
- rest periods (minimum rest requirements).

To better address the scientific principles underlying fatigue management, a GA operator may identify limits which vary according to different factors such as the time of commencement of duties, the number of consecutive work periods, the number and direction of time zone changes, and whether it is a single-, multi-, or augmented pilot operation. These limitations should be included in the operator's Operations Manual.

Three tables from the *Duty/Rest Guidelines for Business Aviation*[28] are attached as Appendix D. They are industry developed guidance on duty and flight time limitations, rest requirements and crew scheduling guidance based on the scientific principles outlined in Chapter 2 and are not to be considered as a regulatory standard or suggested limits. GA operators may wish to review those guidelines as a starting point for developing or reviewing their maximum flight and duty periods and minimum rest periods.

[28] Developed by the Flight Safety Foundation and the National Business Aviation Association (2014) and posted at http://flightsafety.org/current-safety-initiatives/duty-rest-guidelines

In developing limits that address their unique operational context, it is not enough to simply identify maximum flight and duty periods and minimum rest periods for operational personnel. Principles from fatigue science should also be used improve schedule design (see Chapter 2, *Operational Implication 8: Scheduling*). . Since the effects of sleep loss and fatigue are cumulative, scheduling needs to address both individual flights, multiple-leg flights, (successive duty periods without extended time off), and successive individual assignments over an extended period.

Where possible, schedules should be published sufficiently in advance to allow crew members to plan for work and rest periods. While late schedule changes are sometimes unavoidable, ideally GA operators should attempt to keep changes at short notice to a minimum and minimise their impact, especially where they infringe or overlap the WOCL.

When developing schedules, the GA operator should also give careful consideration when assigning unscheduled duties (e.g. standby or last-minute roster changes) and when altering work periods to manage operational disruptions on the day. These are discussed further below.

4.1.1. UNSCHEDULED DUTIES

The specific challenges associated with unscheduled duties (e.g. standby or last-minute roster changes) are their inherent unpredictability and the likelihood of being assigned unscheduled duties. In many cases, controlling the likelihood of being called in to undertake an unscheduled duty may be impossible. A particular feature of GA operations is their unpredictability. To address the associated fatigue risks, GA operators should consider the following when establishing processes for the assignment of unscheduled duties:

- The need for protected sleep opportunities before and after unscheduled duties. As for any other duty period, the crew member needs an opportunity to plan their sleep (as much as is possible) to enable them to perform to a satisfactory level. He/she also needs to be able to recover from the fatigue accrued across the duty period.
- Adjusting the length of the standby period in relation to the length of the notification period. Short notification periods require the GA crew member to be fully rested and immediately ready to undertake the duty. Longer notification periods can offer the opportunity to sleep in preparation for the duty, which allows the crew member to remain available longer to be assigned an unscheduled duty. Therefore the length of the period on-call should be directly related to the length of the notification period.
- Duty length may need to be adjusted in relation to the time spent on call or standby, depending on the length of the notification period.

In making the judgement on the extent to which an on-call period counts as work, the following considerations may be useful, considering that sleep during on-call periods may be less restorative:

- the location of the on-call period (e.g.at home vs at the workplace vs at a hotel);
- the length of the notification period (e.g. does it afford an opportunity to sleep prior to reporting?)
- the inclusion of protected periods during which the safety relevant worker will not be disturbed;
- the possibility for the safety relevant worker to sleep during the on-call period (e.g. at home during either of the windows of circadian low); and
- the extent to which an on-call period is counted as a work period is related to the level of fatigue it is likely to produce.

4.1.2. MANAGING OPERATIONAL DISRUPTIONS ON THE DAY

The nature of GA operations may mean that sometimes operational circumstances (including the need to address broader risks) will necessitate extending beyond the identified limits. These circumstances should not be occurring on a regular basis or be reasonably predicted to occur, based on past experience. If they are able to be reasonably predicted (e.g. known seasonal conditions that increase flight times or delays due to peak traffic periods), the GA operator should schedule accordingly, building in “buffer periods” (scheduling additional time to allow for operational variability).

To address operational needs and wider operational risks in unexpected operational circumstances, the GA operator should develop a procedure to ensure that an acceptable level of risk will be maintained. It should include:

- the circumstances in which the extensions to limits may be used;
- the operations to which immediate extensions may be applied;
- the outer limit to extend duty periods and/or reduce the minimum rest, and
- the necessary mitigations to address the increased fatigue risks.

In all cases, the ability to use these outer limits should depend on the crew member’s assessment that they are fit to continue or that they can adequately recover from their previous duty period and perform safely in their subsequent duty period. They should not be required to do so by the operator.

The use of exceedances of the maximum duty period and reductions of minimum rest should be recorded by the operator. Analysis of trends in these occurrences is one source of data for identifying the GA operator’s fatigue hazards.

4.2. USING SMS PROCESSES

As previously noted, Annex 19 requires GA operators of large and turbo-jet aeroplanes to have an SMS that is commensurate with the size and complexity of their operation[29].

Figure 4-1 identifies the components of an SMS and outlines how an operator can include fatigue as one of the hazards it manages:

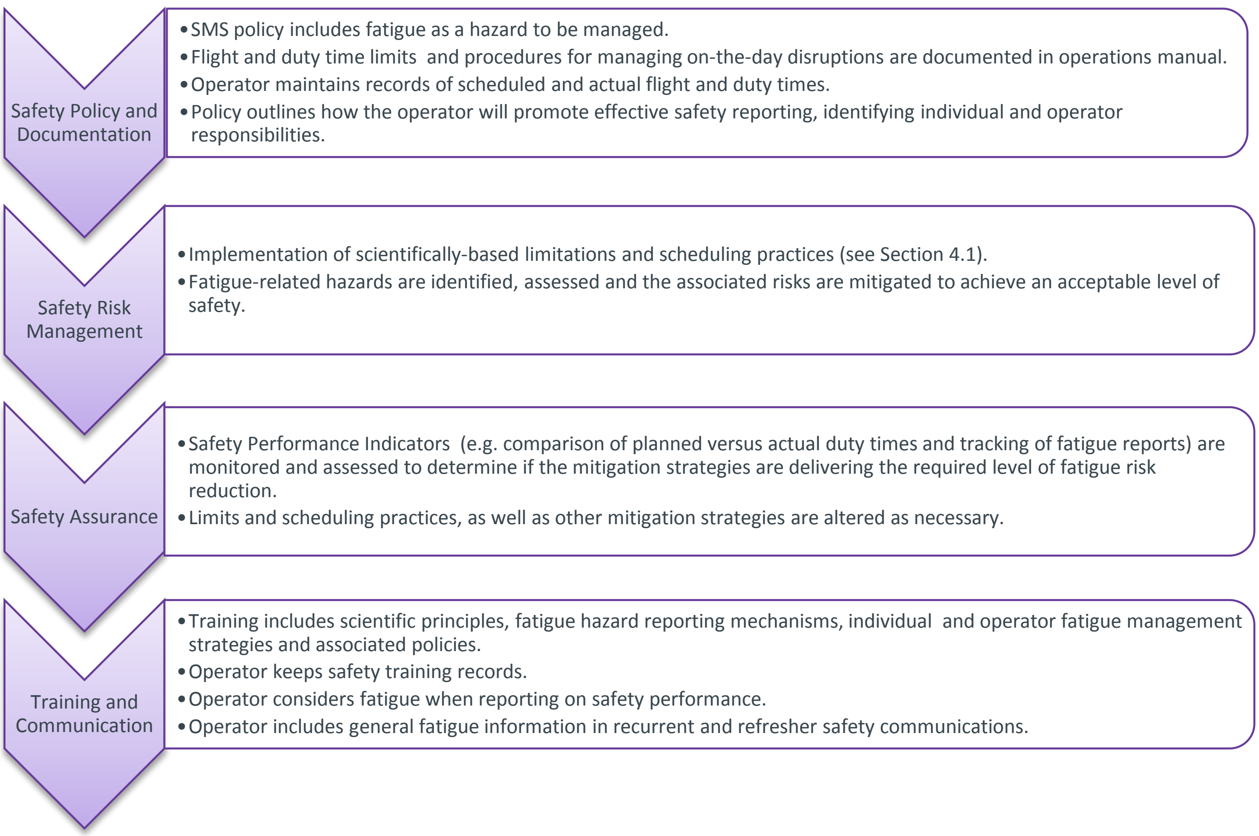

Figure 4-1 Fatigue considerations in an SMS

These are discussed in more detail below.

[29] *More complete guidance on developing and using an SMS is provided in the ICAO Safety Management Manual (SMM), Doc 9859 at* http://www.icao.int/safety/SafetyManagement/Pages/Guidance-Material.aspx. *The IBAC SMS Toolkit at* *http://www.ibac.org/safety/sms-toolkit* *provides guidance specifically oriented to business aircraft operators.*

4.2.1. SMS POLICY AND DOCUMENTATION

In GA operations, a clear understanding by management (including owners, corporate management) and/or principle passengers of the hazards, the inherent risks and how the risks are being managed, will significantly enhance the safety, efficiency and effectiveness of the operation. The SMS policy provides the mechanism for senior management to communicate their commitment to safety and the approach being used to identify hazards to safety and to manage their associated risks, including those related to fatigue. In order to ensure that owners, corporate management and/or principle passengers understand these hazards and associated risks and are committed to supporting how they are being managed and not attempt to exert negative influence, the flight department management must engage them in an effective two-way dialogue. These discussions should be an ongoing process so that senior management is always informed of the evolution of safety and fatigue risks, the mitigations being used to the manage the risks and the appropriateness and effectiveness of these efforts. With specific reference to fatigue management, the operator's SMS policy should:

- identify management and operator personnel responsibilities in managing fatigue risks;
- require that clear lines of accountability for accepting and managing fatigue-related risks are identified; and
- clearly state the process for protection and management of fatigue-related data.

4.2.2. SAFETY RISK MANAGEMENT

Risk management processes, as an essential component of an SMS, require the identification of hazards, assessment of the associated risks and implementation of mitigations where necessary. The following sections describe how fatigue can be identified, assessed and mitigated as part of risk management processes of a GA operator's SMS.

IDENTIFYING FATIGUE HAZARDS

There are a number of sources of data that can be used to identify where fatigue might constitute a hazard. Most, but not all, involve 'reactive hazard identification', which means that fatigue is identified after it has occurred. Depending on the size of the GA operator and the maturity of its SMS processes, some or all of the following examples might be acceptable for use:

- considering fatigue reports resulting from hazard reporting schemes;
- gathering information from previous accidents and incidents (internal and external);
- considering fatigue related information resulting from published scientific research;
- considering fatigue related results of internally or externally conducted safety assessments/audits;
- considering fatigue related safety information from external sources, i.e. similar GA operations in other organizations, media, accident investigation bodies, audit reports etc.;
- brainstorming, where the GA operator's Safety Committee or a small group of suitably experienced members meet to consider work and scheduling practices and identify possible fatigue hazards in this manner; and
- GA Operators involved in operations where exposure to fatigue is more prevalent may additionally use bio-mathematical modelling, conduct surveys to examine feedback on fatigue-related topics from groups of personnel; and analyze crew member fatigue data collected during flight operations.

