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Fatigue in military aviation

School of Aerospace, Transport and Manufacturing

PhD

Academic Year: 2023-2024

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This thesis is submitted in partial fulfilment of the requirements for the
degree of PhD.

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Academic Integrity Declaration

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- the thesis submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
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Abstract

Fatigue in military aviation is gaining momentum as its fast paced and unpredictable environment is affecting airmen alertness, cognitive performance and impaired decision-making abilities among many other risks that may trigger or lead to errors and accidents. This thesis explores fatigue management arrangements in the selected transportation and logistics unit of one of the European Union Air Forces. Different methodological approaches were taken to investigate current fatigue and sleep arrangements among crew members (i.e. pilots and loadmasters) in the selected air base. The First study in semi-structured interviews gives clearer understanding of the overall organisational and operational activities, related to fatigue, including within military culture. The second study is a questionnaire survey which examines the data gathered and focuses on a construction of a military-specific model encapsulating the fatigue stressors and countermeasures whilst exploring current management of fatigue and sleep training. The last study of this thesis uses heuristic evaluation methodology to develop a military-specific fatigue report form which considers the needs and complexity of the selected air base. It considers key fatigue-related factors and their relationships. As a result of this thesis's research, a Structural Equation Model was identified to present the correlation of interactions of fatigue, sleep and fatigue countermeasures and a Fatigue Report Form was developed to enable crew members in the selected air base to report fatigue. This thesis offers great impact on military aviation as it is a step towards the development of a Fatigue Risk Management System which is currently not in place in any European Air Force. Not only does this thesis have an impact on military aviation, but also in other settings such as, healthcare, manufacturing, and civilian transportation among many others which could benefit from the research and results of this thesis.

Keywords:

Sleep, countermeasures, stressors, model, predictive, proactive, reactive, alertness, performance, reporting, culture.

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List of Abbreviations

AF	Air Force
ANOVA	Analysis of Variance
ApEN	Approximate Entropy
ASR	Air Safety Report
ATARES	Air-To-Air Refuelling and Other Exchange of Service
ATM	Air Traffic Management
BAI	Beck Anxiety Inventory
BAM	Boeing Alertness Model
CAS	Circadian Alertness Simulator
CRM	Crew Resource Management
CSDP	European Common Security and Defence Policy
DASR	Australian Defence Aviation Safety Regulation
DERA	Defence Evaluation and Research Agency
EASA	European Aviation Safety Agency
EATC	European Air Transport Command
EDA	European Defence Agency
EEG	Electroencephalogram
EMAR	European Military Airworthiness Authorities Forum
ESS	Epworth Sleepiness Scale
FAST	Fatigue Avoidance Scheduling Tool
FAID	Fatigue Audit InterDyne
FDM	Flight Data Monitoring
FRI	The Fatigue Risk Index Model
FRM	Fatigue Risk Management
FRAM	Functional Resonance Accident Model
FREF	Fatigue Regulation Evaluation Framework
FRMS	Fatigue Risk Management System
FRMSG	Fatigue Risk Management Sub-Group
FTL	Flight and duty Time Limitation
HFACS	Human Factors Analysis and Classification System
HoS	Hours of Service
HSE	Health, Safety and Environment
IATA	International Aviation Transportation Association
ICAO	International Civil Aviation Organisation
IFALPA	International Federation of Air Line Pilots Association

IMO	International Maritime Organisation
KMO	Kaiser-Meyer-Olkin Test
KSS	Karolinska Sleepiness Scale
LPS	Landing Performance Score
LSO	Landing Signal Officer
MAA	Military Aviation Authorities
MATB	Multi-Attribute Tas Battery
MAWA	Military Airworthiness Authorities Forum
MSA	Measurement Systems Analysis
NVG	Night Vision Googles
NATO	The North Atlantic Treaty Organisation
NTSB	National Transportation Safety Board
OSH	Occupational Safety and Health
PERCLOS	Percentage of Eye Closure
PhD	Doctor of Philosophy
POMS	Profile of Mood States
PTSD	Post-Traumatic Stress Disorder
PVT	Psychomotor Vigilance Test
RCAF	Royal Canadian Air Force
RQ	Research Question
RTSW	Repeated Test of Sustained Wakefulness
SAFE	Systems for Aircrew Evaluation
SAFTE	Sleep, Activity, Fatigue and Task Effectiveness
SCN	Suprachiasmatic Nucleus
SD	Standard Deviation
SEM	Structural Equation Modelling
SIRA	Systems Integrated Risk Assessment
SMS	Safety Management System
SOP	Standard Operational Procedure
SPI	Safety Performance Indicator
SARP	Standard and Recommended Practice
SAST	Serial Addition Subtraction Task
SSS	Stanford Sleepiness Scale
SynWin	Standardised neurocognitive functioning assessment tool
SYNWORK	Synthetic Work Battery
SWAI	Sleep Wake Activity Inventory
SWP	Sleep Wake Pattern
TEM	Threat and Error Management

UAE	United Arab Emirates
URL	Unrestricted Line
USA	United States of America
USAF	United States Air Force
USARMY	United States Army
USNAVY	United States Navy
VAS	Visual Analogue Scale
WOCL	Window of Circadian Low

Chapter 1 - Introduction

Throughout the history of the Air Force, several safety layers have been set to improve safety and reduce injury by continuously reviewing existing operational and organisational processes, systems, and procedures. The safety measures have been employed to avoid human error, prevent foreseeable accidents, and minimise the consequences of unforeseen safety events. The United States Air Force (USAF) first used the Human Factors Analysis and Classification System (HFACS), which was developed by the United States Navy, to systematically investigate and analyse the role of human factors in adverse safety events by identifying active and latent factors that lead to an event and target training and other prevention methodologies to prevent reoccurring hazards and identify potential future safety risks/trends (Shappell & Wiegmann, 2000). Furthermore, the Crew Resource Management (CRM) training programme has been introduced as one of the preconditions for preventing adverse safety events, and it is still in place as a regular mandatory training programme for all Air Force employees to improve communication and interaction in any environment (Kuřakowski & Nowakowski, 2019). Moreover, using an operational risk management system, employees have been familiarised with potential operational and organisational risks through several training programmes and promotional materials such as posters, bulletins, etc. Also, an appropriate training programme on how to handle safety risks has been used to educate employees on risk causes, consequences, and mitigation strategies. Similarly, the Fatigue Risk Management System (FRMS) has been introduced by many Air Forces worldwide, such as the USAF, Royal Canadian Air Force (RCAF) and Royal Australian Air Force, and a fatigue report form has been a part of the FRMS (Peek, 2017). The introduction of the FRMS in those Air Forces has enabled the indication of fatigue related risks and how to properly manage those risks which include long working hours, inadequate time off duty, unpredictable schedules, inadequate staffing, and cumulative fatigue among others. Responsibility for managing fatigue has become no longer only airmen's responsibility but also organisational and the FRMS has become vital in mitigating fatigue by providing tools, relevant education, and effective mitigation strategies. Fatigue management has become everyone's responsibility. It is important

to mention that the FRMS has not been developed and implemented in European military aviation. The impact of not having an appropriate FRMS in place may cause safety concerns and potentially lead to severe safety issues. As proved by the Air Forces that have already developed and implemented the FRMS, the operational safety level has been improved. Therefore, the FRMS is part of a solution to the general fatigue problem in military aviation. This research explores one of the European Union Air Forces where issues of lack of fatigue reporting cause safety concerns and an appropriate FRMS is missing. The European Union Air Force in this thesis has not yet developed and implemented the military-specific FRMS and fatigue reporting system due to several obstacles in a regulatory framework, especially the need for change at the management level. Generally, the concerned Air Force is aware of the importance of having an FRMS in place, but currently, as stated by the selected Air Force, the management is not committed to any changes and constant discussions are taking place to move towards the development of the military specific FRMS. The research studies of this thesis are a part of this process.

Furthermore, fragmentation of rules and standing orders, continuous cutbacks in military aviation, organisational, operational, and cultural obstacles towards an effective and efficient FRMS including a military-specific fatigue reporting system, which has been addressed as one of the pillars of the Fatigue Risk Management Systems, represent the main issues in moving forward. Also, military aviation is generally not in favour of external research studies and therefore, there is a lack of literature available on this subject and there is a need for more research studies to identify all aspects influencing fatigue in military aviation. Looking into fatigue risk management processes and procedures, it is important to understand current fatigue-related practices from the management point of view, as well as organisational and operational ones. Military aviation has a history of traditional regulatory principles defining operation, assurance, key responsibilities, and endorsement of individuals, which may restrict the organisational and operational safety referring to fatigue reporting. In the selected Air Force unit, the issue of lack of fatigue reporting is known. Despite some planned organisational changes, they are restricted due to the top management changes.

Therefore, it is of the utmost importance to address this fatigue reporting issue and investigate the current situation concerning fatigue in the selected Air Force base, collect relevant data through different methodological approaches, analyse it and develop a tailored fatigue report form.

1.1 Aims and Objectives

This thesis aims to improve fatigue risk management procedures and processes within the Transportation and Logistics unit in of one of the European Union Air Forces. To achieve that, this research has the following four objectives:

1. *To examine the prevalent fatigue stressors and countermeasures within military operations at the selected air base.*

There are a number of different stressors in the military aviation environment that affect operational personnel, increase fatigue levels and decrease performance in terms of difficulty focusing, attention lapses, slower reactions, unclear speech, errors of omission and impaired short-term memory. How fatigue-related risks affect operational activities is crucial for further managing fatigue within military aviation.

Existing policy and documentation processes on fatigue are an important part of the Fatigue Risk Management System, represented as an organisational activity including fatigue promotion processes, which include communication plans and training, whereas policy issues represent the fragmentation of rules and standing orders. Understanding organisational and operational activities such as working time arrangements, deployment scheduling, fatigue stressors, countermeasures, and mission planning is crucial in fatigue investigation and identification. Therefore, fatigue management arrangements and tools should be identified and described at the beginning of the research process, which help examine prevalent fatigue stressors and countermeasures later in this research. Despite their limitations, for example, software tools such as bio-mathematical models are used by many operators/organisations as predictive,

proactive, and reactive fatigue risk management processes. They are of great help in identifying and predicting fatigue hazards (Dorrian et al., 2012; James et al., 2018).

2. To construct a military-specific fatigue model that encapsulates the fatigue stressors and countermeasures identified.

A circadian desynchronisation is one of common issues in military and civilian aviation; its interaction with sleep and performance is important in delivering safe operations. It is common knowledge that lack of sleep influences cognitive, behavioural, and physiological functions. Usually, the effects of the circadian and homeostatic processes are best visible in shiftwork, night work, deployments, and continuous and sustained operations (Good et al., 2020; Sabzevari Rad et al., 2021).

Operational personnel are exposed to different factors affecting fatigue. Therefore, appropriate fatigue and sleep hygiene training, including mitigation strategies and countermeasures, should be mandatory for all operational personnel, including management. The military-specific fatigue model would show relationships between factors such as fatigue stressors and countermeasures which influence fatigue and give further indications of fatigue management within the selected air base.

3. To explore the current management of fatigue and sleep training.

The current management of fatigue and sleep training was explored as it gives important information about fatigue and sleep management of crew members in the selected air base. Their sleeping habits explain the reasons for potential sleep disorders and/or any other relevant disorder. Furthermore, fatigue training shall offer crew members proven strategies for combating fatigue, fatigue countermeasures and help them to identify fatigue stressors (Backs et al., 1999; de Carvalho et al., 2016; Havinga et al., 2017; King, 2005; Klein et al., 2015; Kułakowski & Nowakowski, 2019; Lieberman et al., 2002; Littlepage et al., 2016).

4. To develop a military-specific Fatigue Report Form that captures key-fatigue-related factors and their interrelationships.

Through data collection and analyses, fatigue risk management processes can identify potential fatigue hazards by using different identification processes such as reactive, proactive, and predictive. Furthermore, each identified fatigue hazard needs to be risk assessed, and appropriate safety risk controls and mitigation strategies need to be developed and implemented. This includes the process of monitoring the effectiveness of the overall fatigue risk management system in terms of delivering defined safety objectives (Gander et al., 2014; Sprajcer et al., 2022; Wu et al., 2016).

Generally, fatigue reporting mechanisms provide a real-time and continuous operational situation, but in this thesis, real-time and continuous operational situation monitoring was not possible as crew members cannot use the relevant devices during their mission. Therefore, a fatigue report form was developed based on data collected and recommended for use in the selected military base, identifying fatigue issues based on developed fatigue reporting before, during and after the mission. Also, it was essential to gather and analyse the fatigue relevant information from military operational personnel. This data further provides management personnel with appropriate feedback helping them to determine the overall safety of the operation and its associated risks.

A Fatigue Report Form can be developed and implemented through the research process of identifying elements of the FRMS in existing systems and processes such as, identifying impacts of fatigue on operational settings and interactions of factors affecting fatigue, including fatigue countermeasures and mitigation strategies. Research findings show how fatigue management reduces the level of fatigue and better manages the overall fatigue risk management processes and procedures within their operational environment. It will also be a step forward towards developing specific FRMS with clear guidance on how to manage fatigue.

Available scientific research on fatigue risk management systems in military aviation is limited. Therefore, the objectives of this thesis are exploratory and descriptive in nature. Multiple methods, such as qualitative and quantitative approaches were used to achieve

the objectives. Further descriptions of research methods and processes are discussed in Chapter 4.

1.2 Research Scope

The areas assessed through this thesis are inter-correlated, exploring the relationships between fatigue, circadian rhythm, and homeostatic processes. These areas are:

- Fatigue risk management,

Exploration of fatigue and how to manage fatigue has become frustrating for a wide range of safety-sensitive environments. Military aviation has its own regulatory approach to managing fatigue and safety within its operations, and the tools used to manage fatigue depend primarily on financial background. Therefore, continuous cutbacks in military spending are not in favour of improving fatigue management. Appropriate and efficient fatigue management is crucial for an efficient and effective safety system. Due to this, a military-specific fatigue risk management framework is of great importance for the future of military aviation. Scientific Aviation literature lacks research on the Fatigue Risk Management System (FRMS) in military aviation, its development and implementation. Current, available research has only investigated individual fatigue factors and components of the overall FRMS with no guidance on how to manage fatigue through the military-specific FRMS, and nevertheless accounts for the military culture (Caldwell et al., 2019a; ICAO, 2016; Olaganathan et al., 2021). The central key area of interest of this thesis is to explore current fatigue arrangements and to develop a military-specific Fatigue Report Form designed for the selected Air Base. Chapters 2 and 3 describe Fatigue Risk Management System-related work, which also helped to develop the mentioned Form.

- Scheduling,

Developing work-rest guidance for the crew that takes rapid change of time zone into consideration and issues related to deployments, is important in achieving the required operational and safety standards. Therefore, all factors affecting sleep and performance must be addressed, including all available fatigue countermeasures that help

acclimatisation, such as good sleep hygiene, bright light, appropriate nutrition, and pharmacological agents as the last choice when there is no time for acclimatisation. Although scheduling is not the focus of this thesis, it is important to mention it since it affects circadian and homeostasis processes, which are important aspects when analysing fatigue issues (Dongen et al., 2017).

- Sleep hygiene,

Sleep is easily disrupted by various conditions such as environmental stressors, individual's health condition, poor sleep habits, medications, inappropriate nutrition, family situations, and rapid time zone changes. Sleep science is trying to explain the process of sleep, how good sleep hygiene can be achieved, and how important it is. Among others, the relationship between fatigue and sleep is an important area of this research. For that reason, sleep hygiene training should be crucial for military aviation personnel due to their continuous exposure to several sleep stressors, and information on sleep hygiene is crucial in assessing and analysing fatigue issues (Gallais et al., 2017; Reis et al., 2016).

- Performance and fatigue measurement,

Fatigue affects performance, and there are combined objective and subjective tools for measuring fatigue and, consequently, performance, such as a widely used psychomotor vigilance task (PVT) or Samn-Perelli fatigue scale. This is another key area of interest in this research: how military aviation is currently measuring fatigue and performance levels, what objective and subjective tools are currently in place (if any) and how effective these tools are (Borghini et al., 2014; van den Berg et al., 2016).

- Fatigue stressors and consequences,

Several stressors affect fatigue, such as circadian desynchronisation, work overload or underload, individual factors, scheduling practices, job and social factors, training, strategic needs, and sustained/continuous operations. Therefore, several consequences arise from people being fatigued, which has an influence on overall performance and operational safety. Some of the consequences relate to decreased vigilance and

situation awareness, cognitive decrements, absenteeism, attentional lapses, memory impairment, health issues, errors, accidents, and financial issues. These factors are important in this research and are also examined to facilitate the elaboration of a Fatigue Report Form for the selected Air Base (Phillips, 2016).

- Fatigue countermeasures,

Military personnel use several fatigue countermeasures, such as effective sleep management and caffeine intake, which help them combat decreased performance and alertness levels. There are not many research studies that investigate fatigue-proofing strategies and countermeasures that developed spontaneously and informally among military personnel, though these strategies are common practice amongst them. This thesis explores fatigue countermeasures used by crew members to fight their fatigue levels.

- Fatigue reporting mechanisms and associated feedback,

The fatigue report form provides an opportunity for crew members to report any concerns relating to fatigue and to identify the roots of fatigue (BALPA, 2015). Moreover, they provide an opportunity for operational personnel to overview their organisational processes and procedures. An associated feedback report mechanism is used to improve organisational systems, processes, and procedures (modify, re-design, change procedures, enhance training, etc). Currently available fatigue reporting mechanisms in the selected air base are important factors to address in this thesis.

- Military aviation,

This study focuses exclusively on military aviation. While fatigue management practices in civilian aviation and other industries might offer valuable insights, the unique complexity and specific operational environment of military aviation require a tailored approach. Although this research explores practices in other industries—particularly civilian aviation—to consider potential lessons learnt, it does not directly compare them. This is due to the fundamentally different organisational and operational contexts between military and civilian aviation. Military aviation adopts International Civil

Aviation Organisation (ICAO) principles wherever possible but adapts them as needed to fit the complexity of the military environment. Therefore, the military cannot simply adopt operational and organisational settings directly from civilian aviation. Given the greater complexity in military aviation, a direct comparison with civilian aviation is omitted in this thesis.

1.3 Structure of the Thesis

This thesis begins with an explanation of military aviation fatigue-related context and fatigue report form development as its research topic. Chapter 1 identified the motivation, importance, and reason behind this research. The Fatigue Risk Management System description was necessary to provide an understanding of fatigue and fatigue management beforehand. This is presented in Chapter 2, where Fatigue Risk Management was investigated and presented by reviewing the related literature. Chapter 3 explored Fatigue Risk Management in military aviation at the selected air base of one of the European Union Air Forces. Chapter 4 described research methodology and helped to frame the research's accessible literature (Chapter 2) and the research methods applied to every study carried out for this thesis: semi-structured interviews, questionnaire survey, and military-specific fatigue report form. The chapter identified how research questions for this thesis were addressed at every stage.

Research studies and their results are in:

Chapter 5 semi-structured interviews detailing their findings. This study aims to provide an understanding of fatigue arrangements at the selected air base and leads to the exploratory inductive approach to researching three separate parts of the interview, organisational arrangements and individual job requirements and responsibilities, fatigue risk management processes and tools, and demographics. This study allowed the researcher to explore and develop both the themes and sub-themes that were identified throughout the interviews, and all data collected represents the most relevant issues identified.

Chapter 6 questionnaire survey's main objective was to investigate fatigue in the military aviation transportation and logistics unit. To explore which factors, have the most significant influence on fatigue and by which indicators they are affected, taking into consideration two constructs affecting fatigue, sleep hygiene and fatigue countermeasures, using Structural Equation Modelling.

Chapter 7 discusses the development of a military-specific fatigue report form for the selected Air Force base. It details the outcomes of the earlier two studies of this thesis, semi-structured interviews, and the questionnaire survey to construct an appropriate fatigue report form, which shall contain all relevant factors identifying fatigue level and its reasons and consequences, including countermeasures taken to combat reported fatigue. The development of a military-specific fatigue report form concludes the chapter.

Chapter 8 concludes the overall conclusions drawn from this thesis research and the contribution to military aviation fatigue research as well as other settings, including limitations for each study and general thesis limitations, along with the contributions of this thesis and possible future research.

Chapter 2 - Fatigue Risk Management System in Literature

2.1 Chapter Introduction

This chapter examines the key literary domains that bolster the investigation for this thesis research. Fatigue is described as the central part of this research, including the lack of agreement on fatigue definition and its measurement. Fatigue interacts with several factors and may influence safety, decision-making processes, bio-mathematical modelling, and performance. Moreover, interactions between circadian rhythms, homeostatic processes, performance, and safety are described to better understand how fatigue is influenced by these interactions of factors. Fatigue Risk Management Systems are rising in importance and implementation across a wide range of safety-sensitive settings, including civilian and military industries. Therefore, the FRMS is described in order to identify all its components and activities, including the most used software programs for modelling, and predicting fatigue.

Furthermore, sleepiness and fatigue are often understood as identical, therefore, the chapter also distinguishes sleepiness and fatigue and further describes sleep science, including subjective and objective methods for measuring sleepiness and outlines the most common sleep disorders.

This chapter's conclusion with biomathematical models in aviation and a discussion on Fatigue Risk Management Systems in military aviation, including military-specific fatigue reporting systems.

2.2 Approach to Literature Review

The researcher used a narrative approach to the literature review, ensuring a comprehensive review of the research topic by identifying and evaluating the main research studies similar to the topic of this thesis, particularly those related to fatigue management and sleep hygiene in military aviation. A primary and secondary literature was explored using search criteria and phrases matching the topic of this thesis. Several sources were used to conduct a literature review, including scientific journals, books,

white papers, standards and recommended practices, and regulations that were identified through electronic science databases (namely ResearchGate, ScienceDirect, PubMed, Elsevier), Scopus and Google Scholar search engines, European Military Airworthiness Requirements, the International Civil Aviation Organisation, and the United States Air Force websites, including a reference trailing. This was conducted by using key terms such as fatigue, sleep hygiene, fatigue countermeasures, fatigue modelling, FRMS, fatigue report form, fatigue risk, deployments, night work, shift work, sustained operations, safety in military aviation, and others. Many papers were reviewed and identified also by the combination of key terms (e.g., fatigue AND military, etc.) and title and abstract.

First, the focus was on the literature on military aviation, and as there was not enough information available, the researcher followed by exploring literature on civilian aviation, civilian transportation (including rail, road, and maritime), healthcare, neuroscience, and other settings that experience fatigue issues. It was critical to evaluate the literature that covers what this thesis discusses; therefore, making notes to keep track of the narrative approach and comprehensive understanding of fatigue in military aviation was crucial.

The literature review was limited to include studies providing high-quality information and evidence considering the research topic and were excluded if these were not sufficient, including study languages other than English. A comprehensive literature review was done using selected papers.

2.3 Fatigue

Fatigue has been described differently by several authors, across and within, a wide range of settings such as, transportation (Sallinen & Hublin, 2015), occupational settings (Satterfield & Van Dongen, 2013), emergency operations, and regulatory settings due to individual differences in vulnerability, sensibility and adaptations to fatigue, non-specific aetiology of fatigue and the lack of agreement on fatigue measurement (Noy et al., 2011; Williamson et al., 2011). For example, a study of fatigue risk management systems in

commercial aviation identified that physiological fatigue indicators and the impact of physiological and psychological fatigue factors on overall safety are identified through fatigue survey forms (Ziakkas et al., 2022), which shows the importance of considering both psychological and physiological fatigue when assessing fatigue and developing Fatigue Report Forms.

Fatigue has been present in the daily life of humans for centuries from the very first reports in the mid 1800's with reference to symptoms of neurasthenia, which was first described as a well-defined clinical entity by an American neurologist George Beard (Torres-Harding & Jason, 2005). Then, George Poor was able to distinguish between chronic and acute fatigue as well as general and local. The symptoms of neurasthenia, such as insomnia, headache attacks, cognitive disability for cumulative work settings and poor appetite, had become the most common diagnosis of neuropathology and psychopathology. A recent study (Caldwell et al., 2019a) explained the requirements for effective management of fatigue by describing the circadian biological clock, dynamics of sleep hygiene and recovery.

Fatigue has been described in relation to psychological and physiological impairments that result in disrupted functions, a cognitive impairment or breakdown, impaired quality of life, and total overall exhaustion (Caldwell et al., 2019b). Causes of fatigue may originate from physiological, psychological, psychosocial, organisational, and demographic factors. Some of the most common causes of fatigue are related to the circadian rhythm (e.g., time of day), sleep homeostasis (e.g., time since last sleep, sleep deprivation), and the nature of the work itself (e.g., duration, monotony, and workload of the task) (Åkerstedt, Knutsson, et al., 2004; Borbély, 1982; Mallis et al., 2004), but there is actually little known about the interaction of these causes (Williamson & Friswell, 2011) which refers to lack of systems thinking that would analyse interactions in an appropriate context. One possible solution for improving fatigue risk management and overall safety is the resilience engineering approach (Gander et al., 2011; Wears, 2006), which addresses the complexity of real-world relationships, in this case, the fatigue and safety relationship.

Understanding the role of individual differences better is an important aspect in further exploration of fatigue since an individual's response to fatigue is not well understood, many studies claimed that individual response to fatigue needs further research (Saksvik et al., 2011; Van Dongen et al., 2004, 2012; Van Dongen & Belenky, 2009; Worm-Smeitink et al., 2017) Several laboratory studies have examined the effects of individual sleep-related factors on fatigue and performance (Belenky et al., 2003; Darwent et al., 2015; Dinges et al., 1997; Van Dongen & Dinges, 2003). Due to different approaches to managing fatigue, this study considers approaches/countermeasures identified by crew members in the selected military base through a qualitative and quantitative study of this thesis.

In addition, there are also other limitations in understanding the fatigue consequences and causes and the mitigating strategies aimed at minimising the possibility of fatigue-related errors leading to a negative safety outcome (Noy et al., 2011). Gaps in understanding fatigue are represented by numerous issues, including the complex link between safety and fatigue (Williamson et al., 2011), modelling and predicting fatigue (Dawson et al., 2011), demographic issues in fatigue (Di Milia et al., 2011), organisational factors in fatigue management (Horrey et al., 2011), and technological approaches in fatigue management (Balkin et al., 2011; Gander et al., 2011).

To understand the sophisticated connection between safety and fatigue, the development and implementation of the Fatigue Risk Management System (Williamson et al., 2011) is required in the future. The FRMS is data-driven, based on science and knowledge, including, the importance of having an experience-based approach to fatigue-related risks and requiring continuous monitoring. This approach is necessary as a holistic perspective of all factors influencing fatigue and is presented in four pillars, such as Policy and Objectives; Fatigue Risk Management; Safety Assurance; and Fatigue promotion by applying Safety Management Systems principles to identify fatigue risks, fatigue assessment, mitigation strategies and monitoring. Each of the four pillars is described in the following sections. Figure 2-1 shows fatigue in relation to potential

fatigue stressors, effects, and consequences as well as operational and organisational activities that may influence fatigue levels.