Some of these are discussed in more detail below.

4.2.3. FATIGUE REPORTS

Hazard reporting has an essential role in SMS. To encourage open and honest reporting of hazards, a GA operator must clearly distinguish between:

- unintentional human errors, which are accepted as a normal part of human behaviour and are recognized and managed within the SMS; and
- deliberate violations of rules and established procedures. An operator should have processes independent of the SMS to deal with intentional non-compliance.

Reports about high fatigue levels or fatigue-related performance issues provide vital information about fatigue hazards in the day-to-day running of an operation. Reports can come from crew members or other operational staff. As for any other safety hazard, a series of hazard reports citing fatigue on a particular route or associated with a particular part of a schedule may indicate that further action is needed to assess and mitigate that hazard. Fatigue reports can also provide useful examples for recurrent fatigue management training.

Depending on an operator's SMS hazard reporting system, a separate form for reporting fatigue may not be essential. However, adequate information needs to be gathered. This includes information on recent sleep and duty history (minimum last 3 days), time of day of the event, and measures of different aspects of fatigue-related impairment (for example, validated alertness or sleepiness scales).

Fatigue reports should also provide space for written commentary so that the person reporting can explain the context of the event and give their view of why it happened. An example of a fatigue report form showing the type of information needed for fatigue to be evaluated is provided in Figure 4-2 (page 46). Information to identify fatigue as a contributing factor should also be included in mandatory incident/accident reporting forms (see *Analysis of Incidents/Accidents,* p 47).

Crew members should be encouraged to report fatigue hazards such as the following:

- Fatigue contributes to a duty period not being started or completed. The GA operator needs to have a process for reporting 'not fit for duty' due to fatigue, and a clear procedure around the consequences.
- A crew member completes a duty period in which they believe their own fatigue or that of others reduced the safety margin or required some unplanned mitigation.
- A crew member identifies something in their operating environment that could significantly increase their fatigue, or that of others.

An operator may have different reporting processes, for example, for events where fatigue is a safety concern versus not a safety concern, or for calling in when too fatigued to take on or continue a duty period. Information on how to report these issues should be covered in fatigue management training.

To encourage ongoing commitment of personnel to reporting hazards, Fatigue report forms need to be easy to access, complete and submit. Consideration should be given to making fatigue report forms (whether as a stand-alone fatigue report or included as extra fields on the existing hazard forms) available for completion electronically, for example, on laptops, tablets or smart phones. Further, GA operators should take appropriate and timely action in response to fatigue reports and provide feedback to the reporter where possible.

IF CONFIDENTIALITY REQUIRED TICK HERE ●				
NAME		Employee No.		Pilot/CCM (circle)
WHEN DID IT HAPPEN?	Local report date		Time of event (local report time)	
Duty description (trip pattern)				
Sector on which fatigue occurred	From		To	
Hours from report time to when fatigue occurred			Disrupt?	Yes / No
Aircraft type		Number of crew		

WHAT HAPPENED?

Describe how you felt (or what you observed)

Please circle how you felt

1	Fully alert, wide awake	5	Moderately let down, tired
2	Very lively, somewhat responsive, but not at peak		
3	OK, somewhat fresh	6	Extremely tired, very difficult to concentrate
4	A little tired, less than fresh	7	Completely exhausted

Please mark the line below with an 'X' at the point that indicates how you felt

alert -- drowsy

WHY DID IT HAPPEN?

Fatigue prior to duty?	Yes / No	How long had you been awake when the event happened?		hrs mins
Hotel	Yes / No			
Home	Yes / No	How much sleep did you have in the <u>24 hrs</u> before the event?		hrs mins
Duty itself	Yes / No			
In-flight rest	Yes / No	How much sleep did you have in the <u>72 hrs</u> before the event?		hrs mins
Disrupt	Yes / No			
Personal	Yes / No	flight deck nap? Yes / No	If yes, when	start end
Other comments				

WHAT DID YOU DO?	Actions taken to manage or reduce fatigue (for example, flight deck nap)
WHAT COULD BE DONE?	Suggested corrective actions

Figure 4-2 Example Fatigue Report Form

When fatigue report forms are first introduced, or other activities that raise fatigue awareness are launched, there is likely to be an increase in fatigue reporting. This "spike" does not necessarily represent an increase in fatigue occurrences or risk. It may simply be due to people being more likely to report. Other safety performance indicators may need to be evaluated to decide whether the increase in reporting should trigger further action by management.

4.2.4. ANALYSIS OF INCIDENT/ACCIDENTS

Basic fatigue-related information, similar to that suggested for inclusion in hazard reports, can be collected in relation to incidents and accidents, with more in-depth analyses reserved for events where it is more likely that fatigue was an important factor and/or where the outcomes were more severe. For the purposes of fatigue management, the aim is to identify how the effects of fatigue could have been mitigated, in order to reduce the likelihood of similar occurrences in the future. If fatigue was reported by a pilot then it is important that any investigation focuses on the potential sources of fatigue and the impacts of fatigue rather than whether fatigue was actually present.

Depending on the severity of the event, a fatigue analysis could be undertaken by the operator or an external fatigue expert. The findings of any fatigue investigation should be recorded as part of the SMS documentation.

There is no simple test (such as a blood test) for fatigue-related impairment. To establish that fatigue was a contributing factor in an event, it has to be shown that:

1. the person or crew were probably in a fatigued state;
2. the person or crew took particular actions or made decisions that were causal in what went wrong; and
3. those actions or decisions are consistent with the type of behavior expected of a fatigued person or crew.

Tools for the evaluation of the contribution of fatigue to safety events are presented in Appendix B, p 76.

4.2.5. BIO-MATHEMATICAL MODELS

When used in an operational context, bio-mathematical models aim to predict aspects of a schedule that might generate an increased probability of fatigue. However, they were all initially developed as computer programmes used by scientists to test their current understanding of how factors like sleep loss, circadian rhythms, and workload interact to affect human alertness and performance. The modeling process begins by trying to write a programme that can simulate a "developmental data set," for example, self-rated fatigue and performance measured during a sleep loss experiment in the laboratory. If this works, then the model is used to predict a different situation. Data are then collected in this new situation (a "validation data set") and model predictions are tested against the new data.

Scientific modeling is a continuous improvement process. Bio-mathematical models are accepted as being incomplete and transient scientific tools. In scientific best practice, scientists continue designing new experiments to try to find out where their models fail. In this way, they find out where their current understanding is incomplete or possibly wrong. (This is a much more efficient way of increasing scientific knowledge than just doing random experiments.)

A range of bio-mathematical models have been commercialized and are marketed as tools for predicting fatigue hazards relating to scheduling. There are also several models available in the public domain. Used properly, these models can be helpful tools in fatigue management because it is difficult to visualize the dynamic interactions of processes like sleep loss and recovery or the circadian biological clock. To use models properly requires some understanding of what they can and cannot predict. An important question to ask about any model is whether it has been validated against fatigue data from operations similar to those that you are interested in.

Currently available models:

- predict group average fatigue levels, not the fatigue levels of individual crew members;
- do not take into account the impact of workload or personal and work-related stressors that may affect fatigue levels;
- cannot take into account the effects of personal or operational mitigation strategies that may or may not be used by crew members (caffeine consumption, exercise, improved rest facilities, etc.); and
- do not predict the safety risk that fatigued crew members represent in a particular operation, i.e., they are not a substitute for risk assessment (see *Assessing Fatigue Risks*, below). Several available models try to predict safety risk by merging safety data from a range of operations in different industries but their applicability to GA flight operations has not yet been validated.

The most reliable use of currently available models is probably for predicting relative fatigue levels. Is the fatigue hazard likely to be greater in one schedule versus another? However, model predictions should not be used without reference to operational experience, when making decisions about schedule design. On the other hand, if model designers follow a continuous improvement philosophy, data collected in the course of SMS processes could prove to be a rich resource for improving the performance of bio-mathematical models.

Another potential use of some bio-mathematical models is as an investigative aid of accidents and incidents.

4.2.6. RETROSPECTIVE SURVEYS

Retrospective surveys are a comparatively cheap way to obtain information from a group of people on a range of topics such as:

- demographics (age, flying experience, gender, etc.);
- amount and quality of sleep at home and on trips (see above);
- experience of fatigue on duty; and
- views on the causes and consequences of fatigue on duty.

A limitation of retrospective surveys is that the information gathered is subjective, and therefore, its reliability is open to question. Reliability is a particular issue when people are asked to accurately recall details of past events, feelings or sleep patterns. This is not to question peoples' integrity as inaccurate recall of past events is a common and complex human problem. Concerns about whether some people might exaggerate in their responses, for personal or industrial reasons, should be minimal in a just reporting culture as is required for an effective SMS. In addition, extreme ratings are obvious when compared with group averages.

Employees' confidence in the confidentiality of their data is likely to be a very important factor in their willingness to participate in surveys and to provide complete information on questionnaires. Despite limitations, retrospective surveys from time-to-time can be a useful source of information in an SMS.

Retrospective surveys can also be used to track the effectiveness of fatigue management activities across time (i.e., as an SMS safety assurance process – see Section 4.2.11, p 60).

4.2.7. MONITORING AIRCRAFT CREW MEMBER FATIGUE DURING FLIGHT OPERATIONS

GA operators involved in long range operations, as well as operations that involve operations which approach fatigue boundaries, may find it in their interest to monitor aircraft crew member fatigue during flight operations. This can be achieved by having crew members rate their fatigue and sleepiness at different stages of flight.

The following things should be considered when choosing rating scales for monitoring aircraft crew member fatigue and sleepiness during flight operations.

1. Is the scale quick and easy to complete?
2. Is it designed to be completed at multiple time points, e.g., across a flight?
3. Has it been validated? For example, has it been shown to be sensitive to the effects of sleep loss and the circadian body clock cycle under controlled experimental conditions?
4. Is it predictive of objective measures such as performance or motor vehicle crash risk?
5. Has it been used in other aviation operations and is data available to compare fatigue levels?

The following two scales, described further in Appendix A, p 67 meet these criteria:

- The Karolinska Sleepiness Scale (KSS);
- The Samn Perelli Checklist

ASSESSING FATIGUE RISKS

Once a fatigue hazard has been identified, the level of risk that it poses should to be assessed and a decision made about whether or not that risk needs to be mitigated. When assessing the risks associated with fatigue there should be a clear understanding between owners, corporate management and/or principle passengers, management of the operation and front line employees on the acceptable level of risk. This should be an element of the dialogue discussed in Section 4.2.1 and in reviews of safety performance.

GA operators should conduct risk assessments across all hazards as part of their SMS. Assessing fatigue risks can be challenging because:

- fatigue can diminish an individual’s ability to perform almost all operational tasks; and
- there are many factors which can contribute to an individual’s level of impairment. Many of these factors may be unknown to the person making the risk assessment.

PERFORMANCE EFFECTS OF FATIGUE

- Inconsistent, but overall slower, reaction times;
- Lack of concentration;
- Impaired recollection of timing and events;
- Irritability;
- Reduced capacity for communicating with others;
- Reduced hand-eye coordination;
- Reduced visual perception;
- Reduced vigilance;
- Reduced capacity to judge risk;
- “Tunneling” of thoughts;
- Diminished judgement;
- Diminished responsiveness due to propensity to fall asleep.