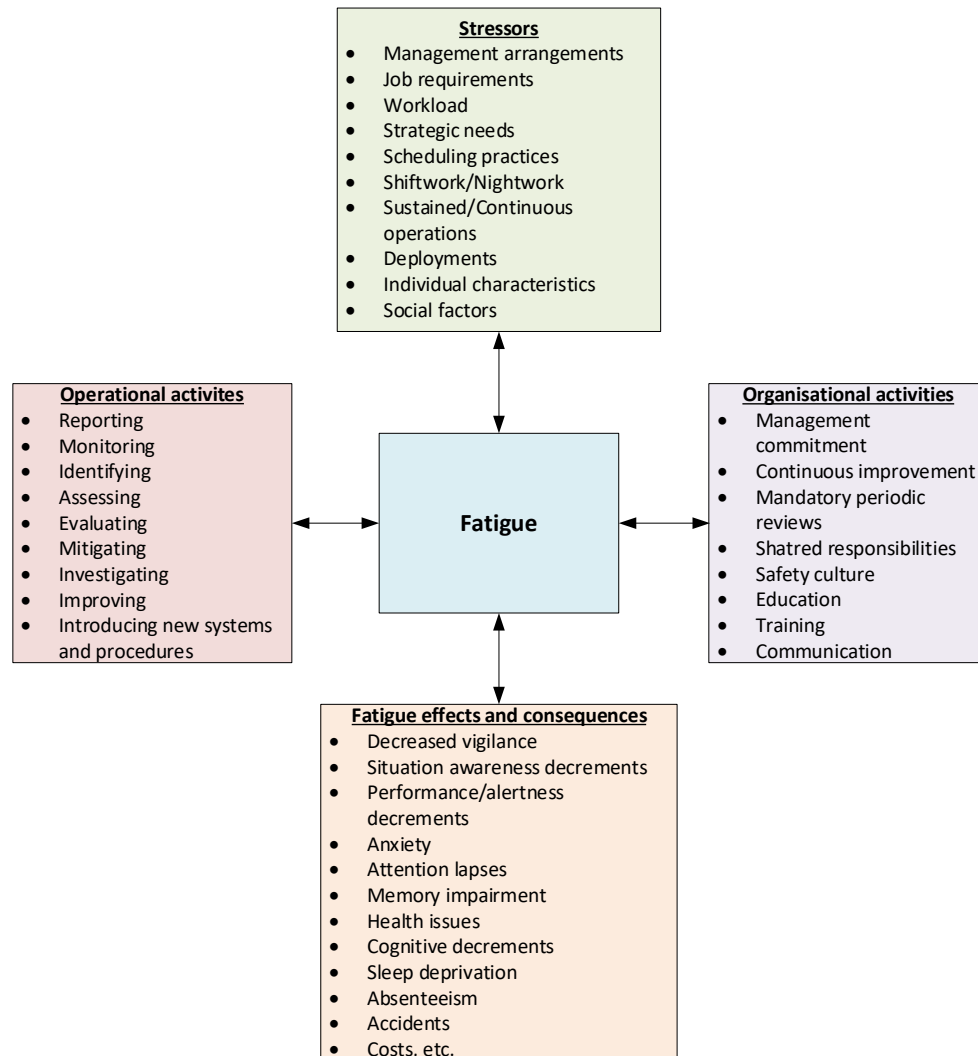


Figure 2-1 Fatigue, fatigue stressors, effects, and countermeasures

2.3.1 Distinguishing sleepiness and fatigue

Sleepiness and fatigue are often interchangeable and commonly used terms in practice. Many people are unaware of their complexity and heterogeneity; therefore, it is mandatory to distinguish their distinct implications so that they can be studied in their own right. Several objective and subjective methods that evaluate sleepiness and fatigue are available, but the lack of objective fatigue measures causes an issue in measuring fatigue and calls for further development (Shahid et al., 2010).

Generally, sleepiness is a complex phenomenon, the combined effect of factors such as sleep homeostasis and circadian factors, according to the two-process model of sleep regulation. A failure to agree upon operationalisation of fatigue has caused some researchers to understand fatigue and sleepiness synonymously (Phillips, 2015). For example, some researchers in the transportation industry have focused on sleepiness as seeing sleep/wake homeostasis factors vital for transportation safety (Dawson & McCulloch, 2005; Phillips, 2015).

There is evidence that people can hardly distinguish between fatigue and sleepiness in case of strongly operationalised measures; moreover, in these cases, fatigue may be even more prevalent (Caldwell et al., 2019b). Furthermore, a number of research studies showed that the performance effects related to tiredness cannot be explained by sleepiness alone. For instance, several laboratory and simulator studies show rapid task-related decrements in vigilance performance, and time-on-task studies concluded that monotony may accelerate the onset of sleepiness (Connor, 2009; Phillips, 2015; Smit et al., 2004). For example, the study of fatigue (May & Baldwin, 2009) confirmed the driver's performance decrement through the task effects or by increasing the tendency of sleep-related fatigue. A failure to distinguish the concepts of fatigue and sleepiness may be due to poor understanding of the causes of tiredness-related performance decrements. Sleepiness and fatigue are two distinct, although interrelated terms, and the transport industry needs to fully understand the impact of fatigue on performance. Also, it is necessary to have a clear understanding of how tiredness impacts performance (May & Baldwin, 2009; Phillips, 2015).

Sleepiness is a basic physiological state and is generally described as the amount of effort the individual must perform to stay awake (Mairesse et al., 2014; Van Dongen & Dinges, 2000). On the other hand, fatigue relates to a condition in which individuals maintain their physical or psychological energy more difficultly through the increasing duration of time (Mairesse et al., 2014).

Because fatigue and sleepiness are commonly used interchangeably due to poor understanding of the causes of tiredness-related performance decrements, many research studies have used mixed methods to measure and explore sleepiness and fatigue to get more reliable results. One of the biggest challenges is to measure fatigue and sleepiness as there is no common agreement on measurement tools' validity, therefore, the lack of validity and reliability of measurements is causing confusion in assessing and identifying fatigue and sleepiness. Most research studies have used both subjective and objective fatigue and sleepiness measurement tools to deliver results which aim to reflect the real-world performance level (Thomas et al., 2015). Some studies claimed that subjective measures are more commonly linked to fatigue than objective ones (Dahlgren, 2006; van der Hulst, 2003), but subjective measurements are more prone to intentional falsification and, consequently, invalidity. Therefore, data collected through different objective measurements are known to be more reliable as they measure fatigue through different aspects and interactions of factors objectively. Moreover, combined subjective and objective measurements can give the most reliable results.

2.3.2 Measuring sleepiness and fatigue

There are several subjective measurements, including the Visual Analogue Scale (VAS), Karolinska Sleepiness Scale (KSS), Stanford Sleepiness Scale (SSS), Samn-Perelli fatigue scale (SP) and sleep diaries. Subjective scales are easy and quick to administer but, at the same time, easy to cheat, and as previously mentioned, they lack validity and credibility as they do not reliably reflect objective performance measures. On the other hand, objective measurements, including actigraphy, polysomnography and Psychomotor Vigilance Task (PVT), are well-validated tools. Bio-mathematical models are commonly used objective fatigue measuring and predicting tools, which require great caution when used due to the lack of evaluation of effectiveness.

Several researchers (Åkerstedt, Folkard, et al., 2004; Fletcher et al., 2015; Gander et al., 2014; Hobbs & Williamson, 2003; Lenné et al., 1997; Mitler et al., 1988; Roach, Roberts, et al., 2017; Williamson et al., 2011) have drawn links between fatigue and safety and

found it extremely difficult to prove the role of fatigue in safety events as it is not easy to measure and identify. Fatigue and fatigue trends should be continuously measured and monitored as part of the FRMS processes to identify higher levels of fatigue and monitor the effectiveness of mitigation strategies.

Up to now, fatigue research studies have been explored using several different methods in the laboratory as well as in the operational environment. Sleepiness alone is not sufficient to explain performance effects related to tiredness, which was shown by different laboratory and simulator studies, which concluded that monotony may accelerate the onset of sleepiness (Connor, 2009; Phillips, 2015; Smit et al., 2004). Therefore, the large majority of studies have used combined subjective and objective fatigue and sleepiness measurement tools such as sleep diaries, actigraphy, different self-reported questionnaires (e.g., KSS, SSS), EEG and PVT to make data comparisons available and deliver more reliable results on performance level (Dahlgren, 2006; Dahlgren et al., 2012; Sallinen et al., 2017; Shahid et al., 2010; Thomas et al., 2015; van der Hulst, 2003). Furthermore, semi-structured interviews were used as a collection of qualitative data, and one of the studies that used this kind of interviews was a study of protective behaviour, which aimed at collecting self-reported examples and identifying informal fatigue-proofing strategies that can mitigate fatigue-related risk by military aviation personnel (Dawson et al., 2017). A qualitative methodology was also used in a study, which aimed to elicit the experiences, attitudes, opinions, beliefs, and perceptions of safety and the FRMS within the fire-fighting organisation (Dawson et al., 2015). This study highlighted possible limitations of using a qualitative methodological approach as the interviewer may unintentionally influence participants' answers. Moreover, the universality of this approach may be limited; therefore, the results of the interviews may not be generally representative.

Several research studies of fatigue using different research methods have also been conducted in military aviation (Fast et al., 2014; Miller, 2014b, 2014c, 2014a; Miller et al., 2014, 2015; Miller et al., 2007, 2011, 2012). The methodological approach may not always be the same as in civilian aviation due to the sensitive nature of the military

aviation environment, which represents difficult working conditions, including combat environments, reduced/restricted sleep, psychological factors, and unpredictability of operational needs, based on strategic requirements. Therefore, measuring fatigue is a challenge due to difficulties in quantifying effective performance in the operational context, particularly, in the war fighters' environment. Consequently, several research studies have been performed in the laboratory or a high-fidelity simulator which include cognitive testing, physiological monitoring, polysomnographic evaluations, self-reported questionnaires, and flight simulations (Dahlgren et al., 2012; LeDuc et al., 2000). There have been several studies using self-reported fatigue questionnaires and self-reported sleep duration data focusing on and exploring sleep issues during military operations (Capaldi et al., 2019; LoPresti et al., 2016; Miller et al., 2011; Pruiksma & Peterson, 2017; Seelig et al., 2017). Self-reported questionnaires have included questions about demographics, deployment history, mental health symptoms (e.g., using the Beck Anxiety Inventory (BAI), Beck Depression Inventory-II, Post-Traumatic Stress Disorder (PTSD) Checklist-military version, perceived sleep issues, and accidents or errors that affected the mission. Furthermore, the most used objective performance measures used in military aviation were identified, which refer to the PVT (Capaldi et al., 2019), actigraphy and bio-mathematical model FAST, including the standardised neurocognitive functioning assessment tool SynWin (Rabinowitz et al., 2009). For example, polysomnography is not practical and applicable in military aviation real-word research studies as it is a time consuming, expensive, and intrusive method.

It has been challenging to objectively assess fatigue in military aviation due to equipment limitations and tactical factors. Research studies have shown that fatigue is most measured through subjective evaluations, for example, a study of aircrew, subjective readiness in a combat environment used to complete individual work/rest logs (Miller et al., 2007; Storm et al., 1992). Consequently, this may refer to the possibility of intentional falsification and invalidity.

2.4 Fatigue Risk Management

Fatigue Risk Management explains/shows the importance and benefits of having FRM and how it contributes to the enhancement of safety and the improvement of operational performance. For example, the concerned Air Force and most probably also others Air Forces has regulations that specify flight and duty time limitations such as a minimum rest and maximum hours of flight. FRM takes a scientific approach to regulating crew members rest, their requirements concerning adequate periods of rest in flight and following duties. FRM seeks to achieve a realistic balance between safety, productivity and cost and identify opportunities to improve operational processes and identify deficiencies after adverse events. The core activities of FRM are safety risk management and safety assurance governed by an FRM policy and supported by FRM promotion processes. The FRM described in this thesis is modelled on the SMS framework. It is, therefore, an integral component of SMS, Just Culture and Restorative Just Culture, where Just Culture principles give details about crew members suspected of suffering from unacceptable levels of fatigue or doubt about being able to accomplish duties. Furthermore, Restorative Just Culture focuses on restoring and learning from occurrences and identifies the next steps towards improving safety (Boskeljon-Horst et al., 2023).

The FRM objectives are to ensure crew members are adequately trained to understand and manage their responsibilities concerning fatigue risk management and are fit to fly; an organisation shall ensure safe flight operations by minimising hazards and associated fatigue risk, including balancing rostering practices with operational needs through fatigue mitigation strategies identified in FRM and their continuous improvement.

2.4.1 Regulatory approach to FRM

The study of fatigue and safety has been limited by a number of methodological issues that prevent clear conclusions on fatigue from being drawn (Di Milia et al., 2011), such as not having a common definition of fatigue within and across disciplines, a variety of diverse designs for investigating and measuring fatigue, which are mostly lacking

ecological validity, the need for firmer and more objective measures of fatigue as this phenomenon has been strongly linked with subjective measures, and finally, the fact that demographic variables influencing fatigue should be considered in future research studies as independent variables rather than covariates or confounders (Di Milia et al., 2011). There is a need for an expansion in methodological approaches to better address and predict fatigue and to be able to better understand safety outcomes, as well as to estimate and evolve the understanding of safety outcomes. Estimating and evolving appropriate fatigue-related countermeasures would increase the level of organisational and operational safety (Phillips, 2016; Williamson et al., 2011).

2.4.2 Prescriptive and performance-based approach to Fatigue Risk Management

The prescriptive regulatory framework of Hours of Service (HoS) regulations and the alternative performance-based Fatigue Risk Management System have increased safety in all operational settings.

Regarding this, the first government regulation limiting working hours in the United Kingdom (UK) was the Factories Act from 1802 followed by the Factory Act from 1833. The former restricted the number of working hours and working time, including lunch breaks and inspections of the workplace in the textile industry, which was primarily to protect working children. Following the UK's example, countries such as the United States of America, Canada, Australia, New Zealand, France, and Germany also implemented regulations that limited working hours in many occupations (Gander et al., 2011).

In 1970 the first United States Federal Occupational Safety and Health (OSH) legislation was introduced. It was followed by other countries that moved away from traditionally prescriptive limits on working hours to manage workplace safety and health in a more comprehensive manner. In the United Kingdom the Rubens Report (1972) opposed the Factory Acts and Regulations and proposed a set of principles for the Health and Safety at Work Act of 1974 (Gander et al., 2011).

The British anthropologist Mary Douglas emphasised the highly relevant socio-political context of perception and risk, which made significant progress in understanding how complicated the risk is (Gander et al., 2011). The Cultural Theory was proposed referring to the fact that individuals may have different views of life and claimed that risks maintain people's way of life. Later developments were put forward in Cultural Cognition Theory explaining the connection between psychological processes and values to people's perception of risk.

Performance-based occupational safety and health legislation requires safety and health standards that must be met by the operators, but there is no specification on how these standards should be applied, so some flexibility may be possible. The FRMS approach is compromised with performance-based Occupational Safety and Health (OSH) legislation, contrary to the Hours of Service (HoS) regulation.

Traditional HoS regulations reduce fatigue-related risk by limiting the maximum hours worked and the minimum number of breaks between working hours (Gander et al., 2011). HoS regulations are known as the uni-dimensional approach (one-size-fits-all approach) to fatigue risk management (McCulloch, Baker, Ferguson, Fletcher, Dawson, Marcil, Booth-Bourdeau, Laurence, 2007) and represent a single layer of defence in an organisational framework. Furthermore, they exclude fatigue from other possible hazards, which does not comply with the modern OSH legislation. Additionally, HoS limitations are imposed by the regulators which are known for their inability to consider the complexity of fatigue (Dawson & McCullough, 2004). They also do not consider the daily cycle of the circadian biological clock, nor do they include the commuting time, time needed for recovery, sleep, and other activities that are not related to work (Dawson et al., 2011). An example of the circadian process claims that the timing of the break is much more important (Caban et al., 2012) than the duration of the break itself. The regulations on the hours of service generally fail to follow the rapid changes in industry practices such as the transportation industry, which is fast-changing and challenging (Gander et al., 2011).

To conclude, several operators in transportation settings have moved away from the traditional HoS regulations and introduced newer approaches to fatigue risk management that emphasise OSH performance rather than standard compliance, which results in greater self-regulation and flexibility. FRMS is performance-based approach that allows an operator to focus on managing the concrete operational fatigue risk instead of predicting fatigue based on prescriptive limits.

2.4.3 Lessons learned from other industries

Fatigue is closely related to the number of working hours, making hours-of-service regulations a significant safety concern across the transportation industry. For example, in the USA (1938) the regulators limited commercial drivers to a maximum hour of work and minimum rest time in the 24-hour cycle. This was followed by government agencies in the United Kingdom, Australia, New Zealand, and Canada implementing similar legislations (Gander et al., 2011).

In Addition, in 2003 the United States Federal Motor Carrier Administration (FMCSA) further limited working hours from 15 to 14 hours and driving hours from 12 to 11 hours. European Union, EU regulation No. 561/2006 set the daily driving limit to 9 hours, which could be extended to a maximum of 10 hours twice per week. New Zealand set the limits to a maximum of 13 hours to both working and driving in the 24-hour cycle. The link between fatigue and safety in the road industry was presented by several commercial vehicle crash studies, but there remain gaps in knowledge that would link the complexity of fatigue and safety. The research study of fatigue in New Zealand truck drivers (Baas et al., 2000) revealed that fatigue is primarily related to sleep impairment, which in turn, is influenced by the operational and social constructs. This research called for mandatory rest breaks, allowing enough time for restorative sleep, and more effective strategies to mitigate fatigue (Baas et al., 2000). The National Transportation Safety Board (NTSB) studied 107 single vehicle truck crashes and linked them with the role of reduced sleep (*National Transportation Safety Board, n.d.*). Another example, the naturalistic driving study of 100 instrumented cars was monitoring drivers for a longer period and found that fatigue was one of the contributing factors in 12% of crashes and

10% of near misses (Dingus et al., 2006). A naturalistic study of commercial vehicles (Hanowski et al., 2007) confirmed the importance of sleep restriction, and in the transportation industry, the impact of sleep disorders on safety outcomes has been largely studied (Smolensky et al., 2011; Thorpy, 2017).

Commercial road transportation in Australia introduced FRMS in 2007 and defined standard operational limits, which stipulated the frequency of how often they might be exceeded, and the strategies of effective mitigation to be applied in case when standard operating limits are exceeded. Nevertheless, fatigue is still the fourth most common contributor to accidents. Several studies have examined classification systems and tools to identify fatigue risks, the impact of work hours and new strategies to mitigate fatigue-related errors. For example, different parameters of motor vehicle crashes were compared and identified several fatigue-related causes (Filtness et al., 2017; Roach, Roberts, et al., 2017). The extent to which subjective and objective measures of fatigue can predict the performance outcome were examined (Kosmadopoulos et al., 2017; Roach, Roberts, et al., 2017). Another case study examined the relationship between the number of hours worked and non-fatal crash risk (Meuleners et al., 2015; Roach, Roberts, et al., 2017) and researchers further examined the effectiveness of using social media to deliver safety-related messages (Hawkins & Filtness, 2015; Roach, Roberts, et al., 2017).

Railroad industry

In the United Kingdom, the first legal regulation requirements were set in the Railways Safety Critical Work regulations on limiting working hours in 1994 (Gander et al., 2011).

In 2008 the United Kingdom introduced the Public Law 110-432 and implemented a required fatigue management plan for all rail operators. In Australia, the Federal model Rail Safety Bill in 2006 required an SMS with fatigue management plan in place for all rail operators. In Canada, the SMS regulations came into force in 2001, and in 2003 the new regulations also required a general fatigue management plan. In the United States rail operations, on-call operations demonstrate a particular problem because of the

circadian impairment of irregular working hours, particularly in night operations and the requirement to work overtime work due to staff limitation (Sussman & Coplen, 2000). The importance of the relationship between fatigue and safety is implicit in the complex regulations covering the hours-of-service legislation and, therefore, requires further research.

Maritime industry

In the maritime industry, the European Working Time Directive 93/104/EC does not refer to seafarers, so several initiatives attempted to set prescriptive limits of working hours. International Maritime Organisation (IMO) has passed many different resolutions regarding the mitigation of fatigue and fatigue management for seafarers, but there remain gaps in managing fatigue in several other industries such as fishing (Gander et al., 2011).

Maritime operations in New Zealand introduced a fatigue risk management programme based on the safety management system titled Safe Ship Management Programme. The programme of the Great Barrier Reef Pilotage Safety Management Code also features fatigue management plan (Gander et al., 2011). The most common causes of seafarers' fatigue are lack of sleep, poor quality of rest, workload, and stress. The categorisation of fatigue causes has been divided into four general factors such as crew specific factors, management factors, ship specific factors, and environmental factors (Lee & Kim, 2018; On et al., 2001).

Commercial aviation industry

New Zealand, where in 1995 regulations on limiting working and duty hours were modified, enabling air operators to either comply with the standard prescriptive scheme or have a company-specific scheme approved with incorporated additional factors that affect fatigue such as time zone changes, rest prior duty, and in-flight napping (Cabon et al., 2012; Leigh Signal et al., 2008) has the longest experience in aviation FRMS. New Zealand has also developed highly successful FRMS (Cabon et al., 2012).

Dawson and McCulloch (2005) first introduced a Safety Management System (SMS-based) fatigue approach. The model (see Figure 2-2) was designed on the basis of the integrated principles of the holistic approach to error management by Reason's Hazard Control framework, which advocates that safety is jeopardised when the hazard can infiltrate a number of defensive layers, and Helmreich's (1999) Threat and Error Management model, which is a process where individuals and organisations share their responsibilities (Helmreich, 2000; Helmreich et al., 1999). The proposed FRMS model conceptualises a system of multiple defensive layers along the possible event trajectory, and each of these layers of defence offers the chance to identify and prevent fatigue-related errors or any other threatening adverse safety outcome. The model is a defence-in-depth proactive approach to fatigue risk management (McCulloch, Baker, Ferguson, Fletcher, Dawson, Marcil, Booth-Bourdeau, Laurence, 2007).

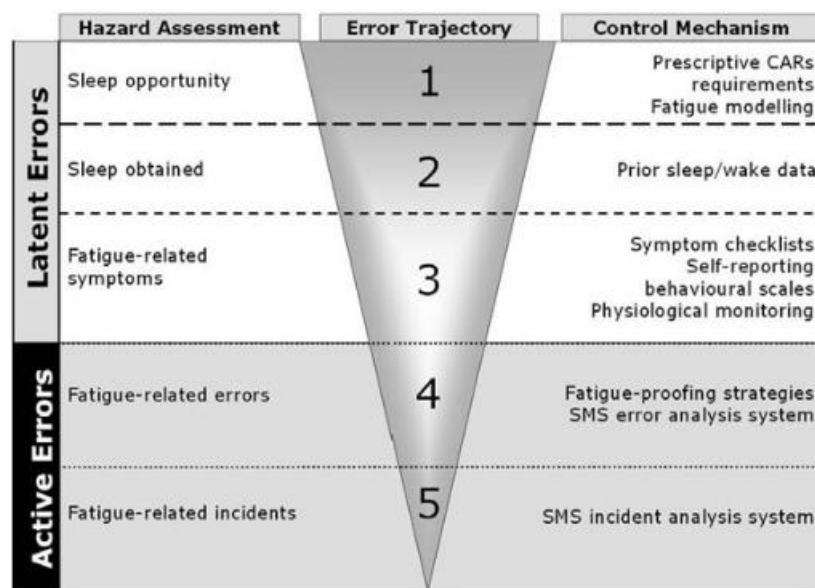


Figure 2-2 Fatigue hazard control model, adapted from Policies and Procedures Development Guidelines (Baker & Dawson, 2007b)

The Fatigue hazard control model incorporates five levels of fatigue hazard control mechanisms to ensure that sufficient sleep opportunity is given to employees based on fatigue modelling or prescriptive requirements. There is a need to verify if a given sleep opportunity is used by employees, and whether they obtain sufficient sleep or not.

Furthermore, identification and monitoring of the fatigue-related symptoms and behaviours and implementing fatigue-proofing strategies is crucial and are described further below. Fatigue-related symptoms and behaviour may not always follow a trajectory, and this may be one of the limitations of this model. The model ends in fatigue-related incidents and their investigation.

As already mentioned before, the FRMS is defined as a “scientifically based, data-driven, flexible alternative to prescriptive flight and duty time limitations that usually forms a part of an organisational SMS and involves continuous process of monitoring and managing fatigue risk” (Wu et al., 2016). The FRMS may be integrated within an existing organisational SMS, or it may be a stand-alone system. Each organisation is unique in terms of different operational aspects; therefore, the FRMS needs to be tailored to meet the needs of specific operations, as there is no “one-size-fits-all” approach.

Singapore Airlines successfully introduced FRMS in their Ultra Long Range (URL) flight operations in 2003 and EasyJet was the first major European airline to introduce FRMS in their operations as part of their Systems Integrated Risk Assessment (SIRA) in 2005 and moved away from the prescriptive Flight and duty Time Limitations (FTL). The system has proved to be effective in reducing fatigue (Caldwell et al., 2009a) and since having an effective FRMS in place, EasyJet have also managed to considerably reduce their insurance premiums. The reporting culture may still be missing in commercial aviation as people are not fully confident and are worried about any potential penalties they may face from an operator despite the no penalty policy.

International Civil Aviation Organisation (ICAO) had an initiative to release Standard and Recommended Practices (SARPs) and guidelines to support the development of FRMS in the aviation industry (Capon et al., 2012). In 2006, the ICAO established a Fatigue Risk Management Sub-Group (FRMSG) to develop a regulatory framework for FRM in commercial aviation. For example, the current European regulatory framework includes the consideration of the effects of the circadian biological clock and improved flexibility (Gander et al., 2011). Furthermore, the Manual for the Oversight of Fatigue

Management Approaches, which is a comprehensive approach to fatigue management was issued by ICAO with its latest edition in 2016 (ICAO, 2016). EU regulation No 83/2014 addresses the pilot and cabin crew fatigue-related regulations and was implemented in 2016 (European Commission, 2014; Lee et al., 2017). Many organisations, including ICAO, IATA, and IFALPA (International Federation of Air Line Pilots' Associations), are working closely on reducing fatigue of airline pilots.

2.5 Fatigue Risk Management System (FRMS)

Usually, as mentioned in a previous paragraph, FRMS is a part of an operator's SMS, addresses a major area of operational safety risk and includes several fatigue-mitigation strategies, which can be irregular or formal. It features organisational safety and a system to sustain safety and compliant performance standards, as well as on-going monitoring of these standards. FRMS focuses on a single task only, and that is fatigue and, therefore, safety (Sprajcer et al., 2022). Moreover, it complements existing safety management processes within an organisation's SMS to maximise their combined effectiveness to promote safe operations (Ziakkas et al., 2022).

The transportation industry has been continuously mitigating fatigue-related issues and has employed several fatigue-risk countermeasures in its operations to successfully manage and mitigate fatigue at each level. To mitigate factors leading to fatigue before it occurs, it may be best to use a preventive strategy considering factors that show the level of fatigue and reduce its impact or an operational strategy that mitigates the effects of fatigue when fatigue is already present (Satterfield & Van Dongen, 2013). A comprehensive defence-in-depth approach to fatigue risk management includes effective strategies to mitigate fatigue and is a step forward from traditionally prescriptive hours of service regulations, which, as previously mentioned, also vary among countries (Caldwell et al., 2009a; Sprajcer et al., 2022). This was also investigated throughout this thesis using different methodological approaches such as semi-structured interviews and a questionnaire survey trying to identify fatigue risk precursors, mitigation, and preventive strategies.

Current regulations and practices focus on fatigue-related optimisation of duty schedules and FRMS approach to fatigue management, which are comprehensive ways of reducing fatigue and increasing safety (Satterfield & Van Dongen, 2013). It is an evidence-based approach to mitigation, management, and measurement of fatigue risk (Sprajcer et al., 2022). The development of these new approaches has improved fatigue and performance prediction approaches, but several issues related to awareness of fatigue consequences and causes, and its mitigating strategies have been identified at the same time.

Generally, aircrew find reasons for their fatigue due to the lack of sleep that they have experienced, as well as circadian process disruptions due to time zone changes and unpredictable working hours, which might refer to early morning or late evening duty starts, time constraints, the number of consecutive duty days and periods, workload pressure and monotony, and finally, insufficient time to recover and sleep (Caldwell et al., 2009a; Sprajcer et al., 2022). For example, one study (Cabon et al., 1993) studied human vigilance in railway and long-haul flight operations. It was found that long-haul pilots were more vulnerable and sensitive to vigilance lapses during low and monotonous workload periods since these periods can reveal physiological sleepiness (Caldwell et al., 2009a). Another study mentioned the effects of early duty starts on the rosters of short-haul pilots. The results showed a reduced amount of sleep during the 12 hours prior to duty, and the extent to which starting early may influence performance and safety. This study recommends regulators to consider the time-of-day factors in scheduling working time arrangements (Roach et al., 2012). In the research study where ULR (Unrestricted Line) pilots were being monitored for their fatigue, awake and sleep time patterns, and FRMS's compliance recommendations regarding sleep while on a layover, the results showed that pilots reported getting quite normal hours of sleep per 24-hours. This could be because they used one of the countermeasures to mitigate fatigue by means of napping during flight. They performed poorly in terms of their sleeping time while on a layover (Holmes et al., 2012). Several studies have demonstrated that planned in-flight napping during long haul flights helps to maintain pilots' performance. For example, cockpit napping is not allowed in the U.S. military

aviation except in the B-2 bomber. Similarly, coordinated napping used by crew members is identified throughout this thesis.

A significant stage in safety and fatigue management is hazard identification, which is performed by means of using reactive, proactive, and predictive analyses, risk assessment, defences, and recovery from incidents/accidents (Gander et al., 2011). The Flight Safety Foundation outlined the indispensable elements of comprehensive FRMS. The FRM policy should be a component of an organisational safety policy and should function in an open and collective manner. Mechanisms for reporting crew member fatigue s require intensive monitoring where reports on fatigue patterns are necessary. Proper education and awareness about fatigue and sleep hygiene through regular organisational training sessions and communication channels can improve the effectiveness of FRMS. In addition, procedures, and measures for monitoring, reporting, and recording incidents should contain a feedback system with technological approaches to fatigue management in real time (Balkin et al., 2011). The major component of FRMS is a process that is used to evaluate data related to fatigue, focusing on closing the information loop.

A multi-dimensional FRMS consists of four levels of activities: two operational (see Figure 2-3) and two organisational. Comparably to the existing SMS, the FRMS activities, such as the FRMS Policy and Documentation, FRM Processes, FRMS Safety Assurance Processes, and FRMS Promotion Processes, complement the SMS processes to attain the greatest combined effectiveness on safety and fatigue.

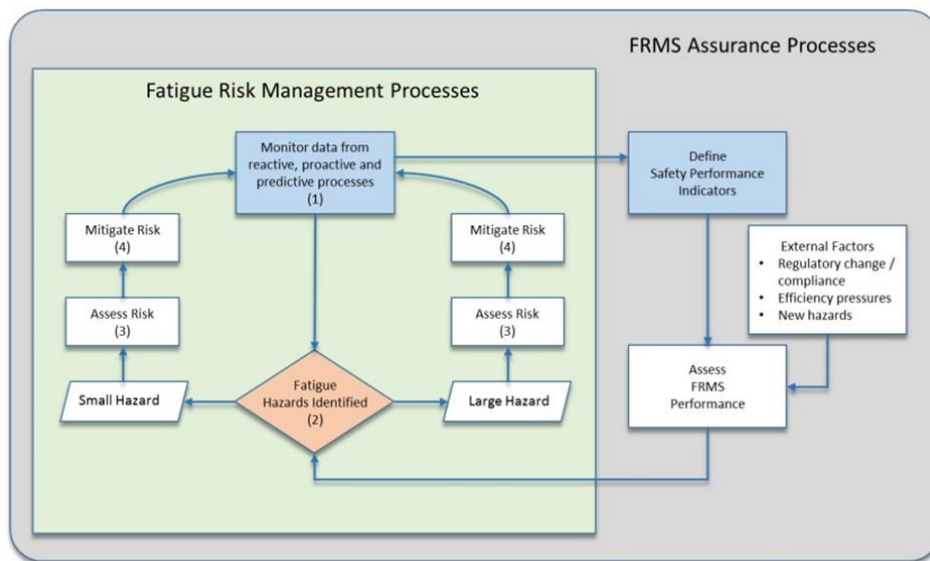


Figure 2-3. Operational activities of an FRMS (ICAO, 2016)

The Policy and Documentation relates to the reflection of shared responsibility within the organisation, states the accountabilities for the procedures and processes, defines management commitment to effective safety reporting, identifies fatigue reporting mechanisms, and states the definition of FRMS objectives. In order for employees, employers, and regulators to meet their responsibilities under FRMS, it is critical that they are aware of fatigue consequences and causes. Furthermore, the FRM processes outline the three fundamental fatigue hazard identification processes with different tools to address them. There is a need to develop, maintain and document predictive processes (e.g., previous experiences of an operator or regulator, bio-mathematical modelling, evidence-based scheduling practices), proactive processes (e.g., fatigue surveys, safety data and scientific analysis, sleep monitoring, planned versus actual time worked analyses, self-reported fatigue risks), and reactive processes (e.g., fatigue hazard reports, audit reports, confidential reports, event investigations, audits). Additionally, effective risk assessment involves the development and implementation of risk control and mitigation strategies, including safety performance indicators, to evaluate whether the required level of risk reduction is achieved by delivering effective mitigation strategies and continuous monitoring (Gander et al., 2011; ICAO, 2016; Sprajcer et al., 2022; Williamson et al., 2011).

Safety assurance processes provide continuous improvement of the overall FRM such as routine evaluations of the existing procedures, processes and equipment, identification of the need for introducing new processes and procedures, and elimination or modification of the existing procedures and risk control that need to be modified or are no longer needed. Safety assurance processes provide comprehensive FRMS performance monitoring and continuous development and improvement of the FRMS. Moreover, to improve the FRMS implementation, there is a need for a deeper understanding of the complex relationship between safety and fatigue. Better integration of the latest developments, such as resilience engineering (Dekker et al., 2008; Gander et al., 2011; Sprajcer et al., 2022) and operational tools for supporting risk and accident analysis (e.g., Risk Matrix, FREF (Fatigue Regulation Evaluation Framework)) are needed. For example, the Risk Matrix helps to visualise and compare the severity and likelihood of identified risks and prioritise actions needed in response to that identified risk. Therefore, it is a step forward towards enabling safer working practices. Another method for evaluating fatigue management is FREF which was used in a study that evaluated Australian flight crew fatigue and identified factors that need to be incorporated into fatigue regulations and ensure safer operations (Mannawaduge et al., 2024). These methods supporting risk and accident analysis may provide more reliable approaches to identify circumstances and situations where fatigue can jeopardise safety (Gander et al., 2011; Williamson et al., 2011). Data that are monitored in the FRMS through variety of sources are further used to generate Safety Performance Indicators (SPIs) which check and measure on how well the overall FRMS delivers an acceptable level of fatigue risk. It provides a scale for decision-making guidance and meets safety objectives. SPIs monitor fatigue trends over time and if the overall system is functioning, in terms of delivering defined objectives in FRMS policy.

The fourth FRMS pillar relates to the FRMS promotion processes, which support FRMS continuous development and implementation through the fatigue awareness training program and effective communication procedures. Fatigue training should be tailored individually for different groups of employees and management. It should generally focus on the basics of sleep science, such as sleep processes, sleep loss and recovery,

effects of the circadian rhythm, influence of workload, personal fatigue management, roles, and responsibilities in the FRMS and the interaction of these factors.

Effective communication can be managed in various ways, for example, through electronic media, bulletins/newspapers, seminars, and poster campaigns. It is mandatory for implementation and maintenance of effective FRMS (ICAO, 2016; Sprajcer et al., 2022).

The development and implementation of the FRMS is a complex process incorporating several elements and their interactions, of which, some still need to be further researched. This process requires a step-by-step approach and is tailored for specific operation(s).

2.5.1 Fatigue mitigation strategies

Fatigue mitigation strategies aimed at preventing adverse safety events and/or an individual from working fatigued, thus influencing operational safety levels. The transportation industry has applied various countermeasures and strategies in its operations for mitigating fatigue. A suggestion of the countermeasures and strategies in the aviation industry is to divide them into different groups. One of them is in-flight countermeasures and strategies such as activity breaks and naps, bunk sleep on a long-haul and URL flight operations, exposure to lighting, and in-flight rostering approaches (Caldwell et al., 2009a). Another group comprises pre-/post-flight countermeasures and strategies which are associated with the use of hypnotics, health screening and treatment, recovery monitoring, adequate manning, monitoring the number of hours worked, monitoring the quality and quantity of sleep, identification of fatigue symptoms, performance assistance, appropriate rostering, fatigue-proofing and on-line assessment, and monitoring (Caldwell et al., 2009a; Phillips, 2016).

There are five groups of countermeasures related to the potential risk trajectory such as sleep and work schedules, consideration of occupation or industry, individual health, well-being, and demographics (Phillips, 2016). An SMS-based approach to fatigue model

by Dawson and McCulloch has specifically explained how risks can be identified and prevented along the fatigue-risk trajectory using an in-depth approach to fatigue (Dawson & McCulloch, 2005).

As previously mentioned, there is an important step away from traditional HoS regulations with a new method for fatigue-reduction strategies applying the concept of error management (Olaganathan et al., 2021) which address human fallibility, short-lived mental states (e.g., distraction and forgetfulness), working conditions, no blame culture, unintended errors, social and motivational problems, and communication (Reason, 2000). It is important to understand that each point on the FRMS event trajectory provides an opportunity to identify and prevent potentially adverse safety outcomes. Furthermore, an effective and comprehensive fatigue risk management approach requires distinct strategies to be adopted as integral and complementary elements of the FRMS to reduce the possibility that people may become tired at work and decrease the possibility that an individual who is fatigued and operating in the workplace would make an error leading to an adverse safety outcome (Dawson et al., 2012).

2.5.2 Fatigue - reduction strategies

Fatigue-reduction strategies are aimed at minimising the likelihood of a fatigued individual being present at the workplace by using the bio-mathematical models of fatigue for estimating the work-related fatigue and adequate time for recovery or by setting the maximum working hours and minimum rest breaks, but the use of bio-mathematical models of fatigue is a much more appropriate approach to fatigue level predictions founded on a scientific understanding of factors contributing to fatigue level. It is however necessary to be aware of its limitations. Fatigue-reduction strategies are present in the first, second and third levels of the SMS-based fatigue approach, where the first level provides the relative sleep opportunity linked to the work pattern and ensures that employees are not exceeding the threshold of fatigue risk due to work-related fatigue. The second level enables the identification of actual sleep experienced and, therefore, prevents individuals with insufficient sleep from being present at work,

and the third level is related to behavioural symptoms of fatigue such as struggling to stay awake, yawning, and performance impairment, which may therefore also prevent potential fatigue-related risks (Dawson et al., 2012).

2.5.3 Fatigue-proofing strategies

Fatigue-proofing strategies are another set of strategies used to mitigate fatigue issues by using appropriate strategies for decreasing fatigue level and prevent a fatigued worker, operating in the workplace, from making an error. They are adaptive and have been developed spontaneously and informally within an organisation and are aimed at different situations and cultures of a particular workplace. For example, in the aviation and marine industry pilots self-identify themselves as fatigued and informally communicate with others for additional vigilance in critical situations and when making critical and complex decisions. They primarily form an irregular part of an organisational formal SMS and intend to reduce the possibility that fatigue-error will have a negative impact on safety outcomes while an individual is working despite being fatigued. Fatigue-proofing strategy is a type of process referring to re-designing the work system to increase its flexibility and resilience to errors that occur due to fatigue. They could be defined as an implicit operating procedure. Application of fatigue-proofing strategies requires a highly resilient SMS, including open and collective organisational culture. Due to its irregularity, there may be a lack of clear understanding of what the appropriate and effective strategies are. Employees may fail to identify the effective strategies quickly and eliminate dysfunctional strategies. Another issue may be an inaccurate, delayed transmission of effective strategies across an organisation. Therefore, it is of the utmost importance to evaluate the effective strategies for efficacy, and to standardise and document them as a formal part of an organisational SMS (Dawson et al., 2012).

Evolving and integrating fatigue-proofing strategies into organisational SMS creates an additional layer of defence in relation to resilience engineering, which offers an alternative approach to safety management. These strategies indicate gaps in traditional approaches to safety management and improve an organisational awareness of fatigue, which may be one of the possible factors that could help to explain the complex

relationship between safety and fatigue. The use of these strategies has become very common within a variety of industries. Many work groups use them to mitigate fatigue-related issues to prevent performance impairment or any adverse safety outcome.

The most targeted group in aviation are pilots. Long-haul pilots generally undertake several strategies to mitigate potential fatigue during their long duty hours. Most often, they self-identify themselves as fatigued, speak to their copilot or take a short break in compliance with the operator's SOPs (Standard Operational Procedures), such as napping or taking an active break, which might involve stretching their legs. Furthermore, short-haul pilots may feel fatigued due to their early morning operations, inadequate sleep, personal life issues, or health problems and are used to applying many different fatigue-proofing strategies.

Marine pilots and line teams in the nuclear power industry are also fatigue-affected groups that employ several strategies to prevent fatigue-related mistakes while on duty (Chambers & Main, 2015). Doctors in health care are most often threatened by insufficient sleep and most commonly apply strategies to mitigate sleep inertia (Basner et al., 2017; Kovac et al., 2023).

One of the newest and frequently reported categories of protective behaviour in fatigue-proofing strategies are task-related strategies, which are related to task slowing and buffering for a greater level of self-scrutiny and error detection. This includes task rotation, to reduce time spent on a task and to avoid fatigue-related errors (Folkard & Tucker, 2003), double- and cross-checking, and prioritising or assigning the task to others. Another type of frequently used protective behaviour are strategies, which are based on behaviour and involve communications, social interactions, and supervisory oversight (Dawson et al., 2017). The research study of fatigue risk management which documented the use of informal protective behaviour of 18 members of the military aviation personnel (flight crew, aircrew, engineers, and maintenance personnel) identified 147 strategies that were used to reduce or prevent fatigue-related errors. In comparison to fire-fighting studies where fire fighters were not expected to apply these

strategies due to their informality (Darwent et al., 2015; Dawson et al., 2017), it was demonstrated that military aviation personnel knew about the consequences of fatigue as well as the advantages of using protective behaviour and thus, they also used these strategies more often in their operations. This could be a sign of the aviation industry knowing about the relationship between error and fatigue, by means of employing formal principles of Crew Resource Management (CRM) and Threat and Error Management (TEM).

Finally, fatigue-proofing (protective) strategies are further explored, and there is a continuous development of new appropriate strategies through in-depth qualitative investigation of commonly identified fatigue-errors that are the greatest threat to safety (Sprajcer et al., 2022)

2.6 Measuring Fatigue and Performance

Circadian rhythms are present in cells throughout the body regulating biological and behavioural rhythms, therefore, they repeatedly regulate the sleep/wake cycle on a 24-hour basis. Moreover, the role of circadian rhythm is to regulate sleep, wake, and nutrition with daily peaks and troughs in terms of alertness and performance, which are modulated by external cues such as light and temperature. The most dominant environmental time cues known as “Zeitgebers”, German word meaning time givers/time cues, are light cues received by the body clock. Mental and physical peak hours are identified from 8 a.m. to 12 p.m. and 3 p.m. to 9 p.m., whereas off-peak hours are from 1 p.m. to 3 p.m. and 10 p.m. to 6 a.m. (Report, 2010).

Furthermore, the circadian “clock” consists of a small group of hypothalamic nerve cells and tissues in the brain called the suprachiasmatic nucleus (SCN), located in the hypothalamus of the brain, which is responsible for controlling circadian rhythms and for enhancing behavioural adaptation. For example, data from one of the oldest research studies on circadian rhythms (Moore, 2007; Stephan & Zucker, 1972) indicated that the suprachiasmatic nucleus is a brain pacemaker that controls circadian function. Therefore, dysfunction due to trauma, stroke, or tumours or ablation of the

suprachiasmatic nucleus results in loss of regular sleep/wake rhythms as well as other processes which may be disturbed (Ashbrook et al., 2020).

The retina of the eyes, which is located at the back of the eyeball, perceives light and darkness through the retinal ganglion cells that are first hit by the light and receive visual information from photoreceptors. Moreover, photosensitive ganglion cells convert the light through the optic nerve into the images and send them to vision centres from where messages about light levels are transmitted to the suprachiasmatic nucleus. Therefore, the suprachiasmatic nucleus receives information on the length of day and night from the retina directly and sends this information further along their output pathways on to the pineal gland.

The pineal gland produces and secretes melatonin in a circadian pattern with high levels of secretion at night and low levels during the day. Night and shift schedules as well as time zone changes induce circadian desynchronisation where individuals differ in susceptibility and adaptations to changes in circadian rhythm.

Moreover, research studies on performance in both civilian and military aviation have used a variety of methods to measure operational performance. In military aviation, relatively few studies of combat aircrews in operational environments aboard the aircraft have been done due to the nature of the combat environment. One of the studies (Storm et al., 1992) collected data on aircrew performance using the Landing Signal Officer (LSO) scores and a daily activity survey, including several questions about subjective readiness, sleeplessness, sleep quality, and caffeine intake. Another study (Yu et al., 2022) explored the pilot's physical and mental health that may be a contributing factor to safety, observing the mediating effect of personality factors between the health-related quality of life and resilience by using the Structural Equation Modelling method. Two hundred and twenty participants were observed collecting their data on demographics, personality traits, resilience, and social life. The study showed that resilience, social life, and personality factors affects pilots' quality of life and mental health.

Different measuring methods were used in another study (LeDuc et al., 2000), which examined the effectiveness of exercises for sustaining performance. The study was conducted in the laboratory, using an electroencephalogram to collect data of brain activity, the Visual Analogue Scale (VAS) for subjective sleepiness and alertness and the Repeated Test of Sustained Wakefulness (RTSW) for objective sleepiness and alertness. Moreover, the Profile of Mood States (POMS) was used to evaluate changes in subjective mood, and the Synthetic Work Battery (SYNWORK) and Multi-Attribute Task Battery (MATB) examined changes in cognitive abilities. Flight performance was measured with the flight simulation task and the study concluded with suggestions that a small amount of exercise may prevent fatigue associated with sleep loss, for only a short period of time.

A great variety of research methods are available to explore and identify performance and alertness levels, which depend on operational environments and the nature of operations. Moreover, a variety of performance-based questionnaires are available in different formats with many different scales and are discussed in this chapter.

Several health issues arise from the aviation industry environment, which most commonly result from a variety of factors and their interactions such as poor sleep habits, stress, circadian desynchronisation, high operational tempo, different working arrangements, use of pharmacological agents and caffeine, environmental conditions, and personal issues. Military personnel are constantly subjected to these factors; therefore, continuous monitoring of the individual's health is crucial for safe operations as people struggle to cope with several health issues. As discussed previously, various measurements to assess sleepiness and fatigue and the lack of validity and credibility of available measurements cause confusion and bias to reflect the real-world situation. However, also research studies on health have used a great variety of measurements to assess health issues focusing among other issues on psychological disorders, cardiovascular diseases, metabolic syndrome, and obesity.

Blanc et al. (2014) examined psychological distress using self-reported measures and brief questionnaires to monitor health conditions of deployed personnel and these methods have been intensively used in military organisations. The most studied pharmacological agents and performance enhancers in the military refer to amphetamines and caffeine. Measurements of caffeine's effects during combat-stress military training included various measures such as saliva sampling procedures to assess caffeine levels, cognitive and mood testing, visual vigilance scanning tests, repeated acquisition tests, visual reaction time tests, and matching-to-sample tests. A Profile of Mood States (POMS) questionnaire, Stanford Sleepiness Scale (SSS), post-test questionnaire was used to assess whether a received caffeine intake was beneficial and if side effects were experienced. The study, which have used all these measures to assess a caffeine effect during United States Navy training concluded that caffeine had beneficial effects on mood and cognitive performance factors (Lieberman et al., 2002).

Furthermore, there are few published reports, lacking a wide range of data on performance enhancing and performance sustaining pharmacological agents during a combat mission (Lieberman et al., 2012). A study of the use of pharmacological agents in sustained fighter combat operations of F-16 pilots (Miller et al., 2015) used a questionnaire on fatigue to measure stress and fatigue issues and to identify the use of pharmacological agents among pilots. The results showed a significant safety threat and that a proper use of pharmacological agents can be beneficial in mitigating safety risk in sustained combat sorties. More published reports would be of great importance in providing a wider understanding of the use of pharmacological agents and which measurement tools are credible to identify the need for their distribution.

2.6.1 Homeostatic processes, circadian processes, performance, and safety

Interactions of factors influencing fatigue have been examined in several research studies. For example, several studies identified interactions between impaired performance, sleep homeostatic parameters, and increased adverse safety outcomes. It is common knowledge that lack of sleep reduces a wide range of cognitive, behavioural, and physiological functions (Casini et al., 2013). Williamson compared 28 hours of time

awake, and the results showed impaired performance and sleep loss effects on work monotony, poorer concentration levels, and impaired visual discrimination (Williamson & Friswell, 2011). Moreover, a study on the effects of several nights characterised by sleep deprivation due to sleeping only four hours per night showed effects on the speed of performance (Stenuit & Kerkhofs, 2008). Also, there is evidence that one night of sleep deprivation affects speech-perception tasks, temporal judgement, and alertness (Casini et al., 2013). One of the studies conducted in the Australian rail industry investigated fatigue in sleep-deprived participants with an average sleep time of 5 hours, 24 hours prior to work and 12 hours of sleep, 48 hours prior to work and the result showed increased risk and performance impairment (Dorrian et al., 2011). Significant effects of how sleep deprivation may affect performance was introduced on the Sternberg working memory task (Mu et al., 2005) where several researchers demonstrated effects of sleep deprivation on non-verbal planning, verbal fluency (Horne, 1988), and problem-solving tasks (Linde & Bergströme, 1992). Also, studies of memory functions in sleep-deprived individuals have found mixed effects, but generally, lapses in memory have been identified as contributing significantly to several accidents (Shorrock, 2005).

However, there is a less clear relationship between circadian-related fatigue influences, impaired performance functions, and adverse safety outcomes such as aircraft incidents or in extreme cases aircraft accidents which are accompanied by numerous other factors contributing, and which calls for further epidemiological exploration (Williamson et al., 2011; Williamson & Friswell, 2011). Up to date, two narrative reviews of circadian performance and processes have been conducted. One of them found evidence for an underlying circadian process in performance and stated that aspects of performance rhythm were impacted by several various influences, such as tasks and individual and situational factors, including the level of fatigue (Carter, 1982). The other review conducted generally supported these findings but suggested some additional arguments related to the effects of the time of day and the impact of hours spent awake (Carrier & Monk, 2000). The effects of circadian rhythm may clearly contribute to fatigue levels (Williamson et al., 2011; Williamson & Friswell, 2011) and more information on how

circadian rhythm is affected by various flight operations would improve the predictive capability of bio-mathematical models, which is discussed further below.

There is a need to identify cognitive and physiological performance functions that are most sensitive and vulnerable to fatigue. This would prevent and/or mitigate the likelihood that performance will be impaired and also prevent the threatening risk of fatigue-related errors. Failure to react quickly, identification of dysfunctional and inappropriate fatigue-reduction strategies and inattention, have been identified in many accidents across different industries.

The effects of the circadian rhythms and homeostatic processes are best visible in night work, work in shifts, irregular duty periods, time zone changes flight operations and work location because of misalignment of neurobiological processes that regulate sleep and sleepiness in relation to night and day because of the need for an individual to be awake at irregular hours.

2.6.2 Subjective measures

Subjective measures rely on self-evaluated rating scales, and have some limitations related to intentional falsification and include unintended bias (Shahid et al., 2010). Sleepiness and fatigue possess “state”-short term and “trait”-long term features (Geiser et al., 2017). The scales which evaluate “state” sleepiness are the Stanford Sleepiness Scale-SSS, Karolinska Sleepiness Scale, and Visual Analogue Scale. The other, trait-like scales refer to the Epworth Sleepiness Scale-ESS and Sleep Wake Activity Inventory-SWAI.

As previously mentioned, the most widely used subjective self-assessment sleepiness and fatigue scales in the aviation industry are the Karolinska Sleepiness Scale and the Samn-Perelli fatigue scale, respectively. While the subjective scales are easy to use and are reliable to report fatigue and sleepiness, on the other hand, they have some limitations when used in bio-mathematical models. The first issue relates to their similarity and are often introduced as they are indistinguishable, which is discussed

further below. Furthermore, another issue relates to the applicability of scales' fatigue levels to subsequent risk levels. Therefore, a different approach to thresholds using the SAFTE model, which generates quantitative estimates of human cognitive performance effectiveness, was proposed by Rangan and Van Dongen (2013).

The Karolinska Sleepiness Scale

The Karolinska sleepiness scale is a nine-point extensively used self-assessment sleepiness predictor with reasonable results in several studies, which measures the subjective sleepiness at a particular time during the day, and it can be either paper- or computer-based, easy to administer with minimum disruption to the crew. On the other hand, the KSS can be easy to cheat, therefore, may lack the validity and credibility in considering objective performance measures. The scale has been validated against physiological parameters and the value of at least seven on the KSS has been linked with an increased accidents in simulator studies (Åkerstedt et al., 2005). The validity of the KSS was investigated also by Kaida and colleagues (2006), and the results confirmed a high validity of the KSS through the correlation to electroencephalography (EEG) and behavioural variables (Kaida et al., 2006). Usually, the SWP and FRI (Folkard et al., 2007) models employ this metric. For example, among several studies, the KSS was included in the study of commercial airline pilots' sleepiness and alertness management, which examined what pilots generally do to maintain their performance level during flight operations. The KSS showed reliable sleepiness predictions indicating that increased sleepiness results in a high KSS score (Sallinen et al., 2017). Similarly, to Stanford Sleepiness Scale, KSS is not as sensitive a marker of state sleepiness as Visual Analogue Scale.

The Samn-Perelli Fatigue Scale and sleep diaries

The Samn-Perelli fatigue scale, a seven-point self-assessment scale has been widely used in the aviation industry (Lamp, Van Den Berg and Belenky, 2017). The values of five or more on the scale have been linked with severe fatigue, which indicates that flying is not recommended. It is also one of the metrics in the SAFTE model.

Sleep logs are an alternative that is commonly used in measuring subjective sleepiness. The diaries indicate the individual's sleep and waking times, quantity and quality of sleep, and the location of sleep. Moreover, the diaries may include daily activities, nutrition, subjective fatigue and are collected along with the actigraphy. A wrist Actiwatch monitoring indicates the timing of individual's sleep as well as unintentional sleep (e.g., cockpit napping). It is easy to administer and may be used along the subjective measures. A disadvantage of the Actiwatch is that it is not able to record the times when an individual is awake.