Further, not only does an individual's ability to perform safety-related tasks decline with increasing fatigue but their capacity to respond to unexpected increases in task demands also diminishes. Such increases in task demands can be associated with managing threats, such as a flight crew member landing in unfavourable weather conditions or a cabin crew member dealing with an emergency evacuation. Conversely, low workload can unmask physiological sleepiness. Fatigue is rarely the sole cause of an event but is a regularly a likely contributor to varying degrees. The level of risk that fatigue presents is dependent on the task and the context in which the task is being performed.

Assessing fatigue risks using any methodology is limited because it is unclear how the complex interactions that exist between fatigue factors should be weighted. All methods need to be used with full recognition of their limitations.

Because of these factors, current methodologies for assessing risks, when applied to fatigue, are all limited to some degree. Further, the usefulness in application of all risk assessment methodologies is directly related to the knowledge and experience of the user. However, with growing maturity of SMS and more operational fatigue management experience around the world, advances are continuing to be made in the way fatigue risks are assessed.

4.2.8. USING RISK MATRICES TO ASSESS FATIGUE RISKS

Typically, safety risk is defined as the projected likelihood and severity of the consequence or outcome from an existing hazard or situation. A likelihood and severity matrix is commonly used by many aviation service providers to assess all types of risk and assist them to decide whether it is necessary to invest resources in mitigation. The level of the risk associated with a hazard and whether that risk level is "tolerable" is determined by plotting its position on the matrix. The main disadvantage of using matrices to assess risks is that controls and mitigations are not systematically taken into account.

Table 4-1 presents an example of severity classification categories from ICAO's Safety Management Manual (Doc. 9859, 2013, 3rd Edition).Table 4-2 presents an associated risk assessment matrix.

Table 4-1. Severity Classifications (adapted from ICAO SMM, 3rd Edition)

Severity	Meaning	Value
Catastrophic	- Multiple deaths - Equipment destroyed	A
Hazardous	- A large reduction in safety margins, physical distress or a workload such that crewmembers or controllers cannot be relied upon to perform their tasks accurately or completely - Serious injury - Major equipment damage	B
Major	- A significant reduction in safety margins, a reduction in the ability of crewmembers or controllers to cope with adverse operating conditions as a result of increase in workload, or as a result of conditions impairing their efficiency - Serious incident - Injury to persons	C
Minor	- Nuisance - Operating limitations - Use of emergency procedures - Minor incident	D
Negligible	- Little consequences	E

Table 4-2. Safety Risk Assessment Matrix (adapted from ICAO SMM, 3rd Edition)

Likelihood		Fatigue Severity							
		Catastrophic A		Hazardous B		Major C		Minor D	Negligible E
Frequent	5	5A		5B		5C		5D	5E
Occasional	4	4A		4B		4C		4D	4E
Remote	3	3A	Accident	3B	Large safety reduction	3C	Significant safety reduction	3D	3E
Improbable	2	2A		2B		2C		2D	2E
Extremely Improbable	1	1A		1B		1C		1D	1E

When using risk assessment matrices, Service Providers are expected to customise the severity and likelihood categories. The usefulness of using the severity classifications from Table 4-1 to assess fatigue risks is limited somewhat because the worst foreseeable consequence of fatigue-affected performance when performing a safety critical task is always catastrophic.

With regards to fatigue risks:

- to understand the severity of consequences, it is necessary to consider not just how fatigued an individual may be, but also the resulting impact on the individual's performance and how that diminished performance will manifest in the workplace.
- it is the task being undertaken (when fatigued) that determines the severity of the consequences. For example, if an operational person falls asleep in the office while performing a routine administrative task, there are no immediate safety consequences. However, if the same operational person falls asleep on the flight deck or at their work station while performing a safety critical task, it can lead to an accident.

In other words, to assess different types of fatigue risks using a matrix, different severity classifications are needed to better reflect the variety of possible consequences of fatigue-affected performance. Likelihood classifications will depend on the type of fatigue severity classification used. Therefore, when using risk assessment matrices in an FRMS, it is necessary for fatigue subject matter experts to customise their matrices by carefully selecting how severity and likelihood are classified. The following provide simple examples of how severity and likelihood classifications can be adapted in order to assess different fatigue risks.

SEVERITY CLASSIFICATIONS:

As mentioned above, different severity classifications are needed to better reflect the variety of possible consequences of fatigue-affected performance. Examples of methods for classifying severity classifications include:

- Severity classification may reflect "perceived fatigue levels" on the basis that the more fatigued an individual feels, the more likely their performance will decline. In Table 4-3 the subjective Samn-Perelli Scale is used, although other subjective measures may also be used. (see Appendix A)
- Bio-mathematical models aim to predict the average individual's fatigue level at different points across a planned roster. Once the user is able to relate the model's results to the operational context of their organization, severity classifications may be based on defined bio-mathematical model thresholds.
- Severity classification may reflect the number of relevant fatigue factors (i.e. factors that have been found to be associated with increased fatigue) that are germane to a specific duty or work pattern.

Table 4-3. Example Fatigue Severity Classification: Perceived levels of fatigue.

Samn-Perelli Score	Meaning	Value
7	Completely exhausted, unable to function effectively	A
6	Moderately tired, very difficult to concentrate	B
5	Moderately tired, let down	C
4	A little tired	D
3	Okay, somewhat fresh	E
2	Very lively, responsive, not at peak	E
1	Fully alert, wide awake	E

LIKELIHOOD CLASSIFICATIONS

Generally, fatigue likelihood is based on subjective estimations of how often a particular consequence of fatigue-affected performance might occur. Because this is contextually dependent, there are infinite variables that influence the operational consequences.

Where a specific fatigue factor related to a type of shift or work schedule is being assessed (e.g. < 7h between duties; commencement of duties prior to 7am), the measurable frequency with which an individual may experience or be exposed to it may be preferred to determine likelihood classifications.

Further fatigue risk assessment material is contained in Module 2 of the Fatigue Risk Management for Employees material on the Transport Canada web site at: http://www.tc.gc.ca/eng/civilaviation/standards/standards-3919.htm.

Other risk assessment guidance material, which may be of interest to GA operators, is the Airline Risk Management Solutions (ARMS) methodology and toolkit which is available in the EUROCONTROL SKYbrary at: http://www.skybrary.aero/index.php/ARMS_Methodology_for_Risk_Assessment .

MITIGATING FATIGUE RISKS

The risk assessment process determines whether or not a fatigue hazard requires mitigation. The most important thing to consider in choosing fatigue mitigations is the estimated level of associated fatigue risk. All mitigations require resources (effort, time, costs). Limited resources need to be prioritized where mitigations are most needed to effectively control fatigue risk.

Effective controls and mitigation strategies go beyond rest- and duty-times. For duties that are either very long, start very early in morning, finish late at night or go through the night, controls and mitigations need to be considered in the context of successive days and duties. Special attention needs to be given to the circadian influences on sleep- and wake-times regardless of rest- and work- times. Mitigation strategies that focus solely on an isolated duty may not address the effects of cumulative fatigue and become ineffective across a work roster. Therefore, the identification of fatigue mitigations requires a broad understanding of fatigue management scientific principles as well as operational experience. Therefore, the expertise of those within the operation should be used in the selection of mitigations. All involved personnel should clearly understand the hazards and the controls and mitigations designed to manage the associated risk.

SMS processes should require that such risk mitigations are regularly reviewed and assessed to ensure their desired outcome continues. If the controls and mitigations perform to an acceptable standard (i.e., they reduce the risk into the tolerable region — see Table 4-2, they become part of normal operations and are monitored by the SMS safety assurance processes. However, if the controls and mitigations do not perform to an acceptable standard, then it will be necessary to re-enter the fatigue risk management processes at the appropriate step. This could involve gathering additional information and data, and/or the re-evaluation of the fatigue hazard and associated risks, and/or identification, implementation and evaluation of new or revised controls and mitigations.

Different types of mitigations are discussed below according to whether they are:

- implemented by the GA operator; or
- implemented by the operational person.

4.2.9. ORGANIZATIONAL FATIGUE MITIGATION STRATEGIES

As discussed in Section 1.3, GA operators must identify limits and adopt scheduling practices based on scientific principles and operational experience as a means of mitigating fatigue. Table 4-4 provides some examples of organizational-level mitigations pertaining to the adjustment of scheduling practices and policies, for managing risks related to a specific fatigue hazards. These are drawn from IBAC's International Standard for Business Aircraft Operations (IS-BAO) and other industry material. The flight and duty time limits identified within are provided as examples only, and should not be considered as appropriate for standardized adoption.

Table 4-4. Organizational fatigue risk management examples

Particular Fatigue Hazard	Example Controls	Example Mitigations
The nature of the operation is such that flight requirements may come up with only a few days' notice and may involve evening starts and duty into the window of circadian low (WOCL).	Flight and duty period rules that reflect the time of day of the start time.	• Normal duty time limit of 14 hours. • Normal flight time limit of 10 hours with a maximum of two landings. • Flight Time can be extended to 12 hours with additional restrictions and extended rest period. • When there are more than two landings the flight time limit is limited to 10 hours. • When duty time encroaches on the WOCL, duty time is reduced to 12 hours, flight time is limited to 10 hours and second flight segments are prohibited. • Fatigue training programme for all personnel involved in the operation.
The nature of the operation is such that the need may arise any time of the day or night without notice to transport an emergency response team to the location of an industrial emergency.	Flight and duty period rules for call out especially at nighttime. Right of refusal where a crew member considers themselves not fit for duty. Agreements with on-demand charter operators or fractional ownership arrangements to provide supplemental lift at key locations away from home base.	• In addition to above rules, call outs between 2100 and 0600 hours will be limited to five hour duty times. • Agree with the emergency response team that the flight department will provide them with lift as allowed by the foregoing rules. • If a lift requirement is such that it cannot be accommodated within those limits, the flight will be directed to an intermediate point where supplemental lift will be hired to transport the emergency response team the remainder of the way to their destination. • Augmented flight crew to provide opportunity for in-flight rest.
Fatigue would be highly likely when aircraft crews are involved in consecutive night flights.	Scheduling rules to prohibit consecutive night flights and limit length of night-time flight and duty periods Augment crew where aeroplane facilities allow.	• Scheduling and operating personnel are advised of the rules and scheduling software is programmed to prohibit consecutive night flights by aircraft crew members. • When consecutive night flights are required for a long range trip with multiple legs, additional crew members are pre-positioned and provided appropriate rest period prior to commencing flight duty.