2.6.3 Objective measures of fatigue

In an operational context, fatigue can also be measured objectively by using a range of technologies, which still lack the reliable objective measures and tools to define and measure fatigue (Williamson et al., 2011). A widely used objective performance on simulated tasks is the Psychomotor Vigilance Task (PVT), logical reasoning, Percentage of Eye Closure (PERCLOS) in the automotive environment (e.g., motor vehicles (Dinges & Mallis, 1998)), approximate entropy (ApEn) in military aviation, and numerical aptitude (McKinley et al., 2011). An objective measure of fatigue may interpret the data impartial because of the lack of an individual's factors and may be influenced by situational or environmental factors (Thomas et al., 2015).

The pattern of brain activity changes with increased fatigue and can be detected with polysomnography. It measures the quantity and quality of sleep, including the structure of sleep. This technique requires a qualified technician to accompany the crew and, therefore, it is a more obtrusive, time-consuming, and expensive approach. Currently, polysomnography is the most trusted method, which measures brain waves, eye movement, and muscle tone.

Furthermore, PERCLOS and approximate entropy are oculometrics that detect fatigue-related performance decrements. Based on research study by McKinley (McKinley et al., 2011), PERCLOS is not effective in dynamic aircraft environments, contrary to, approximate entropy which is a strong indicator of an operator's fatigue and

performance decrements and an exceptional predictor of G-induced loss of consciousness. Therefore, approximate entropy is a robust oculometry for fatigue monitoring in Air Force environment (McKinley et al., 2011).

Monitoring the fatigue effects on operational performance is feasible with the Air Safety Reports (ASR) and Flight Data Monitoring (FDM). The difference between these two approaches is that with the FDM is more difficult to identify the effects of fatigue due to various other factors involved, therefore, it is less subjective than the ASR.

Both subjective and objective measures have been employed in some studies. For example, long duty shifts were related to decreased subjective and objective performance tasks, a 12-hour shift caused individuals greater exhaustion, increased sleepiness, and sleep deprivation (Dahlgren, 2006). Another study claimed that subjective measures are more commonly linked to fatigue than objective ones (Dahlgren, 2006; van der Hulst, 2003).

As previously mentioned, in the study of fatigue detection in Delta Airlines flight operations both the subjective and objective measures were used to detect fatigue. The results indicated that subjective and objective measures could not detect the different effects on fatigue related to different types of flights such as short- and long-haul flights. Moreover, the PVT did not give the expected levels of fatigue (Thomas et al., 2015).

The fatigue detection technologies and scheduling tools that incorporate the bio-mathematical models of fatigue and performance, should be used with great caution, and not rely solely on the outputs of bio-mathematical models. Some fatigue detection technologies have been proven to limited extent in the aviation industry, including a wrist-worn device that activates an alarm when the inactivity occurs, and some crew scheduling approaches based on already proven and limited fatigue prediction models. The tools and technologies that incorporate bio-mathematical models can be a part of an overall safety management approach but should not be used directly for addressing regulatory limitations.

2.7 Bio-Mathematical Models, Modelling and Predicting Fatigue

2.7.1 Introduction

The development of quantitative models of fatigue was enabled by the improved understanding of homeostatic and circadian processes with the key move forward by Borbely's two-process model of sleep regulation (Borbély, 1982; Miller, 2012). The models were first articulated as circadian mathematics in the 1960 and since the late 1990s they have been extended for use in real-world settings through fatigue risk management to organise shiftwork that has been a common cause for fatigue and sleep deprivation, and thus prevent a negative safety outcome of employees (Dawson et al., 2011). In the initial development phase from 1997 until 2005 the first fatigue predictive models were parameterised using laboratory data and produced outputs indicating an average level of fatigue for a specific work group in each operational environment. Restrictions of applying group means and laboratory-based data have been recognised as a notable problem of bio-mathematical models and are discussed further below.

The underlying physiology of circadian systems and sleep, as well as the impact of fatigue on basic task performance, have been better understood and extensively documented since their inception. On the other hand, there has not been any improvement in understanding of how fatigue affects a complex task's performance on a team or individual level. This is still one of the important gaps in human understanding of fatigue, and similarly, frameworks for modelling and predicting fatigue remain unchanged.

Critics of the initial biomathematical models that quantitatively predict fatigue provided new approaches to improving fatigue and alertness predictions, enabling humans to better understand the scope that will constrain the predictive reliability and validity of the models for intra- as well as inter-individual differences. Several research groups developed software for predicting the likelihood and consequence of fatigue based on timing and duration of sleep and wakefulness (Mallis et al., 2004).

The overall aim of biomathematical models is to predict effects of different working patterns for specific work groups, combining data on sleep, work, and performance into a quantitative framework to interpret an average level of fatigue and alertness (Dawson et al., 2011). Each operational setting has its own acceptable level of fatigue, and this is decided within the specific operational setting considering the relevant factors influencing the level, therefore, the acceptable military specific fatigue levels will depend on the nature of operation and many other relevant factors. Acceptable fatigue levels cannot be the same for all aviation military operations, it varies according to the type of operation. Moreover, models have the potential to assist crew scheduling and compare scheduling practices to reduce fatigue-related safety risk and to identify high level fatigue risk within existing scheduling practices. Also, they can assist in fatigue risk assessment when designing schedules and developing appropriate fatigue mitigation strategies and countermeasures such as light exposure and napping countermeasures (CASA, 2014).

A quantitative approach to an acceptable level of fatigue risk (i.e., fatigue threshold), as mentioned previously, this depends on the type of military operation, for example, an acceptable fatigue level in the fire fighter unit will vary from the acceptable fatigue level in the transportation and logistics units as the environment and operations are different. Therefore, acceptable level of fatigue risks is different, this approach compares biomathematical fatigue models predictions and a fatigue threshold to distinguish acceptable from unacceptable work schedule solutions. This quantitative approach has been criticised because the fatigue risk level associated with a particular duty schedule does not quantitatively take into consideration fatigue risk but only duty time spent at elevated fatigue risk. Another issue arises as to whether a fatigue threshold level, which is acceptable for one transportation setting is also applicable to another transportation setting. An alternative approach proposed by Rangan and Van Dongen consider both the fatigue risk related to extended duty times spent below the level of fatigue and the threshold at those times (Rangan & Van Dongen, 2013).

Current biomathematical models (i.e. Two-Process Model; Sleep/Wake Predictor Model; SAFE Model; Interactive Neurobehavioral Model; SAFTE Model; FAID Model and CAS Model) that are physiology-based, quantifiable, and flexible methods of providing safety and performance in operational settings and are described in the literature have been categorised into two model approaches, depending on the model's required input. Fatigue can be predicted by models either directly by using the data on timing before sleep and wake (i.e., the one-step approach model) or indirectly by assuming an average sleep-wake pattern from work schedules, which is then used to predict fatigue, also known as the two-step approach model (Dawson et al., 2011; Kandelaars et al., 2006). Currently, the researched Air Force unit in this thesis does not use any of the biomathematical models for predicting fatigue and consequences.

2.7.2 One-step and two-step approach to bio-mathematical models

One-step approach models directly use data on work-rest and sleep-wake inputs that predicts average fatigue and performance alertness. Furthermore, a two-step approach model creates artificial consistency to sleep-wake behaviour by using data on work-rest (i.e., working hours) estimates for predicting sleep-wake behaviour and further average level of fatigue, performance, and alertness for a specific group of employees in each industry (Dawson et al., 2011). The most used two-step models are Fatigue Audit InterDyne (FAID) and Sleep, Activity, Fatigue and Task Effectiveness (SAFTE), developed by the University of South Australia and by the United States Department of Defense, respectively.

Models provide a mean group estimate of fatigue in real-world settings because they usually do not have available individual's data on sleep-wake history. Moreover, according to scientific understanding of how the sleep-wake system functions and how it affects alertness, performance, and fatigue, the models distinguish between the two-process and the three-process models of sleep regulation (Akerstedt & Folkard, 1995; Borbély, 1982; Folkard, 2014) which are discussed further below. The two- and three-process models both consider an individual's circadian process-C and sleep homeostatic process-S (Dawson et al., 2011).

A comparison between different bio-mathematical models of fatigue and one-step approach models found that one-step models produce similar predictions of fatigue even if they do not consider sleep inertia (i.e. sleep deprivation) but may underestimate fatigue. Moreover, the two-step approach models showed more differences in their output due to lack of social interaction factors (Van Dongen et al., 2004).

Current bio-mathematical models of fatigue, developed to forecast sleepiness and neurobehavioral performance in a laboratory environment, provide an accurate estimation of a group's average performance based on three basic components that cause fatigue, such as sleep inertia, homeostatic sleep-wake regulation, and circadian rhythm. Furthermore, the dynamic interplay of circadian and homeostatic process as well as short-term sleep inertia is simulated.

The models are valuable tools applied to scheduling tools to predict and prevent performance impairment in operational environments. Overall, in operational context, they may be used alone or as a component of a fatigue risk management system (Hursh et al., 2017).

2.7.3 The two-process model of sleep regulation

A two-process model by Borbély (1982) plays a dominant role in a sleep regulation process where sleep tendency and sleep duration are based on the combined action of the two physiological processes, such as the sleep-independent process C of the circadian rhythm and the sleep-dependent function of prior waking time, the process S. The levels of sleepiness exponentially increase during prolonged waking periods, and the duration of prior waking and sleep parameters are not linear, which was shown in one study's experiment where a subject stayed awake for 264 hours and then slept for only 14.4 hours. The examination in the same study cited, confirmed a nonlinear relationship, and showed a sleep-deprived subject after 90 hours of being awake and then slept for 10 hours (Borbély, 1982). Furthermore, the laboratory experiment showed that sleep deprived individuals' fatigue increases and performance decreases with prolonged wakefulness and fatigue and performance varies over time according to

circadian rhythm (Dongen, 2004). Another example, the study of fatigue in military aviation (Caldwell et al., 2004) showed that 37 hours of sleep deprived F-117 pilots resulted in an overall decline in basic flying skills by more than 40% below average (Caldwell & Caldwell, 2005).

The importance of understanding the individual's vulnerability to sleep deprivation is extremely important as it would improve and give strength to the bio-mathematical models' accuracy of fatigue, performance predictions, and behavioural alertness. To determine an individual's trait-like characteristics is very much related to the circadian and homeostatic processes of sleep and wake regulation. The laboratory research study of individualised mathematical models of a sleep deprived individual considered these two processes using the PVT and sleep physiological data of nine 36-hour sleep-deprived individuals. The results showed the absolute impact of individual's homeostatic differences was twice as large as differences in circadian process. Therefore, the involvement of both processes, homeostatic and circadian, in determining individual differences to performance impairment must be considered (Van Dongen et al., 2012). The strategies that could be incorporated into bio-mathematical models may help to improve individual levels of fatigue, for example the predictors of performance vulnerability such as circadian chronotype-morning or evening type, individual sleep requirements, and individual characteristics based on real-time performance observations.

Challenges and approaches to individualised bio-mathematical models are based on an expanding understanding of physiological processes related to homeostatic, circadian, and performance interactions and on novel empirical and statistical approaches (Goel et al., 2014; Olofsen et al., 2010). Challenges focus on using models from one cognitive domain to predicting performance in another cognitive domain. Incorporating intra- and inter-individual differences by identifying determining factors may improve predictions of sleep loss consequences (Olofsen et al., 2010). The intra- and inter-individual differences are excluded from the present models due to homogenization of a work groups' sleep-wake histories.

An important step toward an individualised performance prediction models for sleep-deprived individuals was done by Rajaraman (Rajaraman et al., 2014), in a laboratory-based study of 48 sleep-deprived individuals who stayed awake for 85 hours. The method used in this study is based on the two-process model of sleep regulation with individual performance information and an “a priori” performance information using a Bayesian framework. The laboratory data enabled consideration of both inter- and intra-individual differences and made further comparison between individualized and group-averaged model predictions. The individual’s objective performance was measured by the PVT, which needed to address its limitation of accurately, considering real-world performance. However, the results indicated, were up to 43%, more accurate in an individual’s predictions than group-average ones. Nevertheless, this study is a significant improvement in model development, which strives for more accurate individual performance predictions by taking into consideration the effects of stimulants, such as caffeine (Rajaraman et al., 2014). Moreover, the two models that consider caffeine-restoring effects on fatigue and performance have been developed (Benitez et al., 2009; Puckeridge et al., 2011; Ramakrishnan et al., 2013). These models have limitations related to objective cognitive performance measures, which were not considered by Puckeridge (Puckeridge et al., 2011; Ramakrishnan et al., 2013), and there the relationship between the homeostatic processes and caffeine-free performance data of sleep-deprived individuals in the model by Benitez (2009) is not known.

Therefore, there are two approaches that may improve the development of individualised models. Firstly, knowledge of individual sleep deprivation sensitivity would optimise predictions on an individual level, and secondly, these novel techniques may enhance individual fatigue prediction without an understanding of individual physiological differences (Olofsen et al., 2010).

For example, the effects of sleep deprivation or caffeine, may show inter-individual differences that are genetically determined (Clark & Landolt, 2017). It is possible to predict individual differences with some baseline measures such as functional magnetic resonance imaging or polymorphisms in genes, but it is also possible to predict

performance without knowledge of an individual's physiology with so called statistical-Bayesian approaches that also suggest a new formulation of statistical models. These approaches involve some features of other machine learning algorithms such as Bayesian statistical modelling that use a small amount of an individual's performance data and relate them to the variability in performance profiles of a population sample from the laboratory or field experiment with some degree of prediction (Van Dongen et al., 2007). The observation of sleep-deprived individuals during a sustained operation is combined with the information previously estimated from the population average and allows for reliable predictions of future performance (Olofsen et al., 2010).

Moreover, the development of neurobiological research still needs to be further explored to better understand the interaction of sleep-wake homeostatic process and circadian process. A neurobiological model of a human two-process model of sleep regulation could identify individual differences through the physiological parameters (Borbély, 1982). Furthermore, it is not clear how individual differences are affected in these two processes (Olofsen et al., 2010). As previously mentioned, individualised models could provide more accurate fatigue and performance predictions than population average models, but even in individualised prediction models, little is known about variation of cognitive capability such as "problem solving" and "decision making" (Olofsen et al., 2010). The degree of individual vulnerability to sleep loss in operational environment is not known and, therefore, it is impossible to predict performance accurately. With the Bayesian forecasting procedure that is used in the two-process model of sleep regulation and predicts performance through the sleep homeostatic process and circadian process is possible to predict individual cognitive performance impairment (Van Dongen et al., 2007). Moreover, the study that examined 21 adults with 36 hours of sleep deprivation with the PVT test (Dinges & Powell, 1986; Olofsen et al., 2010), and the SAST-Serial Addition/Subtraction Task test showed that performance predictions do not translate well from one performance task to the other. The performance predictions in one cognitive domain differ from the other cognitive domain.

In a comparison of bio-mathematical models to other models related to the effects of external time cues called “zeitgebers” that depend on the time of their presentation, physiological implications, and different circadian oscillators, there was an acknowledgement that the sleep-wake homeostatic process can affect the circadian oscillator as an internal “zeitgeber” has been implied and thus the homeostatic process can be affected by external influences.

Moreover, the two-process model was applied as well as in animal sleep research studies (Borbély, 1982), in a neurochemical correlate e.g., (Borbély, 1982; Koski, 1971; Krueger et al., 1982), and in an evolutionary implication (Borbély, 1982).

To sum up, neurobehavioral functions are affected by several factors such as the dynamic interaction between the circadian rhythm and sleep homeostatic processes including masking factors such as stress, boredom, adverse environmental conditions, and stimulant drugs. Therefore, it is crucial to identify biomarkers (e.g., individual variability, environmental influences, and gender differences) that predict human performance and alertness in case of the circadian and homeostatic disruption (Goel et al., 2014).

2.7.4 The three-process model of sleep regulation

The three-process model of sleep regulation (Akerstedt & Folkard, 1995; Folkard, 2014) is an upgrade of the Borbely’s two-process model. Apart from incorporating the circadian process and homeostatic processes, it also incorporates a third parameter, which is sleep inertia (process W). Sleep inertia is a process of temporarily impaired performance, which happens immediately after awakening, and its effects depend on the depth of sleep at the time of awakening. Sleep inertia is also affected by both the circadian and homeostatic processes (Hursh et al., 2017). Moreover, it takes an average of 30 minutes for individuals to recuperate from sleep inertia and return to work tasks (Tassi & Muzet, 2000). According to several research studies, sleep inertia is most significant when individuals are awakened during slow-wave sleep. Usually, it is common in a work setting where employees take naps and may have to perform immediately on

awakening, for example in operational contexts, however sleep inertia is not always included in all bio-mathematical models (Åkerstedt, Folkard, et al., 2004; Dawson et al., 2011; Hursh et al., 2017; Mallis et al., 2004).

For example, the epidemiological study of the impact of sleep insomnia on the perceived physical and psychological health, which compared 209 employees working on night and rotating shifts and 209 employees working on day shift. Both groups of employees who reported with insomnia problems, presented a similar sleep pattern. The employees were complaining about anxiety, depression, and fatigue. Therefore, this study highlights sleep insomnia as an important part of the sleep irregularities experienced by shift workers, which interfere with the quality of their life, work, and overall well-being (Vallières et al., 2014).

In the most three-process models, the rate and severity of cognitive performance degradation are assumed to be independent of the type of activities carried out during wakefulness. Performance and alertness decrease as a function of increasing time on tasks, increasing flight segments during duty period, consecutive shiftwork duty periods, and other factors (Hursh et al., 2017). Cognitive performance and alertness are dependent on a combination of the circadian and homeostatic processes, as well as sleep inertia (Van Dongen & Dinges, 2005).

By taking a meta-view of the discipline, the moves of bio-mathematical modelling and monitoring can be seen as an improvement from the earlier models, but as previously mentioned, a human understanding of the link between fatigue and complex workplace behaviours remains the same.

Darwent (2012) explained in one of his research studies the extent to which psychosocial determinants modify the timing and duration of sleep-wake behaviour and he called for a greater understanding of individual differences related to sleep-wake behaviour and recovery (Darwent et al., 2012a). Genetic differences at the physiological level could identify an individual's level of fatigue and therefore improve the bio-mathematical models, which may be reflected in the relative contribution of individual differences in

sleep homeostatic and circadian processes. This was already showed by one researcher (Van Dongen et al., 2012). His ideas challenged the researcher named Dorrian, especially the genetic ones, who used the long-haul flight data of the same routes and layovers, but on different occasions and showed that the individual differences are not consistent across the time (Dorrian et al., 2012).

2.7.5 Bio-mathematical models and their limitations

There are currently several available bio-mathematical models of human fatigue and performance applied within the aviation industry. Different user-friendly software programs have been developed and then have become a part of an organisational FRMS, but not as an essential element and with several limitations. The users need to have a good knowledge of the capabilities and limitations of the bio-mathematical models to use them correctly and especially with great caution (CASA, 2014). Some of the most important limitations of the models that are currently available relate to restrictions on predicting fatigue risk for an average population rather than precise measures of an individual's fatigue, performance, and alertness level. Moreover, limitations relate to the misinterpretation of qualitative data as the quantitative one, the insufficient description of all fatigue physiological factors, and the limited validation against aviation specific data. This is because they cannot be entirely applicable in the real-time settings. The models can however consider several factors, including circadian and homeostatic processes, additional fatigue-related inputs related to changes in time zones, the number of flight sectors within a duty cycle, frequency and duration of scheduled breaks and the individual characteristics such as circadian chronotype, habitual sleep length, and commuting time. All these factors can complement the essential inputs, but there are still several factors that cannot be considered. For example, there can be very important gaps in fatigue prediction processes because of demographic factors such as health status, age, lifestyle, gender, and characteristics of the personality. In the case of when a specific individual's fatigue level is required, other tools to assess fatigue may be used (e.g., neurobehavioral tests) (CASA, 2014).

Furthermore, the limitations were primarily discussed at the international Fatigue and Performance Modelling Workshop in 2002. As bio-mathematical models are continuously evolving and their user area has been expanding it is very important for the users to understand the bio-mathematical models' limitations (Dinges, 2004; Mallis et al., 2004). Some of the limitations are related to accuracy of model predictions and ecological validity of findings. The accuracy of model inputs that rely on a variety of techniques to obtain data on sleep-wake behaviour, for example through the wrist actigraphy (i.e., Actiwatch), sleep diaries, and algorithmic sleep estimator, are the basis for further model accuracy (Hursh et al., 2017).

As a part of the Fatigue and Performance Workshop there were several sleep, wake, and work research scenarios including extended wakefulness with or without naps, partial sleep deprivation, alertness in freight locomotive engineers, ultra-long range flight operations, and sleep restriction followed by three-day recovery period. Scenarios were compared by model predictions and experimental data of performance and fatigue. The results of these research scenarios based on a laboratory and field settings showed several missing links between the complexity of the neurobiology of fatigue and performance, effects of chronic sleep loss, the use of countermeasures such as caffeine intake, light exposure, and gaps in understanding inter-individual differences. The results called for continued development, validation, and operational transition of bio-mathematical predictive models to develop reliable predictive tools for accurate performance and fatigue predictions (Dongen, 2004).

To summarise, the bio-mathematical fatigue model inputs are essential due to their ability to enable the models to determine output predictions. The minimum input requirements are data on the work-rest schedule and/or sleep-wake data. The models should not be used beyond their range of validity, and they should provide estimates of fatigue and performance impairments (Dinges, 2004).

2.8 Most Commonly Used Bio-Mathematical Models of Neurobehavioral Performance

The Fatigue Risk Index (FRI) and the Fatigue Assessment Tool by Inter Dynamics (FAID) are classified as the only two-step approach models, while all the other models, such as the Circadian Alertness Simulator (CAS), System for Aircrew Fatigue Evaluation (SAFE), Boeing Alertness Model (BAM), Sleep Wake Predictor (SWP), and Sleep, Activity, and Task Effectiveness Model and associated Fatigue Avoidance Scheduling Tool (SAFTE-FAST), are the one-step approach models.

2.8.1 The Fatigue Risk Index model-FRI

This model compares different work schedule scenarios for the likelihood of a high level of sleepiness and the relative risk of an error resulting in a possible adverse safety outcome (CASA, 2014). The model was primarily designed to compare different work schedules and to examine the potential impact of a change to one characteristic (e.g., shift change over time) of a specific work schedule. For example, the Fatigue Risk Index was used to estimate the risk of occupational detrimental safety outcomes in several commonly used rotating shift systems, with and without night shifts, compared to an average estimate obtained in epidemiological studies. The results showed 18% of an increased risk for the rotation shifts excluding night shifts, and 30% of an increased risk for the rotating shifts including night work (CASA, 2014; Tucker et al., 2012). The fatigue associated with any particular shift within a given work schedule, which is an estimate of the potential risk of an accident or injury that can happen, may be identified by the model (Folkard et al., 2007). It incorporates the Fatigue Index and the Risk Index. This model is an exception, based on empirical data from shiftwork and developed based on the three components such as the cumulative component, duty-timing component and job type, and work breaks component. For example, the FRI is being extensively used for dispatchers and maintenance engineers in health and emergency settings, rail industry and nuclear power. The model was used in various sectors among Network Rail and Highways England which adopted Health, Safety and Environment (HSE) approach and supported by the FRI. However, the model has been criticised for the misused cases to

justify work patterns requiring further action reducing the fatigue related risks (Cabon et al., 2012; Executivee, 2006). As a result of this, the alternative models have been proposed by the Australian Civil Aviation Safety Authority and United Kingdom Rails Safety and Standards Board such as FAID, CAS, SAFTE-FAST, and SWP.

2.8.2 The Fatigue Assessment Tool by Inter Dynamics model-FAID

The model estimates fatigue exposure associated with hours of work; therefore, it predicts worker's fatigue directly from shiftwork schedules. Moreover, it estimates the risk of fatigue-induced errors. It considers the start and end times of shiftwork, previous work periods, the circadian process in case of time-zone travel, but it does not use the time of sleep, nor sleep inertia effects as an input (Mallis et al., 2004; Roach et al., 2004). The Fatigue Assessment Tool by Inter Dynamics is a two-process model, which means it is less flexible in reflecting individual personalities, and it does not consider sleep inertia effects (Roach et al., 2004). Although it does enable organisations to consent to occupational health and safety legislation, the countermeasures are not directly evaluated by the model. However, the model provides intra-shift displays to enable targeted risk mitigation strategies, such as light exposure and napping. The important consideration is that the fatigue reduction linked to the light exposure countermeasures is not calculated and does not identify the times of the highest risk within a given shiftwork schedule (CASA, 2014). Roach reported that the model's purpose was to support regulators, accident investigators, and shiftwork (Roach et al., 2004). Moreover, it has been extensively used, parameterised, and validated in aviation and rail industry (McCauley et al., 2021). For example, it has been used by the Australian Transport Safety Bureau, Qantas maintenance engineers, Queensland Rail, and Australian Western Railroad (Mallis et al., 2004; Roach et al., 2004). It has been used in the United States of America, the United Kingdom, Canada, South-East Asia, and South Africa (Fast et al., 2014; Miller, 2014b).

For example, the FAID model was used to generate fatigue levels in one of a series of research studies (Darwent et al., 2015) conducted on Australian train and tram drivers to enhance bio-mathematical models and to use fatigue models as potential tools for

mitigating risks through the identification of work shifts where employees may be sleep deprived (Darwent et al., 2015). The FAID model algorithms (Dean et al., 2007a) are widely used in Australian rail industry (Roach et al., 2004). Moreover, the model provides operators to actively monitor, evaluate, and analyse working hours that are exposed to fatigue (Mushenko, 2014), and has been reliable on predicting the effects of cumulative fatigue. Another example relates to the occupational police stress study predicting police officers' sleep-wake behaviours by FAID and demonstrates high level of sensitivity with the actual sleep-wake behaviours (McCauley et al., 2021). There are some limitations concerning the use of FAID (IATA, n.d.) such as the cost, and not considering sleep inertia effects. Also, the mitigation strategies for reducing FAID scores are limited to changing work schedules in concern to their timing and length, due to the fatigue exposure of FAID arising from hours of work. Moreover, the limitations are related to number of sectors, commute times and some more factors.

2.8.3 The Boeing Alertness Model-BAM

The model by Jeppesen (*Fatigue-in-Aviation*, n.d.) is designed for application in the aviation industry and based on the three-process model of alertness in complex crew management, expanded with sophisticated sleep prediction, augmentation, task load, and the capacity to consider actual sleep and wake data when available. The model can interrelate with the industry through the strength of crew optimisers; therefore, it is useful for pairing and roster optimising during the planning phase as well as for post-analysis of duty schedules.

Moreover, it has the ability to support the evaluation of countermeasures such as light exposure and napping. The model automatically generates the appropriate fatigue mitigation strategies, including sleep/wake pattern and timings for light exposure. In addition, it allows some individualised data as an input to improve fatigue, performance, and alertness prediction, therefore, the outputs are more individualised. Individual fatigue monitoring and data collecting are possible through the associated iPhone/iPad application and CrewAlert application (CASA, 2014).

The ability of the Boeing Alertness Model (BAM) to correctly predict fatigue risk by utilising data from physiological tools and flight performance was intended by the study of fatigue detection in commercial aviation (Thomas et al., 2015). This study revealed that reliable indicators of sleepiness and fatigue are combined subjective and objective measures, although the study is critical to the traditional objective measure psychomotor vigilance test as it did not reflect the anticipated levels of fatigue, and it addresses caution against reliance on subjective ratings or metrics like PVT. The BAM model is known to collect data from individual pilots and generate schedules to reduce pilots' fatigue risks and, therefore, helps to identify an individual's perception of a situation. As a result, it helps to explain and understand humans' behaviour.