Particular Fatigue Hazard	Example Controls	Example Mitigations
Fatigue may be encountered by flights which involve morning departures and evening returns with extended wait periods on the ground.	Split duty day limitations and procedures.	• Normal duty days are limited to 14 hours. • When on the ground if waiting periods are schedule to be 4 hours or longer, aircraft crews are provided with hotel rooms or similar rest facilities. • Half of the time spent in the rest facility can be used to extend the duty day to a maximum of 4 additional hours. • Provide crew with access to food and water and appropriate rest facilities to optimize recovery.
Fatigue may be encountered by successive early morning starts which significantly encroach on normal sleep periods - e.g. 2 hours or more before normal working hours.	Limits to the number of early morning starts by aircraft crew members and maintenance personnel.	• Aircraft crew members and maintenance personnel will not be scheduled for more than two successive starts prior to 0600 hours. • For early starts, reduce the work day. • If this is a frequent occurrence and the number of personnel in the flight department would not permit such a practice, make an agreement with a neighboring operator to interchange personnel as needed This would require ensuring that involved personnel are fully qualified and trained to work with the other flight department.
Reports of flight crew inadvertently nodding off on the flight deck	Scheduling procedures, crew augmentation policies to enable in-flight rest. Coordination with principal passengers to develop trip schedules that take into account fatigue risks. Other fatigue countermeasures.	• Ensure an adequate selection of en-route rest facilities that provide good sleep opportunities. • Include principal passengers' executive assistants in the fatigue training programme. • Procedures for napping in-flight – see information in the following sub-section.
Landings at a confluence of circadian low, long duty period and high work demands.	Scheduling rules and trip planning.	• Procedures for napping in-flight..

As well as adjusting scheduling practices and policies, GA operators can also consider mitigating fatigue through the establishment of procedures for taking naps both in flight and between flights. These are discussed below.

IN-FLIGHT NAPS

As discussed in Chapter 2 (Section 2.1.4), napping is a valuable fatigue mitigation strategy because it limits extended periods of continuous wakefulness. Within a flight, napping may occur in the flight deck or in the cabin, depending on circumstances and the availability of sleeping facilities:

- Controlled naps taken on the flight deck are taken by pilots in response to unexpected fatigue experienced during operations. **It is not a means of scheduling extended flight periods**. On the flight deck, naps should be limited to 40-45 minutes and at least 10-15 minutes be given after waking before returning to flying duties (see *Operational Implication 5*. *Napping as a Fatigue Mitigation* in Section 2.1.2). During this time, a third crew member should ensure the engagement of the pilot flying to avoid both pilots falling asleep at the same time.
- In-flight rest taken in the cabin offers the possibility of longer naps for augmented crews. The length of the nap will depend on the available time away from duties but it should allow enough time for individuals to fall asleep (it may take people longer than usual to fall asleep in these circumstances) and enough time after waking before recommencing duties (at least 10-15 minutes), to ensure that any sleep inertia has dissipated (see *Operational Implication 1: Mitigation Strategies for Sleep Inertia* in Section 2.1.2). In many cases, only opportunistic cabin napping is available (e.g. in a spare passenger seat or on a patient stretcher), and like controlled naps taken on the flight deck, should not be used to schedule extended flight periods. Opportunistic cabin napping is used to manage both sudden unexpected fatigue and fatigue that is expected to become more severe during higher workload periods later in the flight.
- On aeroplanes where suitable in-flight rest facilities are available (i.e. where horizontal sleep can be obtained in a darkened, private, cool and quiet environment), some limited sleep recovery may be possible and flight and duty times may be able to be extended to accommodate a particular route or pairing. Where this is considered necessary, it is recommended that extra measures are used to monitor fatigue levels.

Procedures for the use of in-flight naps need to be established to ensure operational integrity and continued safe operations when used. An example of procedures for napping on the flight deck, some of which are also appropriate for napping in the cabin, is provided in Table 4-5. It is not an all-inclusive list and GA operators are encouraged to adapt these to define their own procedures appropriate for their circumstances.

Table 4-5. Example of Procedures for Napping on the Flight Deck

- Napping on the flight (or controlled rest) deck may be used at the discretion of the captain to manage both unexpected fatigue and to reduce the risk of fatigue during higher workload periods later in the flight.
- Flight crews should use controlled rest only if they are familiar with the published procedures.
- Controlled rest should be used only during the cruise period from the top of climb to 20 minutes before the planned top of descent. This is to minimize the risk of sleep inertia.
- Any routine system or operational intervention which would normally require a cross-check should be planned to occur outside controlled rest periods.
- One pilot only may take controlled rest at a time in his seat. The harness should be used and the seat positioned to minimize unintentional interference with the controls.
- Personal equipment such as eye shades, neck supports, ear plugs, etc., should be permitted for the resting pilot.
- The autopilot and auto-thrust systems (if available) should be operational.
- It should be clearly established who will take rest and when it will be taken. If required, the pilot-in-command may terminate the rest period at any time.
- A short period of time should be allowed for rest preparation. This should include an operational briefing, completion of tasks in progress and attention to any physiological needs of either crew member.
- During controlled rest, the non-resting pilot must perform the duties of the pilot flying and the pilot monitoring, be able to exercise control of the aircraft at all times, and maintain situational awareness. The non-resting pilot cannot leave his seat for any reason, including physiological breaks.
- Hand-over of duties and wake-up arrangements should be reviewed.
- The pilot-in-command should define criteria for when his rest should be interrupted.
- The controlled rest period should be no longer than 45 minutes, to minimize the risk of sleep inertia on awakening.
- Some operators involve a third crew member (not necessarily a pilot) to monitor controlled flight deck rest. This may include a planned wake-up call, a visit to be scheduled just after the planned rest period ends, or a third crew member on the flight deck throughout controlled rest.

BETWEEN-FLIGHT SLEEP ON SPLIT DUTIES

Compared to in-flight napping, split duties offer more latitude to optimize sleeping facilities, resulting in opportunities for longer periods of sleep, and some limited sleep recovery. To maximize the amount of sleep gained between split duties, consideration should be given to providing facilities which optimise sleep recovery (i.e. a safe and secure environment that can be made dark, cool and quiet). It is also important to have easy access to well-balanced meals to ensure fitness for their next duty.

Where such facilities cannot be provided, however, the recovery value of split duty is limited. Sleeping on the ground under the wing of an aircraft, or in the non-airconditioned cockpit of an idle aeroplane, will not reliably result in pilots who are well rested enough to perform their duties adequately.

An appropriate standard of sleeping facilities is also necessary for all crew member layovers.

4.2.10. PERSONAL MITIGATION STRATEGIES

There are also personal mitigation strategies which can be used by crew members to mitigate fatigue risk. Some examples of these are provided in Table 4.6.

Table 4-6. Examples of fatigue hazards and possible individual actions

Fatigue Hazard	Strategic Actions	Tactical Actions
Sleep at home disturbed by new baby.	Move to a quiet part of the house for final 2 nights' sleep before departure. Maximize sleep in 24 hours before departure.	Controlled flight deck napping maximize sleep during in-flight rest periods (if available), strategic use of caffeine in flight (see *Strategic Use of Caffeine,*on page 59).
In-flight sleepiness on non-augmented flights.	Maximize sleep in 24 hours before departure. Programme sleep period (nap) as close as possible to the reporting time.	Strategic use of caffeine in-flight (see p 59).
Difficulty sleeping in on-board crew rest facilities.	Maximize sleep in 24 hours before departure. Programme sleep period (nap) as close as possible to the reporting time.	Use eye mask, ear plugs and arrange for a suitable wakeup call or set an alarm. Avoid caffeine for 3-4 hours before trying to sleep. Strategic use of caffeine after in-flight rest period. Use meditation app.
Difficulty sleeping in noisy, poorly-curtained rooms in layover hotel.	Assess individual fitness for duty. Submit a fatigue report.	Bring a bulldog clip or peg to fasten the curtains. Use eye mask, ear plugs and arrange for a suitable wakeup call or set an alarm. Avoid caffeine for 3-4 hours before trying to sleep. Use meditation app.
Experience of fatigue prior to a positioning flight after an extended duty period.	Assess individual fitness for duty. Submit a fatigue report.	Use sleep hygiene measures to maximize layover sleep. Controlled flight deck napping (if possible), strategic use of caffeine in-flight.
Non-restorative sleep	See a sleep disorders specialist	Comply fully with recommended treatment
Unpredictable call-outs means that it is difficult to ensure adequate sleep prior to duty period.	Ensure that home sleep environment is dark and quiet, and use sleep hygiene measures to maximize sleep quality. Maximize recovery sleep on off-duty days.	Controlled flight deck napping, maximize sleep during in-flight rest periods (if available), strategic use of caffeine in flight.

Fatigue Hazard	Strategic Actions	Tactical Actions
	When feeling sleepy while waiting for call-out, attempt sleep (prioritize sleep over other activities). Assess individual fitness for duty.	
A flight/series of flights results in landing when fatigued.	Submit a fatigue report.	Controlled flight deck napping, maximize sleep during in-flight rest periods (if available), strategic use of caffeine in flight.

STRATEGIC USE OF CAFFEINE

Caffeine is a widely consumed substance that has been shown to increase alertness and improve motivation and concentration[30] . Therefore, it is frequently used as a fatigue countermeasure. Although it can be used to improve alertness in the short term, it does not address the brain's underlying need forsleep .

So why does caffeine make you feel good? A chemical called adenosine builds up in the brain when you have been awake for a long period of time, making you feel sleepy. Caffeine blocks the action of adenosine. Preventing the action of adenosine also results in other chemicals in the brain being released. The consequence is that you feel more alert and energetic. About 15 minutes after consuming caffeine the effects can be felt and these effects can last for between 2.5 to 4.5 hours and even longer in some individuals.

If caffeine is to be used as a fatigue countermeasure, then it should be consumed strategically (i.e., not used when already alert). Caffeine use can be considered after long periods of wakefulness and at times in the circadian cycle when alertness decreases (i.e., approximately 1500-1700 hours and 0300-0500 hours). Caffeine, in combination with a short nap, has been shown to be an effective fatigue countermeasure, and may also minimize the effects of sleep inertia when waking[31]. Since it takes at least 15 minutes for caffeine to enter the bloodstream, an individual can fall asleep before the alerting effects of caffeine occur.

Caffeine consumption should be limited near bedtime, as it can interfere with and disrupt sleep. For some individuals, even small amounts can cause problems sleeping. Care should be taken when caffeine is consumed regularly (i.e. daily) because mild dependence can occur. It is also possible to experience side effects such as stomach problems, dizziness, rapid heartbeat, irritability, anxiety, tremors, dehydration, high blood pressure and insomnia. To prevent more severe health risks associated with high levels of caffeine use it is recommended that healthy adults should not consume more than 500-600mg per day. Table 4-6 provides a list of caffeine amounts in common foods and beverages.

[30] Thomson, B and Schiess, S (2010) Risk profile: caffeine in energy drinks and energy shots. Report prepared by the Institute of Environmental Science & Research, Christchurch, New Zealand.

[31] Van Dongen, H. P. A., Price, N. J., Mullington, J. M., Szuba, M. P., Kapoor, S. C., & Dinges, D. F. (2001). Caffeine eliminates psychomotor vigilance deficits from sleep inertia. *Sleep, 24*, 813-819; Wurts, S. W., & Edgar, D. M. (2000). Caffeine during sleep deprivation: sleep tendency and dynamics of recovery sleep in rats. *Pharmacology, Biochemistry, and Behavior, 65*(1), 155-162.

Table 4-7. Caffeine amounts in some common foods and beverages

Beverage	Caffeine Amount
Espresso coffee	78-106 mg/100ml
Brewed coffee	36-112 mg/100ml
Instant coffee	23-73 mg/100ml
Decaffeinated coffee	0-5mg/100ml
Black tea	13-47 mg/100ml
Energy drinks (e.g. V, Red Bull, Monster)	15-42 mg/100ml
Soft drinks (e.g. Coca-Cola, Pepsi, Lift, Mountain Dew)	9-14 mg/100ml
Dark chocolate	43-125mg/100g
White and milk chocolate	21-23 mg/100g

4.2.11. SAFETY ASSURANCE

Safety assurance processes monitor the continued effectiveness of implemented mitigations over time. On-going evaluation by the SMS safety assurance processes not only enables the management of risks to be adapted to meet changing operational needs, it also allows the SMS to continuously improve the management of risks, including those related to fatigue. In doing so, fatigue-related risk controls and mitigations that have unintended consequences or that are no longer needed due to changes in the operational or organizational environment, can be identified and then modified or eliminated. Such changes to the SMS should be documented so that they will be available for subsequent reviews, audits and evaluations.

Safety assurance processes therefore monitor data collected through the risk management processes of the SMS through the generation of safety performance indicators (SPIs). SPIs provide a metric to guide decision making. For example, changes in SPIs might signal a new fatigue hazard, and they can be used to track the effectiveness of new mitigations. For SPIs to be useful, acceptable values or targets need to be set. These acceptable values or targets need to be appropriate to the level of risk in a given operation, and/or in the ‘tolerable’ or ‘acceptable’ regions of risk assessments.

Figure 4-3 summarises the safety assurance processes of an SMS and how these can be used to monitor fatigue-related SPIs.

Having a variety of SPIs is expected to give a more reliable indication of fatigue levels and how well fatigue is being managed. It is also important to note that different SPIs may be appropriate in different types of operations. The implications of fatigue SPIs should be considered within the context of the entire operation, to distinguish between acceptable and unacceptable levels of safety.

Common types of fatigue SPIs include:

- SPIs that monitor the schedule and duty related causes of fatigue;
- SPIs based on fatigue data collected through SMS processes. Examples include the number of fatigue reports (e.g., on schedule or route), fatigue-related incidents or FOQA events (this methodology is still under development), and measures of absenteeism.

Fatigue SPIs are described further below.

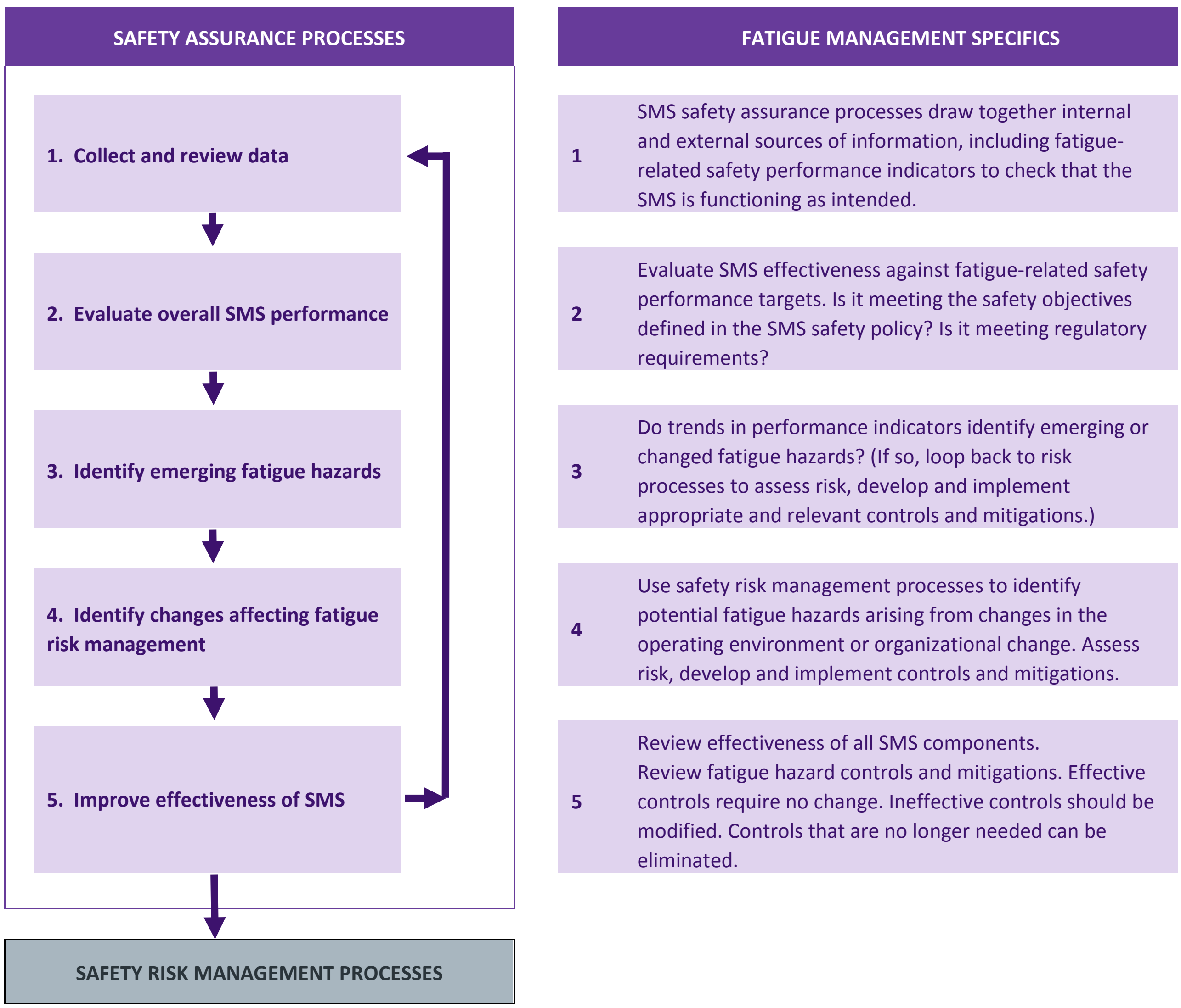

Figure 4-3. SMS safety assurance processes

SCHEDULE AND DUTY-RELATED SAFETY PERFORMANCE INDICATORS

GA operators should keep records of schedules and crew members' flight times, flight duty periods, duty periods and rest periods. Data detailing crew members' times of actual work can be compared to the original work schedule to generate schedule and duty-related SPIs and their acceptable values/ targets and help to identify times in assignments and rosters when fatigue might be higher than expected. Table 4.8 contains some examples of schedule and duty-related SPIs and targets.

Table 4-8. Examples of Schedule and Duty-Related SPIs and Acceptable Values/Targets

Safety Performance Indicator	Acceptable Value/Target
Frequency that maximum schedule duty day (e.g. 13 hours) is exceeded	Maximum scheduled duty day will not be exceeded on more than [*]% of days in any 28-day period
Number of flight duty periods ending [*] minutes later than scheduled	If report time is earlier than 05:00, flight duty period extensions of [*] minutes or more may not occur on more than x% of days in any 28-day period
How often minimum break between duties is reduced	Acceptable on no more than [*]% of flights in any 28-d period. Not acceptable to operate next duty period.
How often duty periods end in the window of circadian low (WOCL)	For non-augmented crew, no duty period longer than [*] hours will be scheduled to end in the WOCL. Delays acceptable on no more than [*]% of flights in any 28-d period
Number of pairings identified as high fatigue risk, e.g., no more than three consecutive night flights scheduled	Target - no exceptions
Number report times earlier than 06:30 on successive days	No more than [*] scheduled. Acceptable on no more than [*]% of flights in any 28-day period
Number of times that notification time for standby crew call-outs is below [*] minutes.	Not to exceed [*]% in any 28-day period

SAFETY PERFORMANCE INDICATORS BASED ON COLLECTED FATIGUE DATA

Using SMS processes, data on crew member fatigue will be collected through the operator's safety reporting system via fatigue reports (e.g. hazard reports and incident/accident reports). From these, trends can be monitored in fatigue-related SPIs such as:

- Number and severity of fatigue reports.
- Number of fatigue-related incidents.
- Number of absenteeism/fatigue calls.

Fatigue reports can also provide data on self-reported sleep history and fatigue levels using measures described in Appendix A. Where the GA operator may have some particular concerns about the level of fatigue risk associated with an aspect of a schedule or route, those same measures may have also been used to collect data at specific times in a work period. SPIs which can be generated using these measures are presented in Table 4.9.

Table 4-9. Proposed measures of crew fatigue and safety performance indicators (SPIs) based on them

Measure	SPIs (1 flight per duty period[32])
sleep/wake history monitored using sleep diaries	1. sleep in the 24 hours prior to duty start time 2. time awake at duty start time 3. sleep in the 24 hours prior to top of descent (TOD) (including in-flight sleep for augmented crews) 4. time awake at TOD
subjective fatigue rated on the 7-point Samn-Perelli crew checklist	1. pre-flight fatigue rating 2. fatigue rating at TOD
subjective sleepiness rated on the 9-point Karolinska Sleepiness Scale.	1. pre-flight sleepiness rating 2. sleepiness rating at TOD

4.2.12. TRAINING AND COMMUNICATION

As part of their SMS, GA operators should have a safety training programme to ensure that involved personnel are competent to perform their SMS duties and a communications plan that encourages their participation. Training of involved personnel should result in their ability to undertake responsibilities regarding the management of fatigue risks. Related training standards for initial and recurrent training should be specified in the SMS documentation.

[32] For duty periods that contain multiple flight segments, it may be appropriate to measure SPIs at the beginning and end of duty, since crew members may not have enough time to rate their fatigue and sleepiness prior to TOD on short flights. It may also be appropriate to have SPIs relating to workload (for example number of flight segments) in multiple-stop operations.

TRAINING PROGRAMME CONTENT

A major element of fatigue management training is that the key principles of fatigue science — managing sleep and understanding the effects of the circadian body clock — are relevant not only to individuals' roles in the management of fatigue at work but also to their lives outside of work, for example, in safe motor vehicle driving and in staying healthy. Thus, fatigue management training covers issues that everyone can identify with and this can help promote the concept of shared responsibility.

The content of training programmes should be adapted to ensure different professional groups involved in fatigue management have the knowledge and skills they need for their roles. All groups require basic education about the dynamics of sleep loss and recovery, the effects of the daily cycle of the circadian body clock, the influence of workload and how these factors interact with operational demands to produce fatigue (see Chapter 2). It is also useful to provide information on managing personal fatigue and sleep issues. Additionally, fatigue management training topics should address specific fatigue risks identified through SMS processes.

It is recommended that, at a minimum, training for operator personnel involved in the operation and maintenance of aircraft addresses the following areas:

- an overview of the operator's fatigue risk management programme, including the concepts of shared responsibility and an effective reporting culture;
- crew member responsibilities and those of the operator for managing fatigue;
- causes and consequences of fatigue in the operation(s) in which they work;
- how to identify fatigue in themselves and others;
- how to use fatigue reporting systems, including how to report that they are too fatigued to fly;
- personal strategies that they can use to improve their sleep at home and to manage fatigue-related risks while they are on duty; and
- basic information on sleep disorders, related treatments, where to find help if needed and any restrictions relating to being fit to fly.