2.8.4 The System for Aircrew Fatigue Evaluation model-SAFE

The SAFE model was primarily developed by the Defence Evaluation and Research Agency (DERA) for the use in the United Kingdom Civil Aviation Authority in the 1990s (CASA, 2014; Mallis et al., 2004; Powell et al., 2014). The SAFE model has a two-process approach that considers self-reported sleep-wake histories as an input and evaluates risks associated with work schedule in the civil aviation industry. It is an effective fatigue predictive tool in all types of civil aviation operations and is also suitable for ultra-long range flight operations. For example, the SAFE model was used to estimate and determine the optimal rest timing and its duration for the crew on the first ultra-long-range aircraft from Singapore to Los Angeles, and from Singapore to New York (Spencer & Robertson, 2007). Spencer and Robertson highlighted the role of the SAFE model evaluating the impact on alertness of ultra-long-range operations and concluded that the model effectively predicted the trends in fatigue all the way through the flight. On the other hand, the model failed to predict the rapid increase in fatigue between top of descent and the end of duty, as well as any individual differences (Spencer & Robertson, 2007). Overall, the model is used for providing advice on fatigue and scheduling in the transportation industry, and in regulating the work duty hours (Mallis et al., 2004).

2.8.5 The Sleep, Activity, Fatigue and Task Effectiveness Model (SAFTE), an associated Fatigue Avoidance Scheduling Tool model (FAST)

The SAFTE model is a three-process, quantitative model of human cognitive performance, which predicts fatigue combining circadian oscillator, homeostatic sleep reservoir, and sleep inertia (see Figure 2-4) (Hursh et al., 2004; IATA, n.d.; Mallis et al., 2004). The main inputs of the model are the sleep-wake history based on actigraphic data collected with the wrist actigraphy, self-reported or estimated shift timing and duration of work shifts, and time of day factors for predicting neurobehavioral performance. The latter is determined by a linear combination of circadian rhythm, sleep homeostasis, and sleep inertia by using Psychomotor Vigilance Task (PVT), showing the extensive vulnerability to daily sleep quantity. A traditional psychomotor vigilance task is a ten-minute reaction time task to complete, which requires subjects to react as quickly as possible at random intervals from two to ten seconds. The most widely used version is a five-minute PVT on a smart phone (DigitalCommons et al., n.d.). The limitation of the PVT is that it does not measure important skills such as situation awareness and decision-making.

The model does not account for the effects of physical work, social and other non-biological constraints on sleep (Hursh et al., 2017) but it does account for time zone changes and individual differences such as circadian chronotype and sleep quality (McCulloh, Baker, Ferguson, Fletcher, 2007). It was primarily developed for the use in industrial settings and military operations in the United States Armed Forces and the United States Department of Defence as well as in the Department for Transportation. Moreover, it was used by Federal Aviation Administration (FAA) for regulatory objectives. The model is particular in its capabilities to capture the fatiguing effects of chronic sleep deprivation and irregular sleep times and quantities (Rangan & Van Dongen, 2013). It was the first model to address the issue of the long-lasting effects of chronic sleep restrictions suggesting that some characteristics of homeostatic process are subjected to slow recovery (Ramakrishnan et al., 2015). Furthermore, the model has a sleep reservoir representing homeostatic process and when chronic sleep deprivation

occurs, the sleep reservoir steadily decreases. The SAFTE model is commonly used to predict performance (Dean et al., 2007b) and it captures sleep quality that is regulated by the circadian process and sleep accumulation.

Moreover, the SAFTE model was applied to one of the biggest studies on fatigue safety thresholds in the railroad industry including on average 1,400 railroad accidents caused by both human and non-human factors, (Hursh, Kaye, Fanzone, 2008; Raslear et al., 2011), to help predict an operators' performance level when accidents occurred. The SAFTE considered inputs such as the work schedules and estimated sleep opportunities of employees, and the results showed a strong link between poorly predicted employees' effectiveness and the risk of negative safety outcome. Therefore, a specific metric of performance such as cognitive effectiveness for the assessment of neurobehavioral performance in real-world settings was developed (Hursh & Balkin, 2004).

Another study of fatigue prediction, using the SAFTE model was related to the landing phases of long-range and ultra-long-range flight operations. This study suggested that long-range flight performance prediction thresholds may also be used for ultra-long-range operations due to their high historical safety records that could form a credible fatigue threshold for a specific work groups' environment in each industry (Van Dongen & Belenky, 2009). Consideration about using historical safety data needs to be taken with great caution as there is a variety of environments and types of operations, and their differences should be applied when interacting with past safety records.

The SAFTE model has been linked to the subsequently developed FAST model. The FAST model optimises the operational management of aviation ground and flight crew. The model provides visual and quantitative evaluation of the effects on the cognitive performance effectiveness and comparing any number of sleep/wake schedules simultaneously. It was developed initially for the United States Air Force to deal with Air Force scheduling issues; to estimate the fatigue effects of different work schedules on human cognitive performance and it was used to validate in-flight naps to maintain

performance of Air Force bomber crews (Hursh et al., 2004). Furthermore, it was developed specifically for the application of it in the aviation industry to provide the aviation operators with future predictions (i.e., up to three weeks) on the level of fatigue and subsequent proactive mitigation strategies to decrease the likelihood of fatigue-related risks. The model distinguishes between the safety critical work events and other events, and it considers sleep disorders caused by environmental factors (e. g., effects of lighting, the quality of in-flight rest facility, long haul trans-meridian flight operations). On the other hand, the model is not able to consider individual characteristics, but only data on average population and that is its limitation (Hursh & Balkin, 2004; Mallis et al., 2004). For military application, the FAST model considers restricted amounts of sleep to optimise performance and diminishes the need for pharmacological agents. Furthermore, it anticipates fatigue effects on performance and therefore allows for guidelines of the crew during the performance of the mission (Hursh et al., 2004). In addition, there are several FAST model users such as Federal Railroad Administration, Federal Aviation Administration (FAA) and National Transportation Safety Board (NTSB). Military operations commonly employ extended working time because of reduced personnel strength, therefore, an appropriate schedule to avoid fatigue is crucial. The FAST can be used as a retrospective as well as a predictive performance tool, but it does not get at the heart of the problem of how to reduce fatigue in military operations and to improve their sleep patterns and overall quality of life (Miller et al., 2007). For example, lack of sleep was evident in military aviation deployments in Haiti, Somalia, Bosnia, and Kuwait. Furthermore, another study investigated the SAFTE-FAST model of performance predictions for civil aviation cabin crew, compromised with the PVT test sessions. The results of this study distinctly supported the validity of the SAFTE model in relation to fatigue predictions in neurobehavioral performance capability (Roma et al., 2012).

Additionally, the model can analyse many different work schedules and evaluate how the level of fatigue at work is affected by them (McCulloh, Baker, Ferguson, Fletcher, Marcil, Booth-Bourdeau, Laurence, 2007).

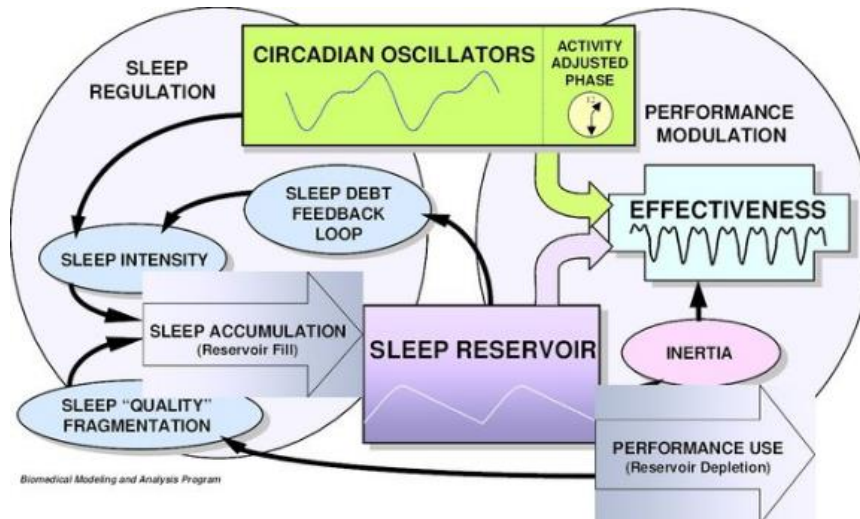


Figure 2-4 Block diagram of SAFTE Model (Hursh et al., 2004)

2.8.6 The Sleep/Wake Predictor model-SWP

The SWP model is based on the three-process model of alertness meaning that it also considers information about sleep inertia's impact on performance and fatigue. The model has been applied in different settings, such as aviation, railways, roads, maritime, nuclear power, and military environments. The software of the model forecasts alertness by estimating the level of sleepiness linked to changes in circadian rhythm and homeostatic processes, with the objective of supporting the assessment of the overall impacts of work schedules. One of the key characteristics used to predict the level of fatigue for work schedule is the data on work and sleep time where sleepiness exceeds the critical limits. This model has been used by sleep researchers, regulators, government organisations responsible for safety, health, and work regulations (Åkerstedt, Folkard, et al., 2004; Dawson et al., 2011; Mallis et al., 2004).

2.8.7 The Circadian Alertness Simulator-CAS

The model is specifically designed for crew planning and is highly sensitive in estimating the possibility of human error. It was primarily designed for its use in 24/7 transportation industry operations and tailored for irregular work schedules (Dawson et al., 2011; Mallis et al., 2004; Moore-Ede et al., 2004). Additionally, it is the longest operationally used model in a wide variety of industry utilisations, providing fatigue risk model for

reducing errors, injuries, incidents, and accidents. The model works on the principle of analysing data like timing, sleep quality, and duration before and after the duty-rest schedule. It uses a three-process model combining homeostatic and circadian factors, along with sleep inertia, and getting an output-fatigue risk score between 0 and 100, where the higher the score is, the higher the fatigue risk is. The following three zones indicate the level of fatigue identified/predicted, enable the assessment of the risk and then the appropriate measures to take to decrease fatigue level and/or prevent safety related incidents.

Low fatigue risk: 0-30

Average fatigue risk: 31-55

High fatigue risk: 56-100



Figure 2-5. The Circadian Simulator (CAS) (Circadian Technologies, 2013)

CAS (see Figure 2-5) has been used for a wide variety of operations in research and consulting projects that both identify fatigued employees and enable risk-informed decisions, supports risk-informed, and performance-based safety culture (Sabzevari Rad et al., 2021). Table 2-1 shows the comparison of models' most common characteristics (CASA, 2014).

Table 2-1. Comparison of Models Characteristics. Key: YES, meets characteristic criterion (CASA, 2014)

Comparison of Models Characteristics							
Characteristics	FRI	FAID	BAM	SAFE	SAFTE-FAST	SWP	CAS
Capacity to estimate actual sleep/wake times		YES	YES	YES	YES	YES	YES
Capacity to consider workload	YES	YES	YES	YES	YES		YES
Capacity to consider commuting	YES	YES	YES	YES	YES		YES
Capacity to integrate time-zone changes		YES	YES		YES	YES	YES
Capacity to integrate individual-specific data			YES	YES		YES	YES
Capacity to output fatigue-related task errors					YES	YES	YES
Capacity to output fatigue-related risk of operational adverse safety outcomes	YES	YES			YES	YES	YES
Capacity to output performance estimates		YES			YES	YES	YES
Applicable to forward scheduling	YES	YES	YES	YES	YES	YES	YES
Applicable to non-scheduled and irregular operations	YES	YES	YES	YES	YES	YES	YES
Applicable to individual fatigue prediction			YES	YES		YES	YES
Validated for the use in aviation	YES	YES	YES	YES	YES	YES	YES

The researched Air Force unit in this thesis does not use any of the above mentioned biomathematical models in identifying fatigue among crew members. The use of the most appropriate biomathematical fatigue model would probably both significantly increase fatigue level prediction and reduce it daily in the Air Force operations. The model that would best suit the researched Air Force unit depends on the operational environment and its requirements. For example, the SAFTE-FAST model can be used by military aviation for identifying fatigue factors such as recent sleep timing, continuous hours awake, cumulative sleep debt, time on task/workload. The model estimates the level of performance degradation. Furthermore, the SAFTE model has been used by United States Air Force as the war fighter fatigue model predicting sleep pattern and duration while FAST was developed for the United States Air Force and the United States Army to estimate sleep algorithm with features of graphical analysis tools, a dashboard of fatigue factors and data-based effectiveness scores. FAST is being used for accurate

estimation of sleep including considering time zone changes (see Figure 2-6). The model also provides a dashboard of information concerning sleep (last 24 hours) such as; chronic sleep debt, hours awake, time of day, out of phase, performance values (e.g., effectiveness, reaction time etc.).

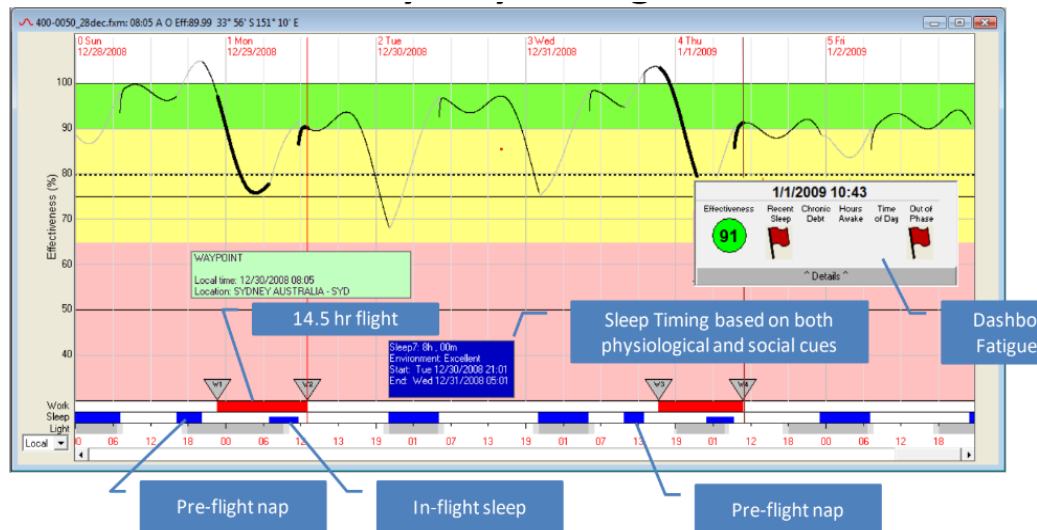


Figure 2-6. FAST aviation analyser example (Raslear et al. 2011)

2.8.8 Summary

Bio-mathematical models are being increasingly used in the airline operations to predict fatigue and performance levels and are suggested as a potential component of an organisational FRMS (Powell et al., 2014). A subjective scale is generally used to express the values of fatigue and alertness. The most prevalent examples of such scales in the aviation industry are the Karolinska Sleepiness Scale-KSS (CASA, 2014), and the Samn-Perelli fatigue scale-SP (CASA, 2014; Samn & Perelli, 1982). A study of Air New Zealand (Powell et al., 2014) compared in-flight fatigue predictions of pilots by using the bio-mathematical model SAFE and observed fatigue measures across a number of in-flight operations. A study that collected different data on subjective fatigue and sleepiness ratings used the Samn-Perelli fatigue scale and Karolinska Sleepiness Scale, and the performance was measured through the Pilot Alertness Test, which is very similar to the PVT measurement of reaction time task. The SAFE model considered inputs such as the duty starts and end times, the start and end duty locations, the number of sectors flown,

the number of flight crew members, the type of in-flight rest facility, and the number of rest periods during the flight operations. The subjective fatigue ratings between predicted and observed fatigue were higher than the reaction time measurements. The model overestimated subjective fatigue toward the start of a duty period and underestimated it at the end of duty periods. Moreover, fatigue levels were overestimated during the morning and underestimated during the evening. The fatigue associated with the length of the duty was overestimated as well. A possible explanation for differences between predicted and observed fatigue in this study could be the model's predictions that pilots are fully rested prior duty, light exposure changes during duty period, cockpit napping or in-flight napping, and time zone changes in ultra-long flight operations.

Overall, this study represents a common problem of the FRMS in airline operations and there is a need for further research studies that make comparisons between predicted and observed fatigue within the industry (Powell et al., 2014).

Another example is the FedEx around-the-clock and across-time-zones operations with the FRMS implementation and integrated model-based fatigue and alertness prediction software in place (Rangan & Van Dongen, 2013). It considers data on human performance and alertness to improve scheduling solutions, and its effectiveness and general pilot alertness and performance. The International Civil Aviation Organisation described bio-mathematical modelling as both a predictive and reactive hazard identification approach to fatigue management and as an optional component of the FRMS to predict fatigue hazard risk (Sprajcer et al., 2022). Like the ICAO approach, the models may also be useful in prospective and retroactive analyses of duty schedules that would consider both past and future impacts and predictions on scheduling solutions and fatigue (James et al., 2018).

The literature on bio-mathematical modelling is restricted to the critical elements of its evaluation of effectiveness despite the use of models being employed by a growing number of operators in a real-world setting. Data that may be informative about the

models' effectiveness does exist but due to its restricted and confidential nature it is not available for analysis and publication. Therefore, it is mandatory to further explore and spread the use of bio-mathematical models across a variety of industries and make more data accessible to researchers to improve the models and their effectiveness (James et al., 2018). Moreover, the bio-mathematical models do not distinguish between different cognitive skills such as decision-making, attention, memory, or language (Balkin, 2012).

Finally, connections between fatigue and safety occurrences in various work environments have been identified by many researchers (Åkerstedt, Folkard, et al., 2004; CASA, 2014; Hobbs & Williamson, 2003; Lenné et al., 1997; Mitler et al., 1988; Williamson et al., 2011). Detrimental safety outcomes are also contributed by fatigue, which is challenging to prove. Therefore, it is difficult and problematic to establish an accurate causal, evidence-based relationship between fatigue and safety. The use of bio-mathematical models for improving this complex relationship is also very difficult, especially in the aviation industry.

2.9 Discussion

The literature review identified a gap in the limited literature on military aviation that focuses on individual components and fatigue-related factors, as well as a lack of literature on European military aviation. Another gap is the ununified definition of fatigue across different settings. From the industry perspective, there is currently no FRMS system in place in any of the European air forces, along with several barriers towards an effective reporting culture, including how fatigue is monitored and reported. Additionally, numerous fatigue measurement tools available lack validity and reliability.

The fatigue risk management system is gaining in its momentum in safety-sensitive industries, which have been continuously mitigating the fatigue-related hazards and implementing several countermeasures to manage and mitigate fatigue (Caldwell et al., 2009a). The amount of research conducted into transportation systems is varied but limited in specific industries such as, for example, military aviation. The reason for that may be the nature of military operations, which is extremely safety-sensitive, restricted,

and mostly confidential. The available literature on the FRMS in military aviation is focusing mainly on individual FRMS components and fatigue-related factors such as scheduling practices, fatigue-proofing strategies, deployment issues, circadian desynchronisation, and homeostatic processes, while the literature on civilian aviation FRMS is describing all the components of the FRMS including its development and implementation processes and is available for further exploration and examination. A literature review identified a gap in the limited literature available on developing and implementing the FRMS in military aviation, including a military specific fatigue reporting system.

The available research has distinguished the interaction of factors influencing fatigue, for example, sleep deprivation, which reduces cognitive, physiological, and behavioural functions (Casini et al., 2013), as well as circadian rhythm which may clearly contribute to fatigue levels (Williamson & Friswell, 2013). One of the studies (Mitler et al., 1988) specified the need to identify performance functions that are sensitive to fatigue and to react quickly to prevent the threatening risk of fatigue-related errors, as well as the need to identify and prevent dysfunctional fatigue-reduction strategies that are not appropriate and may result in adverse safety outcomes.

The FRMS as a proactive approach to safety is flexible and data-driven, and usually as a part of an organisational SMS (Safety Management System), complements existing SMS to improve safety and fatigue as part of the overall operational system (Balkin et al., 2011; Gander et al., 2011; ICAO, 2016). Moreover, the FRMS incorporates fatigue hazard control mechanisms in the fatigue risk trajectory, which consists of five levels (see Figure 2-1). First, there is a need to ensure that employees have enough opportunities to sleep, as sufficient sleep (e.g., night-time sleep) is the optimal method of avoiding fatigue and the need to verify the amount of sleep that employees obtain. Furthermore, a symptoms checklist, behavioural scales, self-reporting, and physiological monitoring are needed to be in place to identify fatigue-related symptoms and mitigate them through fatigue-proofing strategies to prevent potential fatigue-related errors (Baker & Dawson, 2007b, 2007a). Moreover, fatigue-proofing strategies that have been developed spontaneously

and informally within an organisation, require a highly resilient SMS including an open organisational culture and the evaluated effective strategies, which must be standardised and documented as a formal part of an SMS. The latter assures that inappropriate and dysfunctional strategies are not used and, therefore, the avoidance of fatigue-related errors (Dawson et al., 2012; Folkard & Tucker, 2003).

Moreover, the FRMS approach consists of both organisational and operational activities. Organisational activities refer to FRMS policy and documentation processes and promotion processes, while operational activities form the core of the FRMS and refer to FRM processes and FRMS safety assurance processes. Both have an important role in identifying fatigue hazards. The research in this study focuses on modelling/measuring fatigue in the selected Air Force base. One of the roles of the FRMS safety assurance processes is to monitor if the overall system is functioning in terms of delivering defined safety objectives in FRMS policy as well as form an additional layer in defence against fatigue-related risk (Gander et al., 2011; ICAO, 2016; Williamson et al., 2011).

As previously mentioned, each organisation operates individually and specifically in its operational and organisational context. Therefore, an individual approach to develop the specific FRMS and therefore specific fatigue report form within a given operation(s) is required. For example, the FRMS of a specific commercial airline company should not be applied directly to another commercial airline company without tailoring it to its specific needs and complexity. Hence, a caution should be taken when developing and implementing the FRMS within the same or various operational settings. The ICAO has proposed a framework for developing and implementing FRMS including detailed instructions on implementation process and explanation on each component of the FRMS (ICAO, 2016). To develop and implement the FRMS including the fatigue report form in military aviation, the ICAO model could be used as a framework with appropriate modifications to its specific safety-sensitive operations and culture. A literature review identified a gap in exploring FRMS as a whole instead of individual components and fatigue-related factors in military aviation.

The development of fatigue predicting tools such as bio-mathematical models improved the understanding of circadian and homeostatic processes. The aim of the model is to predict fatigue and performance levels through the evaluation of effectiveness of different scheduling practices and by combining data on sleep, wake, and performance. Models have been used as predictive, proactive as well as reactive components in fatigue hazard identification processes in an organisational FRMS (Powell et al., 2014). Despite models being employed by a number of operators, the literature on bio-mathematical modelling is limited and has identified a gap in its evaluation of effectiveness. Therefore, more data should be accessible to researchers to improve the models and its effectiveness (James et al., 2018). One of the models that has been widely used in both the civilian and military aviation industry is the SAFTE-FAST model. As previously mentioned, the SAFTE was developed for the use in industrial settings and military operations, whereas FAST was developed specifically for the application in both the civilian and military aviation industries to predict the levels of fatigue and subsequent mitigation strategies to decrease the likelihood of fatigue-related risks. The SAFTE model was used in many research studies (CASA, 2014; Dean et al., 2007b; Hursh, Kaye, Fanzone, 2008; Hursh et al., 2004, 2017; Hursh & Balkin, 2004; Mallis et al., 2004; McCulloch; Baker; Ferguson; Fletcher; Dawson; Marcil; Booth-Bourdeau; Laurence, 2007; Miller et al., 2007; NATO, 2001; Rangan & Van Dongen, 2013; Raslear et al., 2011; Roma et al., 2012) as a useful tool for predicting fatigue. Whenever using bio-mathematical models, caution should be taken as they are just one component of the FRMS, and users should not solely rely on these models when predicting fatigue and performance.

An alternative assessment tool to the bio-mathematical models is a Fatigue Likelihood Scoring (IFLS) matrix for work rostering. The matrix is based on the total hours worked over a seven-day period; the maximum duration of a single shift, the minimum duration of a short break, the total number of hours worked between 9 p.m. and 9 a.m. in a seven-day period, and the frequency of long breaks (Baker & Dawson, 2007b). Moreover, this matrix is used for various categories of employees to assess sleep opportunity and its appropriate threshold values.

Furthermore, the literature doesn't distinguish between often interchangeable and commonly used terms of fatigue and sleepiness. There is evidence that people struggle to distinguish these terms due to poor understanding of the causes of tiredness-related performance decrements and there is a need for further clarity to be able to consider the whole impact of tiredness on performance (May & Baldwin, 2009; Phillips, 2015; Shahid et al., 2010).

Sleep can also be affected by fatigue, as it is sensitive and easily disrupted by conditions such as shiftwork, time zone changes, pharmacological agents, caffeine, alcohol, and poor sleep habits. A number of research studies on fatigue in both civilian and military aviation have been performed, which indicated an individual's differences in sleep deprivation due to variability in initial sleep pressure, vulnerability and responsiveness of the sleep homeostasis, and genetic factors (Dijk & Archer, 2010; Mairesse et al., 2014; Saksvik et al., 2011; Sookoian et al., 2007; Van Dongen & Belenky, 2009).

A literature review also identified various measurements to assess sleepiness objectively and subjectively, but the measurements lack validity and reliability, which are causing confusion in assessing and identifying sleepiness and reflecting the real-world situation. Research studies showed that the most widely used objective measurement on simulated tasks in aviation industry is the psychomotor vigilance task (PVT), while polysomnography (PSG) is known as the most trusted method, but it is an expensive, obtrusive, and time-consuming approach (Thomas et al., 2015). On the other hand, the KSS and Samn-Perelli Fatigue Scale are the most used subjective sleepiness and fatigue ratings with some limitations such as intentional falsification and unintended bias (Åkerstedt et al., 2005; Kaida et al., 2006; Samn & Perelli, 1982; Shahid et al., 2010). Moreover, research studies showed that the most reliable indicators of fatigue and sleepiness are combined subjective and objective measures (Thomas et al., 2015).

Shiftwork, deployments, time zone changes are causing circadian desynchronisation, therefore, people struggle to cope with several health issues. For example, it is known that sleep disorders due to night shiftwork may cause serious issues such as

cardiovascular diseases (Boivin & Boudreau, 2014; Knutsson, 2004), metabolic syndrome (Biggi et al., 2008; Boivin & Boudreau, 2014; Roberta et al., 2019; Wang et al., 2015), obesity (Roberta et al., 2019; van der Beek et al., 2016; van Drongelen et al., 2011), and psychological disorders (Boivin & Boudreau, 2014; Lee et al., 2017; Roberta et al., 2019).

One of the main objectives of this thesis was to develop a military-specific Fatigue Report Form for the selected military air base. Based on literature review, the initial specific Fatigue Report Form could be based on the ICAO Fatigue Report Form because there is no literature available on the military-specific Fatigue Report Form or overall FRMS. There are also no global set of rules related to military aviation as there are several regulations underpinned by ICAO principles in military aviation (e.g., ICAO-based Safety Management System). The Fatigue Report Form factors are being investigated throughout this thesis.