Training for personnel involved in crew scheduling and other support staff could address the following areas:

- an overview of the operator's fatigue risk management programme, including the concepts of shared responsibility and an effective reporting culture;
- an understanding of how work and trip schedules can affect sleep opportunities and disrupt the circadian biological clock cycle , the fatigue risk that this creates, and how this can be mitigated through scheduling;
- training in the use and limitations of any scheduling tools and bio-mathematical models or other algorithms that are being used by the operator to predict the levels of crew member fatigue;
- their role in the SMS in relation to fatigue hazard identification and risk assessment;
- processes and procedures for assessing the potential fatigue impact of planned scheduling changes and for ensuring that management is engaged early on in the planning of changes with significant potential to increase fatigue risk;
- how to identify fatigue in themselves and others;
- personal strategies that they can use to improve their sleep at home and to minimize their own fatigue risk, and that of others, while they are at work; and
- basic information on sleep disorders, related treatments and where to find help if needed.

It is recommended that at a minimum, training for operational decision-makers and those involved in operational risk management addresses the following areas:

- an overview of the GA operator's fatigue risk management programme including the concepts of shared responsibility and an effective reporting culture;
- an overall understanding of crew member fatigue and the safety risk that it represents to the organization;
- the responsibilities and accountabilities of different stakeholders in fatigue management including themselves;
- linkages between fatigue management and other parts of the GA operator's safety management system;
- how to identify fatigue in themselves and others;
- personal strategies that they can use to improve their sleep at home and to minimize their own fatigue risk, and that of others, while they are at work;
- basic information on sleep disorders, related treatments and where to find help if needed.

While Chapter 2 provides material that GA operators can use to develop their training programmes, other examples of training materials can be found in the fatigue management pages of the ICAO web site http://www.icao.int/safety/fatiguemanagement/Pages/default.aspx.

TRAINING RECORDS

Training is an essential element of an SMS and is particularly important when managing fatigue risks. As part of their SMS documentation, GA operators should keep training records identifying who has been trained, when and to what level. Recurrent training is also expected. The interval between training sessions and the level of training provided need to be related to the level of expected fatigue risk in the operations.

COMMUNICATION PLAN

An SMS requires operators to develop and maintain a formal means for safety communication that:

- ensures personnel are aware of the SMS to a degree commensurate with their positions;
- conveys safety-critical information;
- explains why particular safety actions are taken; and
- explains why safety procedures are introduced or changed.

A training programme that includes appropriate fatigue management elements will address a number of these requirements but there needs to be on-going communication with stakeholders about the activities and fatigue risk management safety performance of the SMS, to keep fatigue "on the radar" and encourage the continuing commitment of all involved personnel. To acquire information necessary to manage fatigue adequately, personnel need to know not only what to report, but feel confident that information they provide will be received in a positive manner and is valued by management. It is particularly important that personnel are advised of all changes made in response to information they provide (e.g. changes to scheduling practices or arrangements for improvements to sleeping accommodations based on fatigue reports).

The communication plan needs to be described in the SMS documentation and assessed periodically as part of SMS safety assurance processes.

APPENDIX A. SUBJECTIVE MEASURES OF FATIGUE

Managing fatigue risks sometimes requires the measurement of the fatigue of personnel. Fatigue measurements can be based on crew members' recall or current impressions of fatigue (subjective measures) or on objective measurements, such as performance tests and different types of physical monitoring. Each type of measure has its strengths and weaknesses. To decide which types of data to collect, the most important consideration should be the expected level of fatigue risk. Some of the more onerous (and costly) fatigue measures often associated with FRMS should be considered when risks are high (refer to *The Fatigue Management Guide for Operators* in the ICAO suite of Fatigue Management Manuals). However, for the purposes of a GA operator's SMS, it is likely that the monitoring of fatigue levels will mainly rely on subjective assessments of fatigue levels and the amount of sleep obtained.

Subjective measures are discussed further below.

A1 RATINGS OF FATIGUE LEVELS

A1.1 THE EPWORTH SLEEPINESS SCALE

The Epworth Sleepiness Scale is a useful tool when conducting retrospective surveys[33]. It is a validated tool for measuring the impact of sleepiness on daily life. It is widely used clinically to evaluate whether an individual is experiencing excessive sleepiness[34] and information is available on its distribution in large community samples[35].

Figure A-1 shows the Epworth Sleepiness scale. The person is asked to rate each situation from 0 = "would never doze" to 3 = "high chance of dozing", for a total possible score of 24. Scores above 10 are generally considered to indicate excessive sleepiness. Scores above 15 are considered to indicate extreme sleepiness.

33 Note that some measures, for example the Karolinska Sleepiness Scale and the Samn-Perelli Crew Status Check are <u>not designed to be used retrospectively</u>. They are meant to be answered in relation to how you feel at a specific moment in time.

34 Johns M.W., "Sleepiness in different situations measured by the Epworth Sleepiness Scale," *Sleep*, 1994, Vol. 17, pp. 703-10.

35 Gander P.H., Marshall N.S., Harris R., Reid P., "The Epworth sleepiness score: Influence of age, ethnicity and socioeconomic deprivation," *Sleep* , 2005, Vol. 28, pp. 249-53.

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired?

This refers to your usual way of life in recent times. PLEASE TICK ONE BOX ON EACH LINE

	Would never doze	***Slight chance***	***Moderate chance***	***High chance***
Sitting and reading	0 □	1 □	2 □	3 □
Watching television	0 □	1 □	2 □	3 □
Sitting inactive in a public place (e.g. theatre, meeting)	0 □	1 □	2 □	3 □
As a passenger in a car for an hour without a break	0 □	1 □	2 □	3 □
Lying down in the afternoon when circumstances permit	0 □	1 □	2 □	3 □
Sitting and talking to someone	0 □	1 □	2 □	3 □
Sitting quietly after a lunch *without* alcohol	0 □	1 □	2 □	3 □
In a car, while stopped for a few minutes in traffic	0 □	1 □	2 □	3 □

Figure A-1. The Epworth Sleepiness Scale

A1.2 THE KAROLINSKA SLEEPINESS SCALE (KSS)

This scale asks people to rate how sleepy they feel right now[36,37,38,39,40] and is a useful tool for inclusion on fatigue reports. Any of the values from 1 to 9 can be ticked, not only those with a verbal description (Figure A-2).

1 = extremely alert

2

3 = alert

4

5 = neither sleepy nor alert

6

7 = sleepy, but no difficulty remaining awake

8

9 = extremely sleepy, fighting sleep

Figure A--1. The Karolinska Sleepiness Scale (KSS)

Figure A-3 shows KSS ratings from 25 flight crew members across ultra-long range flights from Singapore to Los Angeles[41].

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36 Åkerstedt, T., Gillberg, M., "Subjective and objective sleepiness in the active individual," *International Journal of Neuroscience*, May 1990, Vol. 52(1-2), pp. 29-37.

Reyner, L.A., Horne, J.A., "Evaluation of 'in-car' countermeasures to sleepiness: cold air and radio," *Sleep*, 1998, Vol. 21(1), pp. 46-50.

37 Gillberg, M., Kecklund, G., Åkerstedt, T., "Relations between performance and subjective ratings of sleepiness during a night awake," *Sleep*, April 1994, Vol. 17(3), pp. 236-41.

38 Harma, M., Sallinen, M., Ranta, R., Mutanen, P., Muller, K., "The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers," *Journal of Sleep Research*, 2002, Vol. 11(2), pp. 141-51.

39 Gillberg, M., "Subjective alertness and sleep quality in connection with permanent 12-hour day and night shifts," *Scandinavian Journal of Work, Environment and Health*, 1998, Vol. 24 (Suppl 3), pp. 76-80.

40 Reyner, L.A., Horne, J.A., "Evaluation of 'in-car' countermeasures to sleepiness: cold air and radio," *Sleep*, 1998, Vol. 21(1), pp. 46-50.

41 Flight Safety Foundation, *Flight Safety Digest*, 2006, Vol. 24, pp. 8-9.

Signal, T.L., van den Berg, M., Travier, N., Gander, P.H., "Phase 3 ultra-long range validation: in-flight polysomnographic sleep and psychomotor performance," Wellington, New Zealand: Massey University, Sleep/Wake Research Centre Report, 2004.

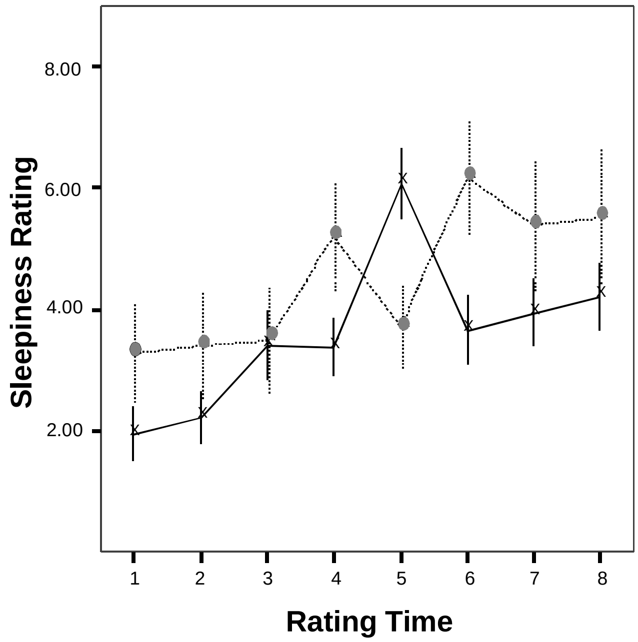

Figure A -2. KSS sleepiness ratings on flights from Singapore to Los Angeles (Solid line: data for the command crew; dotted line: data for the relief crew)

Each flight had two crews (two captains, two first officers). The command crew (solid line) flew both the take-off and the landing and was allocated the 2nd and 4th in-flight rest periods. The relief crew (dotted line) was allocated the 1st and 3rd in-flight rest periods (they became the command crew for the return flight).

Ratings were made at the following times:

- rating 1 – pre-flight;
- rating 2 – at top of climb;
- rating 3 – before each crew member's 1st in-flight rest period;
- rating 4 – after each crew member's 1st in-flight rest period;
- rating 5 – before each crew member's 2nd in-flight rest period;
- rating 6 – after each crew member's 2nd in-flight rest period;
- rating 7 – at top of descent; and
- rating 8 – post-flight before departing the aircraft.

The command and relief crews have different patterns in their sleepiness ratings across the flight, partly as a result of their different in-flight rest patterns.

A1.3 THE SAMN-PERELLI CREW STATUS CHECK

This scale asks people to rate their level of fatigue right now and is a simplified version of the Samn-Perelli Checklist[42],[43],[44]. It is another tool that can be considered for inclusion on fatigue reports.

1 = fully alert, wide awake
2 = very lively, responsive, but not at peak
3 = okay, somewhat fresh
4 = a little tired, less than fresh
5 = moderately tired, let down
6 = extremely tired, very difficult to concentrate
7 = completely exhausted, unable to function effectively

Figure A-4. The Samn-Perelli Crew Status Check

Figure A-5 shows Samn-Perelli ratings for the same ULR crew members on the same flights as in Figure A-3.