Fatigue Report Form

IF CONFIDENTIALITY REQUIRED TICK HERE ☐			
NAME <input style="width: 100px;" type="text"/>		Employee No. <input style="width: 100px;" type="text"/>	Pilot/CCM <input style="width: 50px;" type="text"/> (circle)
WHEN DID IT HAPPEN?		Local report date <input style="width: 100px;" type="text"/>	Time of event (local report time) <input style="width: 100px;" type="text"/>
Duty description (trip pattern) <input style="width: 100%; height: 20px;" type="text"/>			
Sector on which fatigue occurred		From <input style="width: 100px;" type="text"/>	To <input style="width: 100px;" type="text"/>
Hours from report time to when fatigue occurred <input style="width: 100px;" type="text"/>		Disrupt? Yes / No <input style="width: 50px;" type="text"/>	
Aircraft type <input style="width: 100px;" type="text"/>		Number of crew <input style="width: 50px;" type="text"/>	
WHAT HAPPENED?			
Describe how you felt (or what you observed) <input style="width: 100%; height: 20px;" type="text"/>			
Please circle how you felt			
1	Fully alert, wide awake	5	Moderately let down, tired
2	Very lively, somewhat responsive, but not at peak	6	Extremely tired, very difficult to concentrate
3	OK, somewhat fresh	7	Completely exhausted
4	A little tired, less than fresh		
Please mark the line below with an 'X' at the point that indicates how you felt			
<div style="display: flex; align-items: center;"> alert <div style="flex-grow: 1; border-bottom: 1px solid black; position: relative;"> <div style="position: absolute; left: 0; top: -5px; width: 100%;"></div> </div> drowsy </div>			
WHY DID IT HAPPEN?			
Fatigue prior to duty?		How long had you been awake when the	
Hotel	Yes / No <input style="width: 50px;" type="text"/>	event happened? <input style="width: 50px;" type="text"/> hrs <input style="width: 50px;" type="text"/> mins	
Home	Yes / No <input style="width: 50px;" type="text"/>	How much sleep did you have in the <u>24 hrs</u>	
Duty itself	Yes / No <input style="width: 50px;" type="text"/>	before the event? <input style="width: 50px;" type="text"/> hrs <input style="width: 50px;" type="text"/> mins	
In-flight rest	Yes / No <input style="width: 50px;" type="text"/>	How much sleep did you have in the <u>72 hrs</u>	
Disrupt	Yes / No <input style="width: 50px;" type="text"/>	before the event? <input style="width: 50px;" type="text"/> hrs <input style="width: 50px;" type="text"/> mins	
Personal	Yes / No <input style="width: 50px;" type="text"/>	flight deck nap? Yes / No <input style="width: 50px;" type="text"/>	If yes, when <input style="width: 50px;" type="text"/> start <input style="width: 50px;" type="text"/> end
Other comments <input style="width: 100%; height: 20px;" type="text"/>			
WHAT DID YOU DO? Actions taken to manage or reduce fatigue (for example, flight deck nap) <input style="width: 100%; height: 20px;" type="text"/>			
WHAT COULD BE DONE? Suggested corrective actions <input style="width: 100%; height: 20px;" type="text"/>			

Figure 2-7. ICAO Fatigue Risk Report Form (Fatigue Management Guide for Airline Operators, IATA, ICAO, IFALPA, 2015)

The ICAO Fatigue Report Form includes personal details, time of occurrence and flight details, occurrence details and alertness scale, causal factors and sleep evaluation, mitigation strategies, and actions suggested. Referring to FRMS, mitigation strategies are continuously assessed by safety performance indicators whether they deliver an expected level of risk reduction or not. Continuous monitoring of mitigation strategies is mandatory and if strategies do not perform as expected they have to re-enter FRM processes at the relevant level (e.g., to gather and analyse more data, re-evaluate already identified fatigue hazards, evaluate existing risk controls and mitigation strategies or maybe there is a need to introduce new risk controls and mitigation strategies). On the contrary, if mitigation strategies do perform as expected, they

become part of normal operations and are further monitored by the FRMS safety assurance processes.

The FRMS safety assurance processes form an additional layer of defence against fatigue-related risk in fatigue risk trajectory. The processes can also evaluate and monitor if the overall FRMS is functioning in terms of delivering organisational safety objectives defined in FRMS policy. Safety assurance processes collect and review data that was gathered through the FRM processes and evaluate the effectiveness of the FRMS against safety performance targets and safety performance indicators (SPIs). If safety performance targets are not met and SPIs are not at an appropriate level, then mitigation strategies and risk controls may need to be modified by re-entering the FRM processes. Moreover, safety assurance processes use SPIs to monitor fatigue trends over time, which can identify emerging fatigue hazards and fatigue hazards that were not recognised through the FRM processes. Additionally, there is a need to set safety thresholds for each identified Safety Performance Indicator (SPI), including the triggers for action(s). Furthermore, safety assurance processes can identify other potential fatigue hazards arising from changes in operational and/or organisational environment by using FRM processes. Each identified fatigue hazard requires risk assessment in FRM processes and development and implementation of risk controls and mitigation strategies, including SPIs. To improve effectiveness of the overall FRMS, the evaluation of each individual FRMS component is required by mandatory periodic evaluations of systems, procedures, equipment, facilities, and processes. Evaluations may identify that new systems, processes and procedures need to be introduced into the FRMS (ICAO, 2016).

Communication and training are an essential part of the FRMS; therefore, organisational FRMS promotion processes have a great value in providing and maintaining an appropriate safety culture within an organisation. A communication plan should communicate the FRMS objectives and procedures to all relevant stakeholders in the FRMS and assure that they are fully aware of the FRMS objectives and processes, and that they understand their responsibilities. Moreover, a communication plan should aim

to explain why, and which actions are taken, which fatigue-related safety procedures are introduced or modified, and it aims to introduce all fatigue-related information (ICAO, 2016). A crucial part of communication is appropriate feedback, as there is no effective communication without appropriate reporting mechanisms and associated feedback in place. This thesis investigates communication channels that may exist in the selected Air Force base including potential fatigue promotion brochures or any other form of the fatigue/sleep promotion.

Training programs and education plans are well-documented and so are validated processes that identify training requirements and measure their effectiveness. Programs are tailored individually to the specific group of employees or organisation to meet the needs and complexity of specific operation(s). It is known that education in military aviation is less robust than in civilian aviation, moreover, promotion of safety culture may be an additional issue in organisations, which operates without military airworthiness requirements. Consequently, more efforts are needed in military aviation to structure an appropriate education and training system. This thesis investigated fatigue and sleep trainings currently in place at the selected Air Force unit, their objectives, content, frequency, and targeted group of military air base employees.

To sum up, fatigue-related research in aviation industry has been numerous in civilian aviation and limited in military aviation, which highlights a gap in the literature on developing and implementing FRMS processes in military aviation including a Fatigue Report Form. Stressors like job requirements, high workload, scheduling practices, shiftwork, deployments, sustained/continuous operations, and individual characteristics have been shown to be present in both civilian and military aviation industry, having detrimental effects on performance and alertness. Based on literature review, there are still many questions regarding fatigue and its impact on operational performance and overall safety that need further assessment and exploration. For example:

- The complex interactions between fatigue and safety in relation with, sleep, nature of the work itself, and individual's response to fatigue,

- Modelling and predicting fatigue, improvements in bio-mathematical modelling of the critical elements of its evaluation of effectiveness and inability to distinguish between different cognitive skills such as attention and decision-making,
- Development and implementation of the military specific FRMS and fatigue reduction in military aviation (e.g., processes, framework, common set of SPIs),
- Fatigue assessing, indicating, and monitoring strategies and tools, and their improvement regarding validity and reliability.

The research objectives and questions for this thesis explore and assess some of these fatigue-related questions. In particular, this thesis's objectives and research questions are as follows:

Objective (O) 1: To examine the prevalent fatigue stressors and countermeasures within military operations at the selected air base.

Fatigue stressors and countermeasures are important indicators when assessing fatigue and they help us to understand an occurrence, reducing fatigue, and improving the operational performance. Through a different research study, this thesis aimed to identify the prevalent stressors and countermeasures within the military operations at the selected air base, particularly through semi-structured interviews and a survey questionnaire.

Research Question (RQ) 1: Do unpredicted operations and family issues impact sleep hygiene compared to other factors among military personnel?

Fatigue has several negative impacts on operational safety, sleep hygiene and the well-being of personnel. Fatigue can arise from stressors such as unpredicted operations, shiftwork, deployments, sustained/continuous operations, adverse environmental conditions (e.g., temperature, humidity, noise), combat equipment (NVGs, protective clothing), operational requirements, strategic needs, family issues, individual characteristics, etc. Therefore, it is crucial to effectively monitor the overall system's

effectiveness and identify potential adverse safety threats (Caruso, 2014; Dhillon & Boyd, 2010; Paech et al., 2010). Due to high impact of fatigue on various operational and individual aspects, there are issues arising from these impacts, particularly, severe health issues [e.g., neurobehavioral problems (Dinges et al., 1997), cardiovascular and gastrointestinal diseases (Åkerstedt, Knutsson, et al., 2004; Chan, 2009), metabolic syndrome (Biggi et al., 2008). Moreover, additional issues are related to sleep deprivation, cognitive decrements (e.g., memory impairment, reduced capacity for sustained attention), stress, performance and alertness decrements, and anxiety (Blanc et al., 2014; Caldwell et al., 2004; Dhillon & Boyd, 2010; Headley et al., 1997; Killgore et al., 2006; Lieberman et al., 2002; Miller, 2014b; Miller et al., 2014; Miller et al., 2011; Neri & Shappell, 2006; Shappell et al., 2006; Taylor et al., 2016; Thomas et al., 2006). There may be also other factors causing fatigue that are not yet identified in the literature. Additionally, there is an issue of validity and reliability of technological approaches to fatigue identification and measurement (Noy et al., 2011; Reifman et al., 2016). Based on the information the researcher previously received by the selected Air Force, this thesis focused and explored if unpredicted operations and family issues impact sleep hygiene compared to other prevalent factors among military personnel identified in this thesis through Study 1 and Study 2.

RQ2: What is the prevalence of using swapping roles with colleagues, coordinated inflight naps, exercise, and caffeine intake as fatigue countermeasures compared to other strategies?

There are various countermeasures and mitigation strategies divided into in-flight countermeasures and strategies (e.g., breaks and naps, bunk sleep) and pre-/post-flight countermeasures and strategies (e.g., the use of pharmacological agents, health screening and treatment, adequate manning, appropriate education, and training, monitoring number of hours worked, sleep monitoring, fatigue-proofing, and fatigue-reduction strategies). An SMS based multi-layered approach to fatigue through the fatigue risk trajectory has explained how risk can be identified and prevented along the fatigue-risk trajectory. An effective approach integrates mitigation strategies to reduce

the likelihood of people being fatigued at work (fatigue-reduction strategies) and decreasing the likelihood that fatigued individuals in the workplace will make an error representing threat to safety (i.e., fatigue proofing strategies) (Dawson et al., 2012, 2017; Dawson & McCulloch, 2005; Folkard & Tucker, 2003). Moreover, fatigue risk trajectory helps to develop appropriate countermeasures in FRM by preventing fatigue developing at each level of hazards (Phillips, 2016). Research studies indicate various mitigation strategies and countermeasures used by personnel in different operational context (Caldwell, 2005; Caldwell et al., 2009a; LeDuc et al., 2000; Miller, 2014b, 2014a; Miller et al., 2015; Miller et al., 2011; Report, 2010; Shappell et al., 2006; Toblin et al., 2018; Wesensten et al., 2005; Wood et al., 2017). Identification of countermeasures and mitigation strategies that are already available in existing processes will give insight of the current fatigue mitigation and management processes and consequently provide their further improvement. This thesis focused on identifying and exploring the prevalence of using swapping roles with colleagues, coordinated inflight naps, exercise, and caffeine intake as fatigue countermeasures compared to other strategies identified throughout Study 1 and Study 2 of this thesis.

Objective 2: To construct a military specific fatigue model that encapsulates the fatigue stressors and countermeasures identified.

Fatigue model in military aviation represents fatigue risk precursors and consequences identified throughout this research study and systematic literature review. This thesis presents a Structural Equation Modelling (SEM) procedure with latent variables for predicting the fatigue in military aviation. The model includes dependent, independent and mediator variables and the sample of this research represents the transportation and logistics unit at the selected air base. The results indicate that the model represents the prediction of fatigue with respect to sleep hygiene and it has also been determined that two constructs affect fatigue. The first construct in the research is sleep and the other is countermeasures.

RQ3: How is sleep quality connected with perceived fatigue levels and the implementation of fatigue countermeasures in the military setting?

Sleep is one of the main factors influencing fatigue in this research study as it addresses the quantity and quality of sleep and relevant disturbing latent indicators, for example, unpredicted operations, family issues, poor sleep environment, night-time duties, workload, and off-duty leisure activities (Aljurf et al., 2018; Dinges et al., 1997; Van Dongen & Dinges, 2005).

Fatigue countermeasures and mitigation strategies are decreasing the likelihood that fatigued individuals in the workplace will make an error that leads to safety issues, and consequently reduce the likelihood of people being fatigued at work. Individuals take different approaches to preventing fatigue or reducing the level of fatigue using various fatigue mitigation strategies and countermeasures which depend on individual psychological and physiological condition. More longitudinal studies are needed to investigate individual differences and genetic predictors of performance impairment vulnerability (Caldwell et al., 2009a; Miller, 2014b).

While prior models, such as the SAFTE Model, indicate general fatigue limitations without capturing individual variances (Hursh & Balkin, 2004), this study employs Structural Equation Modelling (SEM) to finely map fatigue predictors in military aviation, furthering the foundational insights of previous research (Caldwell et al., 2009b).

Structural equation modelling analysis in this thesis consists of the following steps: determining the research model based on the theoretical framework and the interpretation of the relationship between factors and their measures; assessing construct validity, i.e., convergent and discriminant validity; determining the measurement model including the confirmatory factor analysis; describing the estimated model coefficients and performing the analysis.

Objective 3: To explore the current management of fatigue and sleep training.

A proper management of fatigue and sleep is crucial in fatigue sensitive occupational settings, therefore is it important to constantly educate employees about fatigue and sleep related risks, consequences, and countermeasures they can use in preventing or decreasing the likelihood of fatigue and sleep. This thesis explored what proportion of crew members in the selected air base received training on fatigue and how widespread the training on sleep hygiene is.

RQ4: What proportion of crew members have undergone training that addresses fatigue management?

FRMS promotion processes include an effective training program and communication plan, therefore, periodic, and appropriately tailored training and education on FRMS objectives and principles for all personnel among management and employees involved in the FRMS processes should be mandatory (ICAO, 2016). This helps to promote organisational safety and a just culture, an understanding of shared responsibilities and the FRMS objectives and procedures, a better understanding of the circadian rhythms and homeostatic processes in relation to safety, performance, health, and the overall well-being. It also helps to recognise fatigue-related behaviour and how to prevent and mitigate it. Moreover, training educates people on the proper use of fatigue countermeasures, for example, how and when to use caffeine, napping, and approved pharmacological agents (Borders et al., 2015; Dawson et al., 2017; Hefner et al., 2017; ICAO, 2016; Troxel et al., 2015). Information on training courses such as sleep hygiene and fatigue are important factors in Fatigue Reporting process, therefore, this thesis particularly explored what proportion of crew members have undergone training that addresses fatigue management.

RQ5: How widespread is the training on sleep hygiene among crew members, and what are its perceived effects on sleep quality?

Furthermore, it is not only important what proportion of crew members have undergone training that addresses fatigue management, but also how widespread the

training on sleep hygiene is among crew members. It's also important what the perceived effects on sleep quality are and this thesis investigated this matter as well throughout research Study 1 and Study 2 of this thesis.

Overall, fatigue-related research studies in various safety-sensitive operational settings with similarities to fatigue issues have been explored and they have indicated several factors influencing performance and alertness levels due to various stressors present in safety-critical operations. Development and implementation of the FRMS reduces fatigue and improves overall safety within an organisation, therefore, efforts on successful FRMS implementation and improvements including development of military-specific Fatigue Report Form are essential. All stakeholders should be aware of their responsibilities within the system, acting responsibly in assuring high levels of organisational and operational safety. The literature review identified the most common fatigue-related issues and requirements for further exploration. In the first place, it is essential to agree upon basics such as a common definition of fatigue, and the validity of the fatigue measurement and predicting tools including the further exploration of inter-individual differences in circadian rhythm related to genetic influences. Hence, potential genotypic markers of phenotypic vulnerability to sleep loss need to be further explored. This thesis focused on the above-described Objectives and Research Questions throughout Study 1, Study 2, and Study 3 of this thesis.

Objective 4: To develop a military-specific Fatigue Report Form that captures key fatigue-related factors and their interrelationships.

This thesis aimed to develop a military-specific Fatigue Report Form that captures the key fatigue-related factors, and their interrelationships found throughout this research study, semi-structure interviews and a survey questionnaire. Study 3 of this thesis aimed at developing military-specific Fatigue Report Form for the selected air base and therefore improve the reporting culture including operational safety and performance.

RQ6: Which type of Fatigue Report Form would be suitable for the selected air base?

Generally, the development of an appropriate fatigue report form can be challenging especially in military aviation as each operational Air Force squadron has different management arrangements, operational settings, environment, and requirements, therefore the fatigue report form cannot be generalised for all operational settings within the Air Force, but it must be tailored to fit the needs and complexity of particular squadron. Similarly, also FRMS cannot be generalised over all Air Force, but it must consider the needs and complexity of operations. This thesis investigated fatigue and sleep management arrangements in the selected air base throughout Study 1 and Study 2, while Study 3 discussed the method for developing military-specific fatigue report form, which items are important, and the inevitable construct of the form and their implications for this thesis using heuristic evaluation methodology. Research studies of this thesis enabled the development of an appropriate fatigue report form capturing the key fatigue-related factors and their interrelationships (BALPA, 2015). The proposed fatigue report form can be used by the selected air base in its operations to identify fatigue-related risks and take appropriate measures which would further improve the overall safety.

Chapter 3 - Fatigue Risk Management in Military Aviation

3.1 Chapter Introduction

This chapter introduces fatigue risk management in military aviation in a concerned European Union country as an important issue causing serious safety concerns in the operational context, including organisational arrangements. The greatest concern is constant cutbacks in military spending, expecting to do more with less. Consequently, crew members (i.e. pilots and loadmasters) experience increased workload pressure and operational tempo, which could only be reduced by increasing the personnel strength able to support operational requirements (LoPresti et al., 2016).

The Air Force researched in this thesis is one of the most advanced Air Forces with a long history and has been a NATO member. Therefore, operations are based on NATO recommendations. Up to date, the organisation has not adopted the European Military Airworthiness Requirements (EMAR) as a basis for military aviation SMS, therefore, this could be a missed opportunity towards harmonising their safety management and fatigue risk management with civilian aviation SMS and FRMS and improved safety system. Currently, their SMS development is a work-in-progress process and is expected to be developed and implemented in the following years.

This chapter gives a background insight into its operational context and a background into how to understand the role of fatigue in military aviation whilst presenting the selected air base of one of the European Union Air Forces for this thesis. Moreover, the lack of availability of fatigue-related safety regulations has been identified due to the nature of military aviation, including confidentiality and several organisational restrictions.

3.2 Fatigue in Military Aviation

Military around the clock operations are characterised by flying the highest performance and safety standards accompanied by stressors such as circadian desynchronisation, constantly rotating shiftwork schedules that generally require 48-72 hours adaptation

(Sharpe & Bartlett, 2000), sustained/continuous operations including strenuous and/or prolonged physical strain, high operational tempo, insufficient or no sleep opportunities, high stress level and cognitive workload, environmental conditions, and psychological factors. These and other stressors in the military operational settings usually do not occur in isolation but rather in clusters, and these may contribute to fatigue and sleepiness as well as to decrements in military operational effectiveness and safety. For example, fatigue leads to aircrew performance decrements, less accurate flight manoeuvres, impairments in the capacity to integrate information, significant lapses in judgment and decision-making, decreased vigilance, and increased error rates (Miller et al., 2007). It also led to failures in making comprehensive instrument scans, perform more passive flight control strategies such as abbreviating or skipping routine checks, and micro-sleeps (Dahlgren et al., 2012; Sharpe & Bartlett, 2000) which concluded that soldiers are ineffective in defensive roles after constantly being awake for 48 hours. When sleep loss becomes great, vigilance deteriorates over time, mood changes, judgment is affected, and cognition and perception decrease. Miller, Matsangas, and Shattuck (2007) found that tasks requiring prolonged alertness were most at risk for sleep loss. Therefore, a priority should be the prevention and management of fatigue and sleepiness, despite the lack of predictability in the operational context that tend to result in difficulties in maintaining effective fatigue management.

Constant reduction of personnel strength due to cutbacks in military spending and the desire to do more with less are important issues in military operations, which have led to increased pressure and stress, difficulty in scheduling activities, prolonged duty time, and increased workload and operational tempo (Miller et al., 2011). In addition, there are mediating factors to fatigue levels such as quantity and quality of sleep, timing of sleep, individual differences, health and physical condition, diet, and task characteristics and complexity, which contribute to the issues in military aviation.

It has been challenging to objectively assess fatigue in military aviation as there are tactical considerations and equipment limitations, therefore, most commonly subjective

evaluations are used to address levels of fatigue. In particular, the difficulty in assessing war fighter fatigue has been highlighted. For example, during the Persian Gulf War in Operation Desert Shield and Operation Desert Storm, a study of A-6 and F-14 pilots was conducted onboard the USS America for four consecutive weeks to examine aircrew subjective readiness in a combat environment by completing individual work/rest logs. Multiple-regression analysis found that aircrew subjective combat readiness depended on differences in the time of day the missions were flown, the flight length, the amount of sleep obtained 12 hours prior to flying, and the type of aircraft involved (Miller et al., 2007; Storm et al., 1992).

Deployments across time zones are rapid changes that cause circadian desynchronisation and require fast acclimation to new environments. Military personnel are constantly subjected to eastward/westward deployments, therefore, circadian misalignments may be reduced or synchronised by using various fatigue/sleepiness countermeasures such as the use of pharmacological and non-pharmacological interventions. Here, it is important to mention that in the concerned Air Force pharmacological interventions are, se per information received, not allowed/used. General precautions should be taken when using military-approved pharmacological agents such as sleep-promoting Temazepam, Zolpidem, and Zaleplon, which are used in operational contexts to initiate or maintain sleep. In contrast to this, alertness-enhancing Caffeine, Modafinil, and Amphetamine may be used for temporarily reducing the impact of sustained wakefulness where sleep opportunities are limited (Caldwell, 2005; Miller, 2014b). Pharmacological fatigue/sleepiness management techniques can assist in situations where there are no opportunities for sleep, but these pharmacological techniques should be carried out by experienced flight surgeons because sleep-inducing and alertness-enhancing agents have their limitations and side effects. In relation to caffeine, it is important to mention the use of energy drinks and alcohol misuse, which in high quantities are associated with mental health problems, aggressive behaviour, and fatigue. It was noticed that 30-50% of air force and civilian youth consume energy drinks habitually and 6% on a daily basis, which is concerning information found in a study of Walter Reed Army Institute of Research (Erdogan &

Kurcer, 2018; Toblin et al., 2018). Therefore, military leaders should monitor how energy drinks are used and available in operational environments and consider providing proper education on that. To try to change cultural behaviour regarding the use of energy drinks is essential.

The only way to combat fatigue and sleepiness is to have an appropriate quantity and quality of sleep. In case of sustained wakefulness, prophylactic naps are required, where a 2-h nap before duty may help to maintain an appropriate level of performance (Caldwell, 2005; Sharpe & Bartlett, 2000). Whenever possible, napping during the window of circadian low (WOCL) should be avoided if a person needs to be alert immediately after awakening (Sharpe & Bartlett, 2000).

One of the studies (Marriott et al., 2015) indicated that sleep-deprived personnel experience impaired alertness, cognitive performance, and mood. Moreover, ability to do cognitive work decreases for approximately 25 percent every 24-h period of sleep loss (Caldwell, 2005; Marriott et al., 2015).

Crew members' fatigue is a common problem in the military aviation and on-the job sleepiness is particularly important during training exercises and deployments where sleep difficulties usually occur due to uncomfortable or unfamiliar sleeping conditions. For example, shared bunks for day and night crews together, crowded sleepiness spaces, circadian desynchronization, increased operational tempo that is dictated by strategic needs, and disturbing environmental conditions (e.g., exposure to loud noises, temperature, humidity) as well as personal issues (e.g., worry over current safety and over family back at home). Therefore, it is important to promote fatigue-reduction strategies and set educational efforts to maximise good sleep hygiene in both training and operational environment. Moreover, there is a need for continuous improvement of fatigue management.

Another research (Ja & Sr, 2002) confirmed in their study of aircrew fatigue in the U.S. military aviation personnel that several people experienced sleep deprivation and fatigue due to variety of work schedules, deployments, and intentional sleep

restrictions. Sleep patterns in deployed and post-deployed military personnel may result in adverse mental and physical conditions, including willingness to accept greater risk, decreased performance and threat detection, impaired decision-making, tunnel vision, mood impairment, type-2 diabetes, cardiovascular diseases, and metabolic syndrome. Posttraumatic stress disorder (PTSD) symptoms such as nightmares and insomnia were indicated in people experiencing sleep disturbances (Seelig et al., 2017).

Moreover, insomnia occurs in about one in five soldiers prior to a military deployment (Taylor et al., 2016) and may generally increase the risk of developing depression and other mental and physical health problems. The best approach to treatment is non-pharmacological behavioural treatment; combining good sleep hygiene, stimulus control, and sleep restriction (Bastien et al., 2001; Pruiksma & Peterson, 2017; Smith et al., 2002). How well this approach works for military personnel in the deployed environment is not known (Pruiksma & Peterson, 2017).

Therefore, effective sleep management should be in place to improve sleep-related issues in military aviation. For example, issues with sleep environment may be mitigated with the use of temperature control units and housing soldiers on the same schedules together. For example, the Royal Netherlands Air Force mitigated sleep issues by considering these general measures, including optimisation of sleep facilities, proper mission planning, adequate support for the crew to assist combat mission stress and personal issues. Moreover, specific measures including optimising performance and alertness (i.e., stimulating performance and alertness when circadian trough period, mitigating sleep inertia and effects of pharmacological sleep-promoting agents, and strategic naps planning) were set (LoPresti et al., 2016; Simons & Valk, 1999). Preventing fatigue in military aviation includes supervision and review of mission planning, regular inflight feedback on performance, and proper nutrition and hydration (Sharpe & Bartlett, 2000).

Furthermore, commanders are responsible for the fatigue and sleep management of their subordinates as well as themselves, and they should be able to assess, anticipate,

and address the impacts of fatigue and manage the fatigue and sleep loss effects. They may experience higher fatigue levels for a variety of reasons such as characteristics of the command role including complex mental processes (i.e., complex reasoning, coordination of operational duties, tactical and operational planning, rapid and/or difficult decision-making), command responsibility and several additional stressors. There is a danger due to military virtues that some commanders may ignore good sleep practice and presume their immunity to sleep loss. However, this is not acceptable behaviour in any safety-sensitive operation.

Night Vision Goggles (NVG) are an important stressor to mention regarding fatigue that can cause tiredness, complaints of neck and eye strain, deterioration in psychomotor vigilance skills, reduced decision-making capabilities, and increased reaction times. NVG is generally used at night, during the circadian trough period, therefore, 1 hour of flying with this device requires 10 minutes rest. Due to the circadian trough, it is not clear whether circadian factors are just an additive and fatigue is associated with the device itself, or whether there are some inter correlations (Sharpe & Bartlett, 2000). Therefore, there is a need for further research into human performance using NVG.