[42] Samn, S.W., Perelli, L.P., "Estimating aircrew fatigue: A technique with implications to airlift operations," Brooks AFB, TX: USAF School of Aerospace Medicine, Technical Report No. SAM-TR-82-21, 1982.

[43] Samel, A., Wegmann, H.M., Vejvoda, M., Drescher, .J, Gundel, A., Manzey, D., Wenzel, J., "Two-crew operations: Stress and fatigue during long-haul night flights," *Aviation, Space, and Environmental Medicine*, August 1997, Vol. 68(8), pp.679-87.

[44] Samel, A., Wegmann, H.M., Vejvoda, M., "Aircrew fatigue in long-haul operations." *Accident Analysis and Prevention*, July,1997, Vol. 29(4) pp. 439-52.

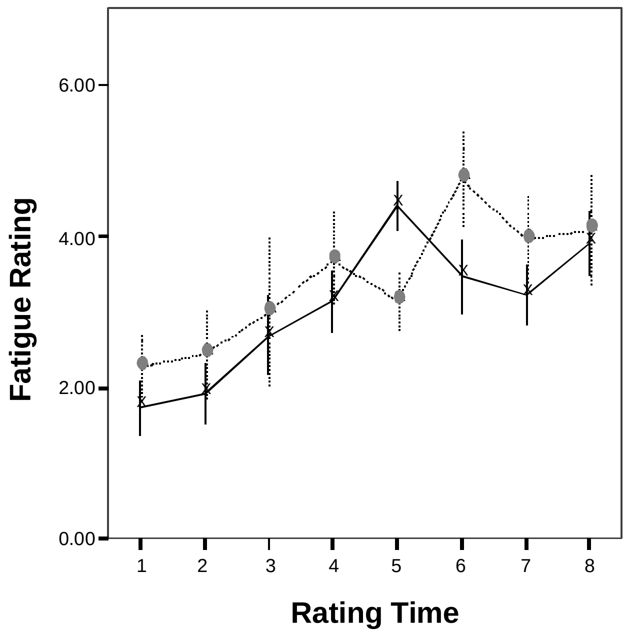

Figure A-5. Samn-Perelli fatigue ratings on flights from Singapore to Los Angeles (Solid line: data for the command crew; Dotted line: data for the relief crew)

A1.4 STRENGTHS AND WEAKNESSES OF SUBJECTIVE RATINGS

Subjective sleepiness and fatigue ratings are relatively cheap and easy to collect and analyze. Furthermore, how a crew member feels is likely to influence his decisions about when to use personal fatigue countermeasure strategies. On the other hand, subjective ratings do not always reliably reflect objective measures of performance impairment or sleep loss, particularly when people have been getting less sleep than they need (sleep restriction) across several consecutive nights.

Concerns about some crew members exaggerating on subjective fatigue and sleepiness ratings, for personal or industrial reasons, should be minimal in a just reporting culture as is required for an effective SMS. In addition, extreme ratings are obvious when compared to group averages.

Subjective sleepiness and fatigue ratings are particularly useful in fatigue management:

1. for gathering information from large groups of crew members;
2. where data are needed fairly quickly to decide whether more in-depth monitoring is warranted or if additional fatigue risk mitigation strategies are needed; and
3. among a range of measures when more intensive monitoring is undertaken for fatigue management (for example, during introduction of long range and ultra-long range operations), because they provide valuable insights on crew members' experience of fatigue.

Management decision making can be guided by comparing average (and/or extreme) ratings with data gathered on other operations.

A2 ASSESSMENT OF SLEEP DURATION

Sleep loss is a key contributing factor to fatigue. In addition, crew members need to get recovery sleep to return to their optimum level of waking function. Sleep can be monitored during flight operations using subjective sleep diaries.

Sleep diaries ask crew members to record the following information about each sleep period:

- where they sleep (home, layover hotel, in flight in a crew rest facility or a business class seat, etc);
- what time they go to bed and get up;
- how much sleep they think they get; and
- how well they think they sleep.

Crew members may also be asked to rate their sleepiness and fatigue before and after planned sleep periods. When sleep is being monitored during flight operations, crew members may also be asked to record actual duty times.

Diaries can have different layouts and they are often adapted to include specific information for a given study (for example, reminders about when to do performance tests or workload rating scales). Paper-based diaries are still more common, but electronic versions are also used (e.g., programmed on a smart phone or tablet). The layout of diary pages may need to be adapted to collect different types of information at different times in a study, for example pre-trip, during flights, and during layovers.

Figure A-6 shows an example of an in-flight sleep diary designed to be used during ultra-long range flight when crews of commercial passenger aircraft have multiple in-flight rest periods (courtesy of the Sleep/Wake Research Centre). This example includes Karolinska Sleepiness and Samn-Perelli ratings before and after each sleep period, as well as a sleep quality rating scale for each sleep period.

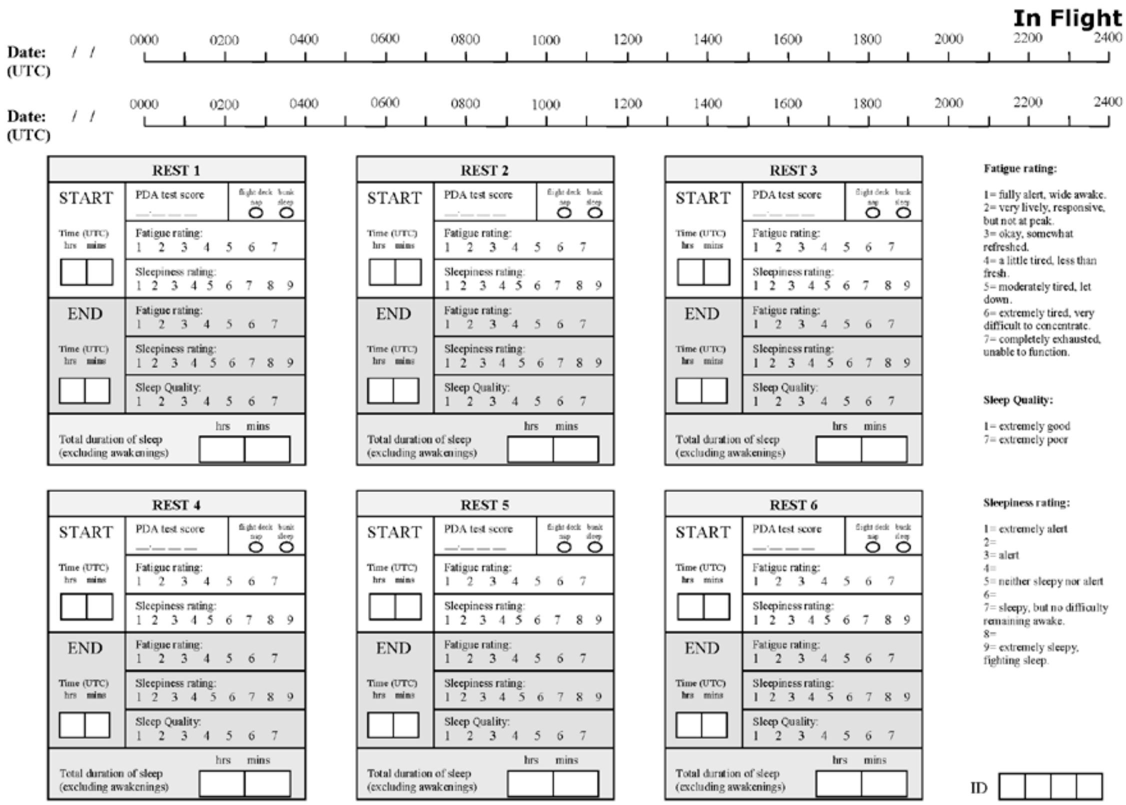

Figure A-6. Example of an in-flight sleep diary for ULR operations.

A2.1 STRENGTHS AND WEAKNESSES OF SLEEP DIARIES

Sleep diaries are cheap compared to objective forms of sleep monitoring. However, information from paper diaries needs to be manually entered into databases, which can slow down the process of getting answers to a particular operational question. Electronic diaries that can be downloaded avoid this problem. Analysis of diary data also has costs associated.

Sleep diaries are known to be less reliable than objective sleep monitoring. One study has compared sleep diaries and objective sleep measures from 21 B-777 flight crew members in a layover hotel and in flight.[45] For in-flight sleep:

- average sleep durations from diaries were similar to those recorded using polysomnography (the accepted gold standard for recording sleep); but

[45] Signal TL, Gale J, Gander PH. Sleep Measurement in Flight Crew: Comparing actigraphic and subjective estimates of sleep with polysomnography. Aviation Space and Environmental Medicine 76(11):1058-1063, 2005.

- the variability among individuals was high. Some crew members over-estimated how long they slept, and others underestimated; and
- crew members' estimates of how long they took to fall asleep, and their ratings of sleep quality were not reliably related to polysomnography measures.

Thus diaries alone may be useful for measuring the sleep duration of groups but *cannot be considered accurate for estimating the sleep duration of any one individual.* In addition, diaries are not generally considered reliable for measuring sleep quality

Despite these limitations, sleep diaries are a relatively cheap way of gathering reasonable information on the average amount of sleep obtained by *groups* of crew members.

APPENDIX B. EVALUATING THE CONTRIBUTION OF FATIGUE TO SAFETY EVENTS

In 1997, the Canadian Transportation Safety Board produced guidelines for fatigue analysis. They suggest four initial questions to decide whether or not fatigue was a contributing factor to an event [46]

1. At what time of day did the occurrence take place? If it was in the WOCL (0200-0600), than fatigue may have been a factor.

2. Was the person's normal circadian rhythm disrupted? (for example, if in the last 72 hours they had been on duty at night, or had flown across time zones).

3. How many hours had the person been awake at the time of the occurrence? . (It may be more reliable to ask 'what time did you wake up from your last sleep period before the event?'). If this is more than 16 hours, then sleepiness may have been a factor.

4. Does the 72-hour sleep history suggest a sleep debt? (As a rough guide, if the average adult requires 7-8 hours of sleep per 24 hours, then a crew member who has had less than 21 hours sleep in the last 72 hours was probably experiencing the effects of a sleep debt. If information on sleep history is not available, duty history can provide information on sleep opportunities).

If answers to the four questions above suggest that the crew member was fatigued at the time of the event, then more in-depth investigation requires looking at whether the person or crew took particular actions or decisions that were causal in what went wrong, and whether those actions or decisions are consistent with the type of behaviour expected of a fatigued person or crew. The following two checklists provide one example of how this can be done.

Checklist 1 is designed to establish whether the person or crew was in a fatigued state, based on a series of questions or probes that address key aspects of fatigue. The answer to each question is compared to the best case response, in order to build an overall picture of the fatigue hazard. Any departure from the best case response indicates increased risk of fatigue.

Checklist 2 is designed to establish whether the unsafe action(s) or decision(s) were consistent with the type of behavior expected of a fatigued person or crew.

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[46] Transportation Safety Board of Canada, *A Guide for Investigating for Fatigue*, Transportation Safety Board of Canada, 1997, Gatineau, Quebec.