Finally, as mentioned before, continuous improvement of fatigue and sleep management is essential to maintain the required level of operational safety. Developing and introducing a Fatigue Report Form could improve the effectiveness of its organisational and operational fatigue related safety with continuous monitoring and improving effectiveness of the overall FRMS.

Air transport support operations in the concerned Air Force recorded accidents, whereas the major one occurred during the airshow, resulting in a number of fatalities in total due to the mid-air collision. Moreover, a crash of C-130H Hercules caused several fatalities. Following the two accidents both civilian and military investigations were undertaken. The civilian accident investigation concluded that the aircraft had technical issues but did not exclude human error, whereas the military investigation on the accident concluded with the human error only. Furthermore, the latter showed that the

pilot had failed the flight check that morning before the flight due to personal issues, but nevertheless, was allowed to fly. Therefore, the cause for the accident was a human error.

Air-transport and logistic support operations were selected for this research, which operate in different air units in the country of the concerned Air Force. The available transportation and logistics unit of the concerned Air Force for this research study supports air transport services and logistics (such as emergency medical transportation), humanitarian missions, civilian protection missions, tactical and strategic transportation operations, bio-contaminated material transportation, special operations, deployments, and support services on behalf of the Ministry of Foreign Affairs and Ministry of the Interior. The selected air base of the concerned Air Force is continuously active in national and international operations worldwide. Some of the past missions refer to the humanitarian missions in Southeast Asia and Oceania, which was affected by the tsunami in 2004. The air unit was also active in the New Orleans (United States of America) hurricane Katrina aftermath in 2005, the earthquake in Pakistan and Iran, and in Georgia and Algeria, which were affected by the flood. Additionally, a team of the ophthalmologists was transported in Mali, Benin, and Gao to help people affected by cataracts. The concerned Air Force transport assets and resources have been shared within the European Air Transport Command (EATC), which controls the aerial refuelling capabilities and military transport fleets of Germany, France, Belgium, Italy, Spain, Netherlands, and Luxembourg. Moreover, the EATC may contribute to the European common security and defence policy (CSDP), which has an important role in crisis management in both civilian and military settings. As previously mentioned, assets and resources are managed through the Air Transport & Air-to-air Refuelling and other Exchange of Service (ATARES) program. The selected air base of the concerned Air Force has a fleet of C-27J Spartan used for various tactical transport missions, C-130J used for several air transport support operations.

The air-transport support operation of the selected air unit is divided into four distinct operational activities, each of which is in charge of overseeing a distinct operational

component of the overall operations. The concerned operational activities are the flight department; training centre; Technical operations; and Logistic operations. Table 3-1 summarises each individual operational activity describing the area of work with different management arrangements, but they have the same objectives and principles.

Table 3-1. Summary of operational activities at the selected air base of the concerned Air Force

Operational activity	Area of work
Flight department	Controlling the three flight groups by the Aircraft Efficiency Group (GEA), responsible for the maintenance of the fleet.
Technical operations	The supply group is responsible for storing and distributing special aeronautical material. The telecommunications and weather group are responsible for telecommunication system and radio communications, including radar services (Air Traffic Control) within the unit.
Logistic operations	The Transport group is responsible for all equipment that is moving on “tires” for transporting men and materials. The installations group takes control over infrastructure facilities such as buildings and roads, including hydraulic, thermal, and electrical systems of the base. Additionally, there are fire protection services available in case of emergency as well as scheduled fire protection activities.
Training centre	The training centre offers courses for various groups such as commanders, co-pilots, instructors, and tactical activities.

Further below (see Figure 3-1) presents the organisational chart of the selected air base.

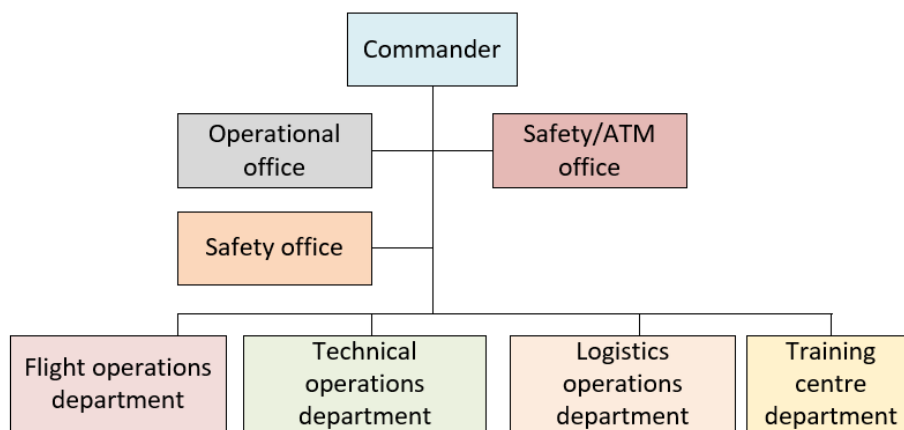


Figure 3-1. The selected air base organisational chart of the concerned Air Force

3.3 Regulations

When discussing the fatigue in the military aviation community, it is crucial to address regulations and policies attempting to reduce the level of fatigue through several regulatory fatigue-preventive measures such as flight time limitations, Safety Management System, aircrew fatigue management, and applicable aviation safety airworthiness requirements for safe human interaction within the holistic military airworthiness system. These regulations aim to set safety thresholds and management arrangements and tools that are in place to measure, mitigate and prevent the consequences of fatigue-related risks. As previously mentioned, European countries, are required by the Chicago Convention, Article 3, to assure that military aviation operations do not interfere with and do not have an impact on civilian aviation safety. Furthermore, the European Military Airworthiness Requirements have been developing the holistic approachable military airworthiness system to introduce a harmonised and standardised common approach to military aviation airworthiness and safety systems driven by the European Defence Authority (EDA), which is discussed further below.

3.3.1 European military aviation regulators

Military Aviation Authorities (MAAs) are responsible for the safe operation and regulation of military aircrafts and the overall promotion of an active safety culture and air safety of the individual country. Generally speaking, military regulations are

underpinned by the ICAO set of principles and the MAAs established by the Secretary of State for Defence who also works alongside the other defence regulators. Moreover, the Military Airworthiness Authorities Forum (MAWA) has been established by the European Defence Agency (EDA) toward the development of the European Military Airworthiness Requirements (EMARs), which are mostly consistent with the EASA framework that aims to establish a common regulatory system that would allow for harmonised and standardised military aviation safety requirements, primarily focused on airworthiness (NATO Airworthiness Policy, 2014; Purton & Kourousis, 2014). Therefore, the future development and implementation of an SMS may be expected, not only in military airworthiness but within other military operational domains as well. Nevertheless, the military specific FRMS can be developed and implemented as well. This would bring benefits such as saving costs, time, an increased effectiveness of military aircraft operations and an effective, efficient, and robust safety system.

The military Air and Airworthiness Directorate of the concerned European Union country has been recognised by several worldwide military organisations (e.g., USAF, USARMY, USNAVY, Singapore Royal Air Force, Israeli Air Force) as a competent MAWA, which follows the EMARs and NATO airworthiness policy, where the EMARs emphasis is put on the common regulatory framework and certification process, including mutual recognition between MAWA members. On the other hand, the NATO airworthiness policy has a robust airworthiness framework based on cooperation, interoperability, and an economy of effort and does not interfere with national airworthiness regulations.

The concerned European union country has not fully agreed to comply with its legacy programs with the EMARs, and this could be one of the gaps addressing the military issue of fragmentation of rules, particularly legacy rules, rules of engagement and standing orders, which represent additional barriers in establishing an effective and efficient safety system.

Achieving a harmonised and synchronised approach to aviation airworthiness and safety systems between civilian (EASA) and military (EDA) aviation through the EMARs can be

one of the bases for the SMS and FRMS development and implementation, as well as in other airworthiness military operational domains. Furthermore, common European Defence Aviation Safety Regulations would provide common safety rules, flexibility, urgent safety measures, and operational imperatives, which has already been applied by the Australian Defence Aviation Safety Regulation (DASR) based on EASA framework (International Military Airworthiness Regulation Conference).

3.3.2 Aircrew fatigue management

The European Air Transport Command (EATC) flight duty regulation sets the limitations for maximum duty time and minimum rest time for different operations under various conditions and time zone differences to avoid fatigue and to overcome the effects of previous duties, including the time necessary in all phases of the flight (i.e., pre-flight, flight, turn-around and post-flight). This regulation is relevant to the Flight Crew and to the Cabin Crew in accordance with National regulations.

Complying with the Flight Duty Regulations (FDR) is not always possible in military aviation environment, particularly when a mission is still in planning or in an execution phase, therefore, an additional approval should be sought in advance from the relevant authority. Furthermore, some operations are excluded from the FDR tactical limitations due to the nature of the operation itself; for example, the aerial refuelling receiver operation is one of them.

The concerned European Union country's Directive on Flight and Duty Time limitations refers to the flight duty limitations, rest period and acclimatisation requirements, proper sleep hygiene, diet, and nutrition for various operations without any requirements on fatigue countermeasures. This Directive dates to 2004, therefore, it does not comply anymore with the European requirements and should undergo an appropriate update.

Fatigue and sleep hygiene were selected to be investigated in this thesis at the selected air base because the concerned Air Force is currently considering developing and implementing an organisational Safety Management System based on ICAO standards.

It is also developing a FRMS which would firstly be implemented as a stand-alone system and in the future integrated into SMS. Consequently, they would like to develop and implement a military-specific Fatigue Report Form tailored to the specific needs and complexity of each air base.

3.4 Chapter Conclusion

This chapter introduced fatigue in military aviation in a concerned European Union country by highlighting the fatigue stressors and consequences of fatigue such as performance and vigilance decrements, impaired integration of information capacity, increased rate of errors, and micro-sleeps. Furthermore, the chapter stated that fatigue in military aviation has been challenging to evaluate objectively because of equipment constraints and operational considerations. Therefore, fatigue is mostly assessed by self-reported fatigue and sleepiness questionnaires, which may influence the overall credibility and validity of predicted fatigue and performance levels. Also, a literature review identified a gap in fatigue measurement tools that lack validity and reliability; therefore, they shall be used with caution.

Military personnel have been continuously subjected to deployments and consequently to circadian desynchronisation, therefore, the identification of fatigue management preventive strategies and operational countermeasures is needed to prevent or relieve the consequences of circadian misalignment.

Furthermore, the concerned Air Force has been presented in this chapter in order to understand the organisational structure of the selected air base for this thesis; addressing operational objectives and principles, including the area of work and management arrangements. The selected air base, including its subordinate units, is presented separately, indicating operational activities and area of work with different management arrangements. Furthermore, the lack of availability of fatigue-related safety regulations due to military aviation confidentiality has been identified, therefore, the ability to consider several fatigue-related safety regulations to discuss fatigue was not possible.

Chapter 4 - Research Methodology

4.1 Chapter Introduction

The research methods, research questions, methodology, and design used in this thesis, which explores fatigue in military aviation and the military-specific FRMS framework with an emphasis on fatigue reporting mechanisms and associated feedback, are described in this chapter. To develop the military-specific Fatigue report form, it was first required to explore and understand the fatigue-related factors and activities by looking into the literature, to use the researcher's own experience, investigate relationships of fatigue-related factors within the military aviation, as well as to understand the military culture. Then, the research questions were identified, and then the approach and the methods to be used to address these questions followed. Therefore, throughout this research, fatigue-related factors were identified and explored, which facilitated the creation of the military-specific fatigue report form. An incremental approach allowed a systematic development of the final fatigue report form for selected air base, based on the findings of each individual research method. There were several research limitations and gaps indicated in the available research studies that are described in Chapter 2 and are part of a problem identification stage in the researcher's approach. The highlighted research gap is the lack of research available on military specific FRMS framework and related fatigue reporting mechanisms and associated feedback.

The available literature on fatigue in transportation industry was explored, particularly, in both the civilian and military context aviation industry. The available literature was found to be limited to aviation military specific FRMS, as well as factors affecting an individual's fatigue level. There was also lack of knowledge on the inter-individual differences in circadian rhythm related to genetic factors. Moreover, there is a lack of military-specific fatigue reporting mechanisms. Due to often interchangeability of fatigue and sleepiness, sleep science was examined, and correlations with fatigue were found. The main fatigue effects explored identified severe health issues, as well as the lack of knowledge and research on the relationships between circadian rhythms and

genetics indicating and affecting fatigue. Furthermore, bio-mathematical neurobehavioral performance models have been found to be a useful component in the FRMS in predicting and modelling fatigue and performance levels, but they need further exploration and improvement in terms of evaluating their effectiveness. The available research is limited to this critical element and more data has been required to be accessible for further exploration and improvement of the bio-mathematical models' effectiveness. Moreover, shiftwork was identified as a complex interaction of organisational factors affecting individual's performance and overall well-being. Bio-mathematical modelling has an important role in shiftwork as it has been predicting fatigue through the evaluation of effectiveness of various scheduling practices and combining data on sleep, wake, and performance.

FRMS was also explored in detail. From the available literature and regulations on fatigue, the military specific FRMS framework could be based on the civilian FRMS framework. The ICAO FRMS framework was explored due to the lack of the FRMS literature and regulations in the military aviation industry. What is more, military aviation is underpinned by the ICAO principles and frameworks wherever applicable and there is currently no available literature on the military specific FRMS framework except the individual components of the FRMS such as fatigue research studies and surveys. This may be due to the military aviation applicability of civilian standards such as a military-specific SMS that is currently work-in-progress in the European Union. The FRMS is an SMS-based approach to safety; therefore, after the development and implementation of the military-specific SMS, it is expected that also the FRMS will be developed and implemented into the military aviation as part of an SMS or as a stand-alone system. Currently, there is only the Australian Defence Aviation Safety Authority (DASA), which specifically requires implementation of an SMS for holders of a Military Air Operator Certificate in initial and continuing military airworthiness organisations. Furthermore, the United States Air Force has incorporated an organisational SMS based on a Plan-Do-Check-Act model in the Air Force's Mishap Prevention Program across all safety disciplines.

Additionally, the review of the available regulations identified issues such as the lack of fatigue-related regulations and an inaccessibility of existing fatigue-related safety regulations due to their confidentiality. The concerned Air Force operates independently, the same as other European Air Forces, as there is no global set of military aviation rules. The concerned Air Force is currently in a process of developing and implementing its organisational SMS, which is based on the ICAO SMS principles and framework.

This thesis discusses its research methods further below and the chapter concludes with the main research questions and objectives and by combining both research methods used. This thesis discusses its research methods further below, and the chapter concludes with the main research questions and objectives and by combining both research methods used. Research clarification is planned in Chapters 2, 3, and 4 by identifying existing research gaps, understanding the main challenges, identifying research objectives and questions, and developing a research plan. Study 1 aims to explore and address the objectives of this thesis by identifying themes and sub-themes of the data collected, while Study 2 further explores the findings of Study 1 through a questionnaire survey and results in the design of a structural equation model. Based on data collected in both studies, Study 3 aims to develop a fatigue report form for the selected air unit. The researcher used her industrial experience related to fatigue management in civil aviation by considering the significant differences between military and civil aviation. The researcher's industrial experience in fatigue management and the approach to the overall methodology are indicated further below in respective sections.

Figure 4-1 represents the contextual framework for this thesis, a sequence of the selected research methods and their objectives. The research methods and their applications are presented in detail below.

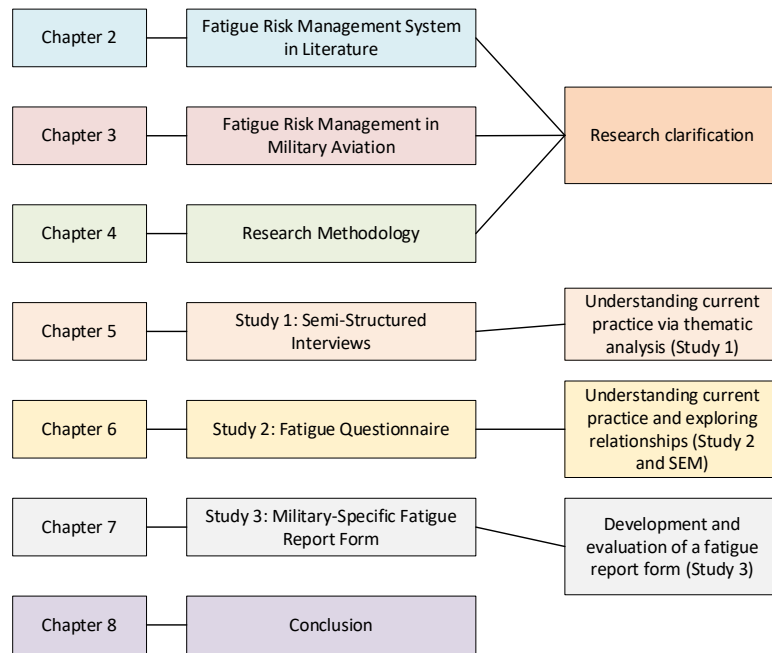


Figure 4-1. Research contextual framework

4.2 Research Questions

The main research questions are derived from literature and their relation to research objectives, which this thesis seeks to investigate and answer. Below, these research questions are replicated:

RQ1: Do unpredicted operations and family issues impact sleep hygiene compared to other factors among military personnel?

RQ2: What is the prevalence of using swapping roles with colleagues, coordinated inflight naps, and caffeine intake as fatigue countermeasures compared to other strategies?

RQ3: How is sleep quality connected with perceived fatigue levels and the implementation of fatigue countermeasures in the military setting?

RQ4: What proportion of crew members have undergone training that addresses fatigue management?

RQ5: How widespread is the training on sleep hygiene among crew members, and what are its perceived effects on sleep quality?

RQ6: What type of Fatigue Report Form would be suitable for the selected air base?

4.3 Research Methods in Aviation

The Methodological approach is varied in terms of exploring and measuring performance level and identifying health issues arising from different work arrangements and the interaction of factors such as high operational tempo, stress, deployments, environmental conditions, psychological factors, and insufficient or no sleep opportunities.

Before it was shown in several research studies that many methods have been used to explore and identify fatigue and its interacting factors within both civilian and military settings. Individual components of the FRMS have been studied in detail with currently no available research study on the overall military specific FRMS framework and fatigue reporting mechanisms. The methods selected for this study are based on the available research methods and on the civil aviation FRMS framework including the fatigue report form, which is already developed and implemented and on an interacting relationship between its factors expected.

It has been stated that there is a lack of military specific FRMS studies available and there is not enough information to describe this, consequently, for this study, an exploratory inductive approach was chosen. The ICAO FRMS framework was explored due to an SMS-based approach to safety, which many defence forces have adopted, with modifications applicable to military operations and military culture. As previously mentioned, military aviation is underpinned by the ICAO frameworks and principles wherever applicable. Therefore, it is expected that a military-specific Fatigue Report Form could be workable.

An understanding of the objectives and procedures of the FRMS and its individual components was required to be able to explore and understand the interactions

between identified components, as well as to explore the fatigue-related factors and their relationships with the FRMS. The first method selected for this study was a qualitative research method, where several semi-structured interviews were conducted with the selected air base to obtain descriptive data, which were also some of the study objectives. These were useful for both the verification and generation of the theory.

Following semi-structured interviews, it was decided to evaluate the findings' generalisability through the use of a survey questionnaire, which contained questions partially drawn from both the literature review and the findings of Study 1. This quantitative approach was selected as Study 2 for this thesis. The selected methods allowed participants to express their opinions and feelings related to fatigue in both operational and organisational environments. Study 3 developed the specific fatigue report form for the selected air base, based on both studies 1 and 2 of this thesis. Moreover, heuristic evaluation and testing was performed to get feedback on the usability of the proposed form.

Ethical approval for Study - reference number CURES/7960/2019, Study 2 - reference number CURES/12528/2020 and Study 3 - reference number CURES/20025/2023 (see Appendix A) as well as the collection of information on organisational structure was sought from the Cranfield University Research Ethics System (CURES), which confirmed the selected research activities could proceed. The concerned Air Force was informed on the overall research process, as well as on the individual research methods selected, which apply to Study 1, 2 and 3. The concerned Air Force was briefed on the approach that participation in these research studies would be voluntary, and that participants could withdraw from studies at any time. Moreover, they were informed about what exactly is expected of them if they decide to participate in the study, including the commitment that all collected data would be made anonymous and treated with the highest confidentiality and security.

4.4 Study 1: Semi-Structured Interviews

The objectives of this thesis were decided upon, as well as the aims to improve FRM processes within military aviation industry, by highlighting the importance of reporting fatigue in the selected air base. Initially, Study 1 aimed to explore and address the following objective of this thesis:

O1: To examine the prevalent fatigue stressors and countermeasures within military operations at the selected air base.

RQ1: Do unpredicted operations and family issues impact sleep hygiene compared to other factors among military personnel?

RQ2: What is the prevalence of using swapping roles with colleagues, coordinated in-flight naps, exercise, and caffeine intake as fatigue countermeasures compared to other strategies?

Descriptive data enabled the comprehension of the overall organisational and operational activities, related to fatigue, including the military culture. There was a need to collect data on currently available fatigue arrangements and its reporting tools, including fatigue stressors experienced and countermeasures used in operational context and how the personnel perceive the effects of fatigue. Examining the consequences of fatigue and the interactions of factors that influence fatigue is one of the objectives of this thesis. Moreover, it aims to explore and select fatigue countermeasures that are effective in terms of cognitive performance and operational endurance. Furthermore, based on the Study 1, it was expected that collected data would be valuable in developing other objectives, namely:

O2: To construct a military-specific fatigue model that encapsulates the fatigue stressors and countermeasures identified.

RQ3: How is sleep quality connected with perceived fatigue levels and the implementation of fatigue countermeasures in the military setting?

O3: To explore the current management of fatigue and sleep training.

RQ4: What proportion of crew members have undergone training that addresses fatigue management?

RQ5: How widespread is the training on sleep hygiene among crew members, and what are its perceived effects on sleep quality?

O4: To develop a military-specific Fatigue Report Form that captures key fatigue-related factors and their interrelationships.

RQ6: What type of Fatigue Report Form would be suitable for the selected air base?

4.4.1 Sampling strategy

Initial meetings with the concerned Air Force management indicated that the staff participating on a voluntary basis in this study were selected by the Air Force itself on a random basis. Therefore, the researcher was not aware of the basis by which 15 participants were selected. Additional meetings were conducted with the flight safety officer of the selected air base and Air Force aviation psychologist, and the exact interview protocol was discussed and planned. The staff chosen for this study were crew members of the selected air base, therefore, pilots and loadmasters were participating in this study. The air transport support operations unit of the concerned Air Force was chosen for this thesis research studies. Further details on the operations of the air base can be found in Chapter 3. Therefore, the data collected in the selected air base reflects their views.

4.4.2 Data capture

The aim of collected data through the interviews is to fulfil the objectives of this thesis as well as to address research questions. Interviewing as a research method can collect and analyse data by using different types and styles of interviews and it is known as the most common choice of qualitative research approach among researchers. The way that data arising from the research is collected and the aims of data analysis both influence

the selection of the method used to analyse interview data (Knottnerus & Tugwell, 2010). In this thesis, the selected method to data collection allows us to find the concepts, which may become the basis for emerging new theories, and hypotheses directly from the field. Therefore, a grounded theory approach such as systematic methodology to data collection was selected as it is the most appropriate approach to cover the objectives of the interviews and allows us to explore and generate plausible and useful theories and concepts from the field. What's more, a grounded theory to data collection approach may not only be suitable for qualitative data collection methods, but also for some quantitative ones (Knottnerus & Tugwell, 2010). This approach was selected as the most appropriate one for studies in this research, as it involves hypothesis and theories based on data collection and its analysis.

This study conducted semi-structured interviews as a qualitative research method, including a pre-structured set of open questions, giving an opportunity for the interviewer to explore further. Semi-structured interviews are flexible and allow for the collection of data to cover topics selected for these interviews, including additional unplanned questions to follow up the answers of the interviewees. The researcher experienced minor challenges in terms of military confidentiality; therefore, some unplanned questions remained unanswered by participants. Questions for these interviews were developed according to the researcher's knowledge of fatigue at the time and knowledge, as acquired through literature review described in Chapter 2. These questions were first reviewed and approved by the researcher's supervisors and concerned Air Force - Flight Safety Directorate due to military-sensitive operational environment and their special requirement. After that, an ethical approval was sought from the CURES. Figure 4-2 presents a semi-structured interviews development process.

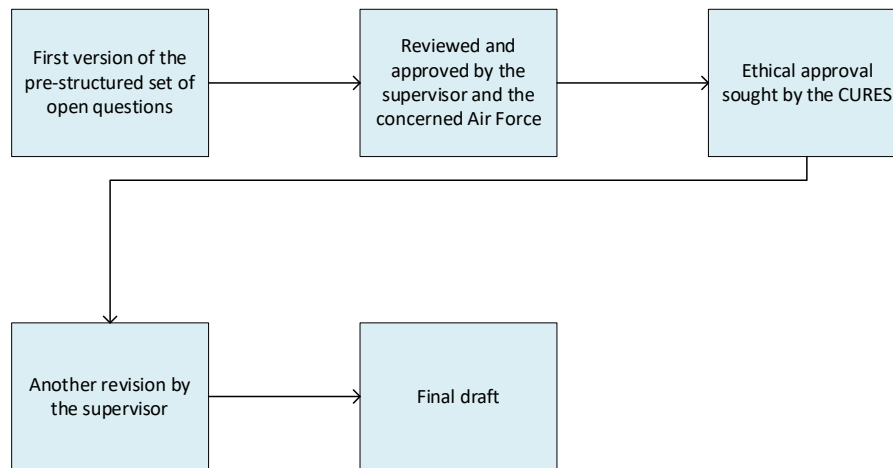


Figure 4-2. Semi-structured interviews development process

The interview script's initial section examined the interviewees' job requirements and responsibilities, as well as how they are related to and affected by fatigue, including the fatigue management arrangements and tools. The second part of the script was designed to explore and describe the indications and impacts of fatigue-related risk, and how they are managed by the interviewees. Moreover, the questions aimed to explore and identify the military culture within the organisation. The semi-structured interview questions can be found in Appendix B.

4.4.3 Data analysis

The preferred method for analysing qualitative data was an inductive thematic approach, which is a data-driven approach without predetermined theories that allows for the identification and examination of themes and concepts from the qualitative data collected throughout the interviews. It also allows for patterns that may otherwise remain unknown, to be uncovered (Naeem et al., 2023). It was expected that some specific themes would emerge from collected data and connections between them based on the literature review in Chapter 2. This approach allows theories and concepts from interviews to be developed, as well as hypotheses directly from the field. Semi-structured interviews were conducted in the selected air base with the specific operational objectives and principles of air transport support operations, management arrangements and active fleets that apply to these operations.

4.5 Study 2: Survey Questionnaire

The results of Study 1 revealed a number of parameters that influence performance or human behaviour during flight and duty time or are the cause of fatigue experienced during operational and organisational procedures, as well as factors arising from family and social life. This research study examined Objectives 2 and 3 and their respective research questions of this thesis:

O2: To construct a military-specific fatigue model that encapsulates the fatigue stressors and countermeasures identified.

O3: To explore the current management of fatigue and sleep training.