Checklist 1 Establishing the fatigued state

Questions	Best Case Responses	Investigator's Notes
Quantity of Sleep **establish whether or not there was a sleep debt**		
How long was last consolidated sleep period?	7.5 to 8.5 hours	
Start time?	Normal circadian rhythm, late evening	
Awake Time?	Normal circadian rhythm, early morning	
Was your sleep interrupted (for how long)?	No	
Any naps since your last consolidated sleep?	yes	
Duration of naps?	Had opportunity for restorative (1.5-2 hrs) or strategic (20 min) nap prior to start of late shift	
Describe your sleep patterns in the last 72 hours. (Apply sleep credit system)	2 credits for each hour of sleep; loss of one credit for each hour awake - should be a positive value	
Quality of Sleep **establish whether or not sleep was restorative**		
How did the sleep period relate to the individual normal sleep cycle i.e., start/finish time?	Normal circadian rhythm, late evening/early morning	
Sleep disruptions?	No awakenings	
Sleep environment?	Proper environmental conditions (quiet, comfortable temperature, fresh air, own bed, dark room)	
Sleep pathologies (disorders)	None	

Checklist 2 Establishing the link between fatigue and the unsafe act(s)/decision(s)

Questions	Best Case Responses	Investigator's Notes
Work History **establish whether hours worked and type of duty or activities involved had an impact on sleep quantity and quality**		
Hours on duty and/or on call prior to the occurrence?	Situation dependent - hours on duty and/or on call and type of duty that ensure appropriate level of alertness for the task	
Work history in preceding week?	Number of hours on duty and/or on call and type of duty that do not lead to a cumulative fatigue	
Irregular Schedules **establish whether the scheduling was problematic with regards to its impact on quantity and quality of sleep**		
Was crew member a shift worker (working through usual sleep times)?	No (The circadian body clocks and sleep of shift workers do not adapt fully)	
If yes, was it a permanent shift?	Yes -days	
If no, was it rotating (vs irregular) shift work?	Yes - Rotating clockwise, rotation slow (1 day for each hour delayed), night shift shorter, and at the end of cycle	
How are overtime or double shifts scheduled?	Scheduled when crew members are in the most alert parts of the circadian body clock cycle (late morning, mid evening)	
Scheduling of critical safety tasks?	S Scheduled when crew members are in the most alert parts of the circadian body clock cycle (late morning, mid evening)	
Has crew member had training on personal fatigue mitigation strategies?	Yes	
Jet Lag **establish the existence and impact of jet lag on quantity and quality of sleep**		
Number of time zones crossed?	one	
If more than one, at what rate were they crossed?	the slower the better	
In which direction was the flight?	westward	

APPENDIX C. EXCERPTS FROM FLIGHT SAFETY FOUNDATION – NBAA DUTY/REST GUIDELINES FOR BUSINESS AVIATION

This appendix contains tables on duty and flight time limitations, rest requirements and crew scheduling guidance from the *Flight Safety Foundation – NBAA Duty/Rest Guidelines for Business Aviation* (2014) document[47]. They are industry developed guidance on duty and flight time limitations, rest requirements and crew scheduling guidance based on the scientific principles outlined in Chapter 2 and **are not to be considered as a regulatory standard or suggested limits**. GA operators may wish to review this material as a starting point for developing or reviewing their fatigue management programme, adapting them as necessary to meet their specific operational context and conditions.

Tables C-1 and C-2 deal with duty periods, flight time and rest periods and Table C-3 is a possible application of Tables C-1 and C-2 to construct a weekly duty and rest period schedule. As noted in the *Flight Safety Foundation – NBAA Duty/Rest Guidelines for Business Aviation (2014)* document, Table C-3 simply combines daily recommended maximum duty periods with minimum rest periods from "on a per week basis", then uses basic arithmetic to calculate the weekly limits. **It should be noted that Table C-3 does not consider organizational or operational conditions that may influence fatigue, or address the GA operator's assessment of the associated level of risk**.

It must be recognized that operational demands can introduce additional fatigue, requiring active fatigue management strategies, which may include reducing weekly limits. Any operational demands that could impact fatigue should be taken into consideration when developing work or trip schedules especially when approaching maximum duty limits, whether on a daily or weekly basis. Scheduling rules and practices, including the basic examples provided in Table C-3, need to be continually reviewed and evaluated using SMS processes.

[47] Downloadable from http://flightsafety.org/current-safety-initiatives/duty-rest-guidelines

Table C-1. Flight and Duty Limits for Non-Augmented Crews (24-Hour Period) suggested in the FSF/NBAA Guidelines

Recommended Guidance for Non-Augmented Crews **24-Hour Period**			
Type of Operation	Duty Period (maximum hours)	Flight Time (maximum hours)	Off-Duty Period (minimum hours)
Standard[1]	14	10	10 Weekly**:** Minimum of 36 continuous hours, including two consecutive nights, in seven-day period
WOCL[2]	12	10 Restricted landings (see Section 2.4.2)	12 48 continuous hours in 7-day period following multiple WOCL duty periods
Extended[3]	14	12 Restricted landings and compensatory time off duty Weekly: Maximum of 4 cumulative hours of extension	12
WOCL	No extensions recommended		48 continuous hours in a 7-day period following multiple WOCL duty periods
Multiple Time Zones			48 continuous hours off duty on return home following a duty period crossing multiple time zones

Notes

1. *Standard operation*s are defined as operations that do not encroach on the WOCL and are not extended operations.
2. *Window of circadian low (WOCL) operations* are defined as a flight in which landing occurs during the WOCL, the flight passes through both sides of the WOCL, or the duty period starts at 0400 or earlier in the WOCL (see Section 2.1).
3. *Extended operations* are defined as any operation with a duty period longer than 14 hours or flight time longer than 10 hours. Extended operations can involve duty/rest cycles longer than 24 hours.

Source: Flight Safety Foundation and U.S. National Aeronautics and Space Administration

Table C-2. Flight and Duty Limits for Augmented Crews (24-Hour Period) suggested in the FSF/NBAA Guidelines

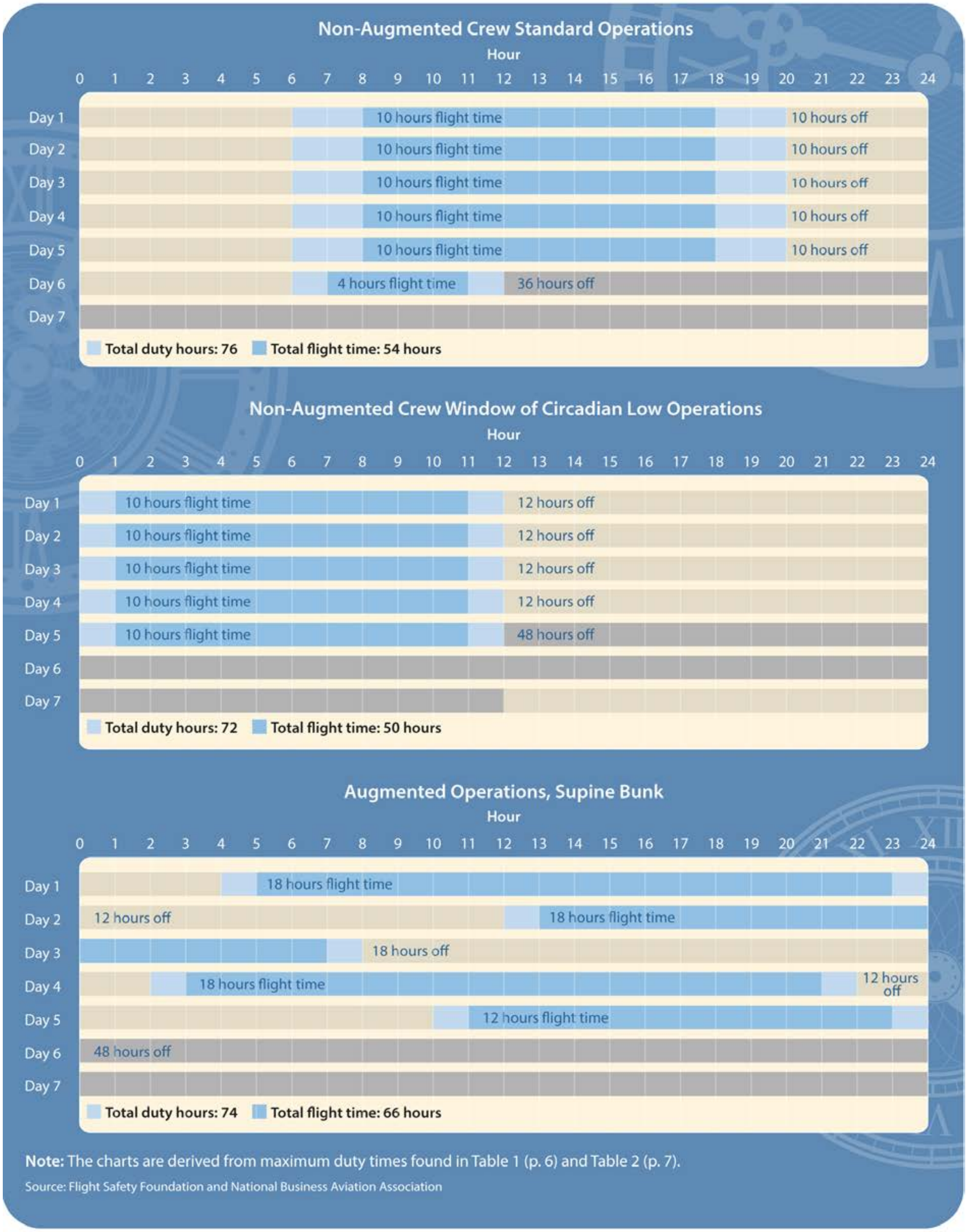
Recommended Guidance for Augmented[1] Crews 24-Hour Period[2]			
Type of Operation	Duty Period (maximum hours)	Flight Time (maximum hours)	Off-Duty Period (minimum hours)
Reclining seat available for rest	18	16	12
Supine bunk available for rest	20	18 Each flight crew member to have maximum sleep opportunity with a minimum of 4 hours total	12 Maximum of two consecutive duty periods with 18 hours off duty after the two consecutive duty periods
WOCL[3]	No extensions recommended		
Multiple time zones			48 continuous hours off duty on return home following a duty period crossing multiple time zones

Notes

1. *Augmented crew* is a flight crew that comprises more than the minimum number required to operate the aeroplane so that each crew member can leave his or her assigned post to obtain in-flight rest and be replaced by another appropriately qualified crew member.
2. Augmented operations can involve duty/rest cycles longer than 24 hours.
3. *Window of circadian low (WOCL) operations* are defined as a flight in which landing occurs during the WOCL, the flight passes through both sides of the WOCL, or the duty period starts at 0400 or earlier in the WOCL (see Section 2.1).

Source: Flight Safety Foundation and U.S. National Aeronautics and Space Administration

Table C-3 – Crew Scheduling using a possible application of Tables 1 and 2 to construct a weekly duty and rest period schedule (from the FSF/NBAA Guidelines).



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