The main basis for the development of the questionnaire was the data collected in the first study, and a fatigue and sleep questionnaire literature review were used as a reference. For example, sleep and fatigue issues surveys (Miller et al., 2011), crew factors in flight operations and exploring whether fatigue is a problem in military aviation. The researcher also used her industrial experience in questionnaire design and statistical analysis. The knowledge and data from Study 1 and literature reviews were used across the questionnaire to direct the creation and modification to questions. Every question was developed and arranged in accordance with the findings of Study 1 and the literature review and reflects the elements that are recommended to be important in future fatigue arrangements. The literature review (Caldwell & Gilreath, 2018; Tassi & Muzet, 2000) was used to construct some questions through changing and tailoring shiftwork questions to before and during pandemic period, whereas others were created to capture the idiosyncrasies of fatigue. For instance, the question *In a typical week, how many hours do you fly?* was modified to shiftwork questions before and during pandemic (question 5 and 6 in the fatigue questionnaire). Moreover, certain questions were simply changed by switching the aircraft type (question 3 in the fatigue questionnaire). Furthermore, the next section discusses the review process, and the questions incorporated into the final version of the fatigue questionnaire.

An agreement about the distribution and form of a questionnaire was discussed with the military front-line staff at the end of Study 1. It was agreed that the questionnaire should be distributed to all crew members (i.e., pilots and loadmasters) in the assigned unit. Therefore, all crew members were invited by the Air Force to participate in the questionnaire survey via emails and intranet. The questionnaire was created for crew members only because the front-line staff (i.e. base commander, etc.) were not available for the participation in this study research. Some initial hypotheses and questions related to managerial level and frontline staff were, therefore, removed from the research. The three components of the questionnaire were designed to assess different features of fatigue experienced by the crew members. Section one focused on the general demographic information, section two assessed crew members' sleepiness experience and view, as well as the quality and quantity of sleep. The third section assessed fatigue experienced by the crew members and how they perceived it during operational performance and if so, how they reported fatigue. Moreover, the third section of the survey questionnaire assessed fatigue training and fatigue reporting features. A Qualtrics internet-based questionnaire survey allowed anonymity of the participants and encouraged their frankness.

The survey question sequence and flow were thoughtfully organised, and therefore, the concept of funnel technique and priming effects was used. These concepts are supported by the initial questions, which examine demographic data and general data, and the views of participants on fatigue and sleep hygiene and work they do. The questions then broaden (funnelling) and expand to a more specific range of questions on sleep hygiene and factors influencing sleep quality and quantity. After that, the questions on fatigue arrangements become even more detailed (funnelling), and they end with questions about training on fatigue and sleep. Every questionnaire section employed the same concepts, such as in the first section *About you and work*, the initial few questions are general like "What is your job role?" and then questions expand to a more specific questions "Before the COVID-19 pandemic, on average, how many hours do you fly in the aircraft in a month?" and "What is your commute time in minutes (from home to work and back)?" . Moreover, the second, third, and fourth sections began with

specific questions to brief the participant on each sub-theme. To give an example, the section *About sleep* begins by examining the participants' average sleep before delving into the variables affecting sleep quality and quantity. Appendix C includes the Fatigue Questionnaire.

Most fatigue questionnaires found in literature reviews focus mainly on factors influencing fatigue, sleep, and scales, which are used to measure fatigue and sleep. Therefore, the fatigue and sleep contributing factors have been also included in this military fatigue questionnaire, while the fatigue and sleep scales are not one of the objectives of this thesis.

4.5.1 Questionnaire design

After several reviews by supervisors and Air Force management staff and finally CURES, the questionnaire was developed. Figure 4-3 shows the questionnaire development process. The questionnaire was initially compiled by 25 questions according to the results from Study 1 and the literature review, excluding questions exploring the pandemic effect on fatigue and fatigue reporting mechanisms and associated feedback. The questionnaire was assessed by supervisors, and their comments and suggestions covered a broad range of topics, including the quantity and nature of questions, missing topics, to the questions' phrasing, which aimed at making the questions clearer, for example by substituting in *a typical month, how many hours for on average, how many hours*. It was further recommended to increase the number of questions and add the missing topics on fatigue reporting, and the recommendations on how to do that were presented. Moreover, it was recommended to use different types of questions, for example, closed format statements, ranking and rating, open format, and different types of responses such as scales (Likert scales), ranking, category selection, and free text. The questions were chosen based on the conclusions from the literature review and Study 1, as shown by the Table 4-1 that summarises the question topics, the questionnaire section to which they belong, and their source.

Table 4-1. An overview of the question topics

Question	Section	Topic	Source
1	About you and work	Job role	Literature review, Study 1
2		Age	
3		A/C type	
4		Flying experience in years	
5		Flying hours before the pandemic	
6		Flying hours during the pandemic	
7		Flying hours in a simulator	
8		Duty hours before the pandemic	
9		Duty hours during the pandemic	
10		Overtime working hours before the pandemic	
11		Overtime working hours during the pandemic	
12		Commute time	
13		Daytime flying before the pandemic	
14		Daytime flying during the pandemic	
15	About sleep	Quantity of sleep	Study 1
16		Unintentional sleep	
17		Sleep disturbing factors	
18	Fatigue arrangements	Fatigue stressors	Study 1
19		Performance degrading effects	
20		Type of performance degrading effects	
21		Fatigue countermeasures	
22		Fatigue reporting mechanisms	
23		Fatigue reporting	
24		Associated feedback	
25		Feedback satisfaction	
26	Training on fatigue and sleep	Training effectiveness	Study 1
27		Type of fatigue training	
28		Training on sleep hygiene	
29		Type of sleep training	
30	Other comments	Other comments	Study 1

Based on the recommendations and comments received, the questionnaire's second version was produced, and the arrangement was made available online. In a pilot testing/pretesting, the questionnaire was given to seven pilots from the Air Force, who were requested to provide feedback on its design, question sequence, relevancy, and the time needed to complete the questionnaire (Reynolds et al., n.d.). General errors were found, and some suggestions were made concerning the content, wording, and the formation of the online questionnaire survey, which would allow participants to

compile it in several intervals due to the nature of the military operations. Following the incorporation of these suggestions and comments, a third version of the questionnaire was produced.

Total completion time of the survey was on average seven minutes, which fell inside the suggested time frame by the Air Force. A further review was made by supervisors and one recommendation on the free-text question was made, which was subsequently considered, and version four of the questionnaire was produced. A final review was conducted by supervisors and Air Force managerial staff and version four of the questionnaire did not receive any final suggestions. Therefore, this version of the questionnaire served as its final iteration, and it was prepared for population distribution. Figure 4-3 presents the questionnaire survey development process.

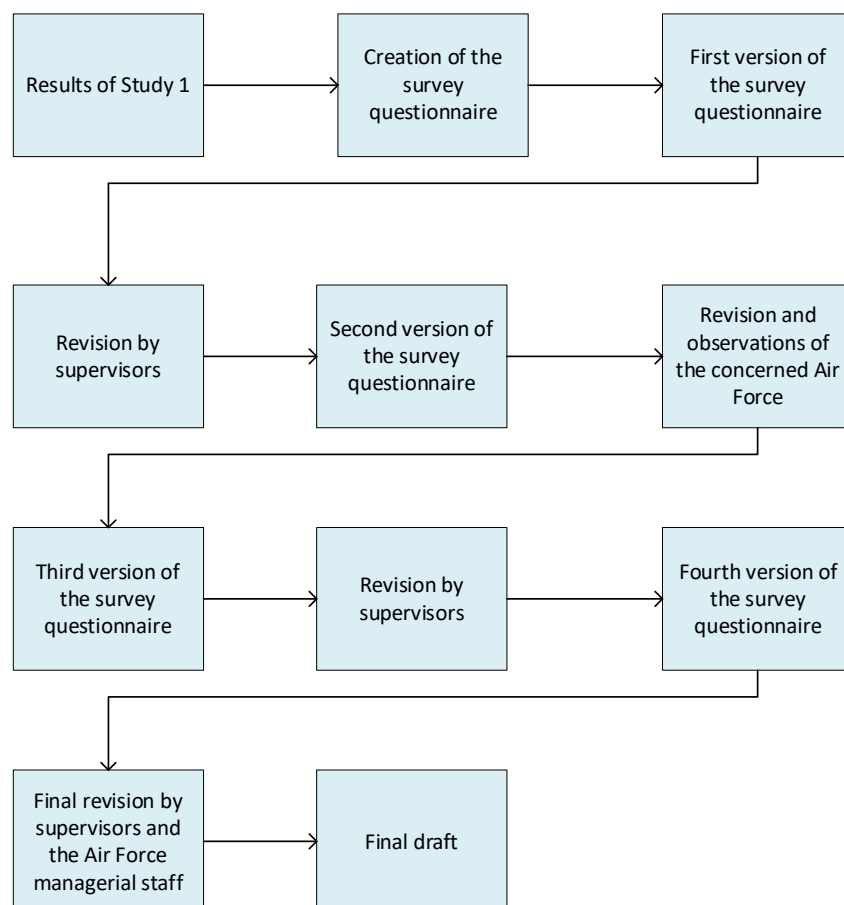


Figure 4-3. Questionnaire survey development process

4.5.2 Data capture

The survey was published online using Qualtrics software, which was available to all crew members in the selected unit. The survey was available to be completed both from a computer or any smartphone device covered by the internet, and crew members were able to complete it in several time intervals as the nature of the operations required a flexible approach to conducting a survey. Furthermore, an invitation to participants was posted on the Air Force selected base intranet and was also sent out via email to all crew members in the selected air base.

Data collection started on the 8th of July 2021 and lasted 12 weeks. A few reminders were sent out by the flight safety officer of the selected unit as some crew members were on an annual leave over summer period. By the conclusion of the quantitative study, 122 responses in all had been recorded where the total number of crew members in the unit has been unknown due to safety concerns. Although the total number of crew members has remained unknown, the Air Force managerial staff confirmed that it was not a biased sample, and the findings reflect the opinions of the chosen sample.

4.5.3 Data analysis

Structural equation modelling (SEM), a statistical technique for estimating and testing models using observed and latent variables, was employed to examine fatigue-related potential risk factors. This approach was selected because it is particularly effective for analysing complex cause-effect relationships involving latent constructs that cannot be directly measured (Tarka, 2018). SEM allows simultaneous examination of multiple dependent and independent variables, making it uniquely suitable for understanding the multifaceted relationships in this study. Alternative techniques, such as multiple regression, were considered; however, they were deemed less appropriate due to their inability to model latent variables effectively. SEM fit indices, including RMSEA (<0.08), CFI (>0.90), and SRMR (<0.08), were evaluated to ensure the model's adequacy. Additionally, the sample size was assessed against the recommended guideline of 10–20 cases per estimated parameter, and it was found to be sufficient.

The data collected was analysed using both descriptive and multivariate statistical techniques in R software, with the Lavaan package utilized for modelling and graphical presentation. For non-parametric analysis, Friedman's ANOVA was used due to the non-normality of the data and the ordinal nature of repeated measures. This method was chosen as it avoids the assumptions of normality and equal variances required by traditional ANOVA. The appropriateness of Friedman's ANOVA for ranked and repeated measures data in this study was confirmed.

A detailed explanation of the statistical techniques used, including the rationale for their selection, assumption testing, and results interpretation, is provided in Chapter 6.3 (Data analysis).

Based on the literature review and qualitative research in Study 1 some predictions were made about cause and effect, which would link the hypotheses identified below. Moreover, measures had to be assigned to these links to test the existence and strength of the relationships. Therefore, the Lavaan tool was used to enable the use of a technique called structural equation modelling, to specify a model, to enter a measurement variable for that model and see how well the model fits the data. Chapter 6 elaborates on the methods used and the analysis's findings.

The hypothesis for this thesis were as follows:

Hypothesis 1. Unpredicted operations and family issues have significant impacts on sleep hygiene.

This thesis investigated whether unpredicted operations and family issues have a higher impact on sleep hygiene than other identified fatigue stressors in this thesis.

Hypothesis 2. Swapping roles with colleagues, coordinated in-flight naps, exercise, and caffeine intake are the most utilised fatigue countermeasures among all crew members.

Fatigue countermeasures were investigated throughout this thesis by first identifying fatigue countermeasures used by crew members at the selected air base, including swapping roles with colleagues, coordinated in-flight naps, exercise, and caffeine intake as some of the most utilised possible countermeasures in comparison to others identified in this thesis.

To address hypotheses H1 and H2, **Friedman's ANOVA** (Analysis of Variance) was used. The rationale for selecting this test is rooted in the data characteristics. To further analyse differences between specific related measurements post-hoc, the **Durbin-Conover** test was applied.

Hypothesis 3. Sleep is positively related to fatigue and to countermeasures.

Hypothesis 3 investigated the relationship between sleep, fatigue, and fatigue countermeasures by applying Structural Equation Modelling (SEM). Structural equation modelling analysis will consist of the following steps: determining the research model based on the theoretical framework and interpretation of the relationship between factors and their measures; assessing construct validity, i.e., convergent and discriminant validity; determining the measurement model including the confirmatory factor analysis; and describing the estimated model coefficients, and then performing the analysis.

For H3, **structural equation modelling** (SEM) was employed using the Lavaan package in R. In addition, **Variance Extracted** (AVE) and **Composite Reliability** (CR) were computed.

Hypothesis 4. There is no difference in the frequency of crew members who have not received any training on fatigue and crew members who have received fatigue training.

Hypothesis 5: There is no difference in the frequency of crew members who have not received any training on sleep hygiene and crew members who have received sleep hygiene training.

Hypotheses 4 and 5 explored one of the important factors throughout this thesis referring to potential training on fatigue and sleep hygiene for crew members at the selected air base. In the development of a military-specific Fatigue Report Form it is crucial among other factors to understand what the fatigue and sleep hygiene training is, as well as when the crew members have received it, and the time frequency the crew members received it. This enables a better understanding of an occurrence reported. The **chi-square test of equality of two proportions** was employed to address hypotheses 4 and 5.

4.6 Study 3: Military Specific Fatigue Report Form - Heuristic Evaluation and Testing

The fatigue reporting procedure is a component of a Fatigue Risk Management Process, including fatigue-related hazards, safety data and scientific studies, fatigue data and information management procedure, procedure for fatigue modelling, analysing work schedules and fatigue risk assessment process. This study details the use of the results of the thesis's two earlier studies: the semi-structured interviews and the questionnaire survey to develop an appropriate fatigue report form, which shall contain all relevant factors identifying fatigue level, its reasons and consequences including countermeasures taken to combat fatigue, sleep hygiene and their relationships.

The principal aim of developing a military-specific fatigue report form is to give an opportunity to all crew members to report any fatigue-related issues and to identify and analyse the role of fatigue in safety events, therefore, to improve the overall safety. This is to be achieved by exploring objective four of this thesis, which tries to address research question RQ6 described in Chapter 2 and replicated below.

Objective 4. To develop a military-specific Fatigue Report Form that captures key fatigue-related factors and their interrelationships.

RQ6: What type of Fatigue Report Form would be suitable for the selected air base?

4.6.1 Development of military-specific fatigue report form

The proposed fatigue report form is structured by 6 sections providing detailed information of the event, namely: Personal details, Fatigue feelings details, Sleep information and potential fatigue causes, Fatigue countermeasures, Fatigue and sleep training and suggested corrective actions.

Participants in this study were selected by the Air Force itself and were anonymous to the researcher. The researcher shared the proposed form and heuristic evaluation checklist with the selected air base through email and the selected air base further distributed the documents to selected crew members for this study which then evaluated the proposed form by filling in the associated Heuristic Evaluation Checklist which is a method used to help identify the usability of the reporting form in terms of its user interface design according to the known usability principles. This Checklist considered the evaluation's objectives and goals, heuristic criteria, how the individual evaluations were conducted, and the results analysed. This method was used to evaluate the proposed fatigue report form at the beginning of the development process and to identify usability problems. Issues found with usability testing represent the real issues of the proposed fatigue report form, while potential issues are identified during the heuristic evaluation which require the users to evaluate the usability by reviewing and offering a feedback based on given heuristics (Jackson & Cheng, 2018). It is important to mention that evaluators were the end-users of the fatigue report form; therefore, heuristic evaluation and usability testing were performed at the same time.

The iteration procedure (see Figure 4-4) for the development of Fatigue Report Form is described as follows:

The first draft developed included five sections providing information on Personal details, Fatigue feelings details, Sleep information and potential fatigue causes, Fatigue countermeasures, and suggested corrective actions. The first draft did not include a section about Fatigue and Sleep hygiene training received, however it was added in the second draft after thorough discussion with the researcher's supervisor as this

information is important for a better understanding of the occurrence reported. After the second draft, the researcher communicated with the selected air base for the revision of the proposed Fatigue Report Form draft and associated Heuristic Evaluation Checklist. The selected air base took 14 days for the revision of the proposed Fatigue Report Form and associated evaluation form; they highlighted the importance of the rank prior to an individual's name in the reporting form. The researcher made required changes in Fatigue Report Form, shared it with supervisors who confirmed the third draft, and the researcher communicated with the selected air base once again for the arrangement of the execution of Study 3. The air base asked for both amended documents (i.e. the Fatigue Report Form and the Heuristic Evaluation Form) to share them with the anonymous participants selected by the Air Force itself. The participants received the documents to fill in via email by the Air Force. After 9 days the researcher received the feedback from the Air Force and started analysing the data by using R programming for statistical computing and data visualisation.

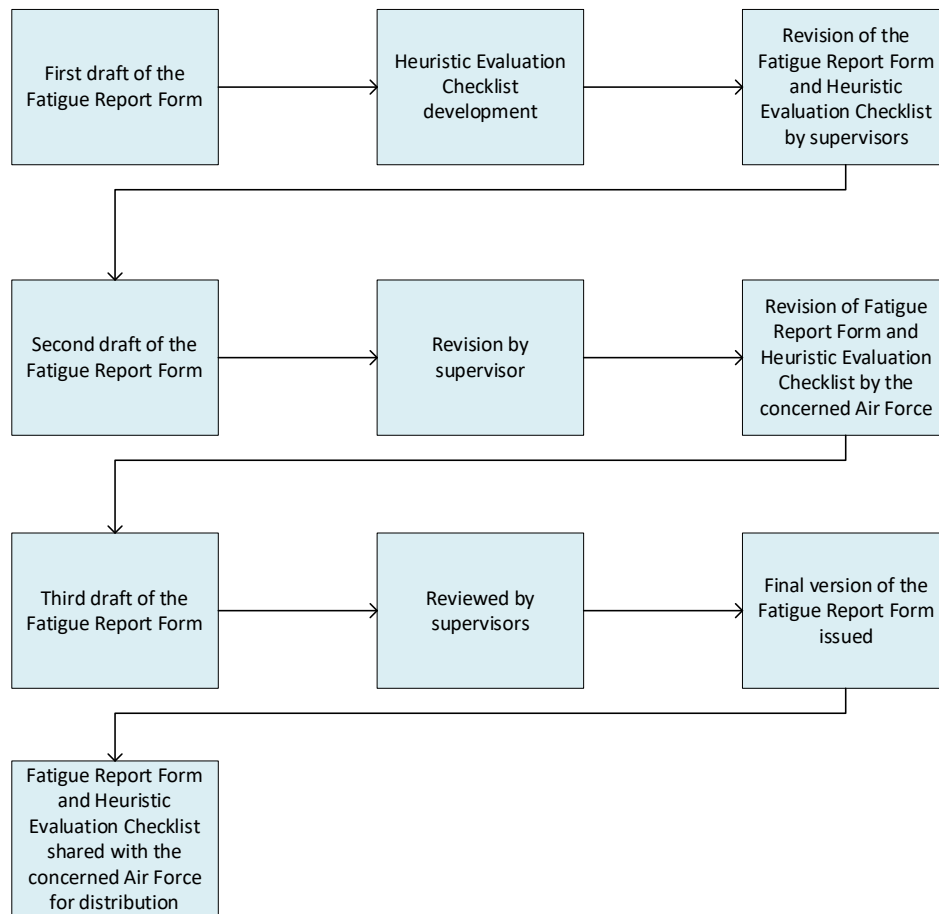


Figure 4-4. Development of the Fatigue Report Form and Heuristic Evaluation Checklist

4.6.2 Data analysis

The answers received were overviewed in two forms: the frequencies of answers for each question in the frequency table, and also in the table of descriptive statistics, which analysed the answers based on their number values (ranks). Additionally, two charts accompanied the tables: bar chart of frequencies illustrating the frequency of each response for the questions, and bar chart of means with standard deviation whiskers depicting the average ratings and the associated standard deviations. Chapter 7 provides an explanation of the analysis's findings using the software R.

4.7 Summary

Chapter 4 described and talked about the chosen research methods applied to investigate the objectives outlined in previous chapters and to respond to the research

questions. Moreover, the methods employed investigated current fatigue management in military aviation at the selected air base of the concerned Air Force. The application of each method, both qualitative and quantitative, was described in detail including their background, results and analyses which are presented in the next chapters. Based on the objectives of this thesis and literature review, an inductive exploratory approach was used. Finally, Table 4-2 presents an overview of the methods and research questions for each research objective.

Table 4-2. An overview of research questions and approaches to each research objective

	Research questions	Approach/Methods
Objective 1	<p>RQ1: Do unpredicted operations and family issues impact sleep hygiene compared to other factors among military personnel?</p> <p>RQ2: What is the prevalence of using swapping roles with colleagues, coordinated inflight naps, exercise, and caffeine intake as fatigue countermeasures compared to other strategies?</p>	<ul style="list-style-type: none"> • Semi-structured interviews • Literature review
Objective 2	RQ3: How is sleep quality connected with perceived fatigue levels and the implementation of fatigue countermeasures in the military setting?	<ul style="list-style-type: none"> • Semi-structured interviews • Literature review • Questionnaire survey
Objective 3	<p>RQ4: What proportion of crew members have undergone training that addresses fatigue management?</p> <p>RQ5: How widespread is the training on sleep hygiene among crew members, and what are its perceived effects on sleep quality?</p>	<ul style="list-style-type: none"> • Semi-structured interviews • Literature review • Questionnaire survey
Objective 4	RQ6: What type of Fatigue Report Form would be suitable for the selected air base?	<ul style="list-style-type: none"> • Semi-structured interviews • Literature review • Questionnaire survey • Heuristic evaluation and testing

Chapter 5 - Study 1: Semi-structured Interviews

5.1 Chapter Introduction

The initial research study on fatigue selected for this thesis; the semi-structured exploring interviews is discussed and explained in this chapter. The chapter explains the background of the selected research method, including the methodological implications of the interviews. What's more, it describes the development, preparation, and execution of the interviews, followed by the qualitative data analysis conducted by using NVivo software. This chapter concludes with the results of the qualitative analysis and iteration of the fatigue-related factors and their interactions within the FRMS framework, which is introduced in Chapter 2.

5.2 Method

In order to support an exploratory inductive approach to researching fatigue in military aviation, an interview script and protocol were developed and revised. Chapter 4 contains more information on the methodology that was employed for this study.

5.2.1 Sample description

Semi-structured interviews have been conducted in the selected air base. First, the interview script aimed to explore interviewees' job requirements and fatigue management arrangements. The second part of the script explored indicants and impacts of fatigue-related risks and finally the script explored the military culture within the organisation. There were 17 interviews conducted, whereas two of them have been excluded, one due to a language barrier and the other where the interviewee was a member of the United States Air Force (USAF), and authorisation should be sought from the USAF to participate in this study. Therefore, there were finally 15 interviews conducted, 7 interviews with loadmasters and 8 with pilots. The interviewees' average age was 39 years old ($SD=8.398$); the youngest was 29 and the oldest was 50. They have 16.4 years of work experience on average in military aviation industry.

5.2.2 Interview procedure

Interviews were scheduled to occur over the course of six consecutive working days with the selected air base. The interviews were conducted in November and December 2019 in accordance with the selected unit. There were three separate parts to the interview: demographics, organisational arrangements and individual job requirements and responsibilities, and fatigue risk management processes and tools. Appendix B shows the interview script.

Every interview was carried out separately in a flight safety department of the selected air base in accordance with previous arrangements with the flight safety officer and military aviation psychologist. As previously mentioned, interviewees were selected by the Air Force itself. A room with appropriate accommodation was given for this qualitative research to allow both interviewer and interviewee to remove any obstacles that might hinder free and open discussion on the selected topics. In accordance with interview techniques, recommended by Robson (Knottnerus & Tugwell, 2010), the interviews were set up as follows.

1. Introduction: The researcher gave a brief introduction, clarified the reason for the interview, guaranteed anonymity, and mentioned that the interview is audio recorded, and notes are taken. Due to a military nature and environment, the permission for audio-recording and taking notes was sought and approved in advance from the Air Force rather than the individual interviewee, as the Air Force had decided.
2. Questions: Participants were given a series of questions about operational and organisational fatigue in military aviation.
3. Any other observations: The interviewees had the chance to offer any additional observations relevant to the topic or to share any aspect of their experience of looking for topics that had not been covered or discussed in the interview.
4. Closure: The interviewer expressed gratitude to the participants for their assistance and time.

5.2.3 Data analysis

An inductive thematic analysis approach was selected for this study, which used the collected data itself to derive the structure of the analysis and to create the themes. Based on the data collected, the ideas and/or concepts were tagged with codes and were grouped, and further summarised. Codes were grouped into higher- and lower-level categories.

Step 1: Data gathering. The method used to gather data was semi-structured, exploratory individual interviews, which were audio-recorded by using Voice Memos on an iPad.

Step 2: Getting the data ready for analysis. Microsoft Word was used to transcribe the interviews (about nine hours of audio) into text format before transferring the data into the qualitative data analysis computer programme NVivo 9.

Step 3: Characterisation and categorisation of themes. After reading over each transcribed interview, interesting topics were noted, categorised, and arranged into preliminary themes. Consequently, an initial template was developed following the individual examination of each preliminary theme, which then led to the first categorisation of themes. A hierarchy was created after each theme was thoroughly and independently investigated for pertinent information.

Step 4: Highest-order themes. A final template that listed the highest-order themes backed by pertinent data, definitions, and names was produced once all pertinent data had been applied to each topic.

All interviews were audio recorded and attended by the military aviation security employee to comply with the concerned Air Force requirements prior to this research study. The collected data was reviewed and analysed by the researcher on a continuous basis after each interview day. Therefore, the researcher had an overview of data collected and could identify when the responses became identical and decided to finish the interviews after interviewing 15 participants (Hennink & Kaiser, 2022). The NVivo

software was used to initially code and categorise collected qualitative data and to develop themes with the focus on the highest order themes, which were used to generate theory and hypotheses directly from the field. Semi-structured interviews are based on inductive reasoning/principles and coding the themes with quotes and keywords; therefore, this research approach aligns with a grounded theory-based analysis. The grounded theory is an inductive process of data collected. There were several themes identified, and Table 5-1 shows an overview of interview quotes, which identified some of the themes in the initial template.

Table 5-1. An illustration of themes and quotes

Theme	Quotes
Organisational arrangements	<p>“There are many layers of organisational issues and there are additional tasks that are not planned and known to the crew so when the crew receive the task there may be unfamiliar tasks added subsequently to the mission”. (I1)</p> <p>“The organisational arrangements are not good enough, not clear”. (I1)</p> <p>“There is a lot more to improve.” (I10)</p>
Deployments	<p>“Accommodation is different for pilots and loadmasters” and “This may be an issue, which can affect loadmaster’s morale” (I11)</p> <p>“The only stressor is being away from my family and if something happens at home, I am not able to help and that is very stressful” (I9)</p> <p>“When I am deployed, I am more focused on the job itself and myself” (I13)</p>
Training	<p>“We have a lot of exercises on a self-management and fatigue” (I15)</p> <p>“Training on fatigue would be beneficial” (I12)</p>

5.3 Results

The analysis began with identifying of **133 codes**, representing distinct patterns and topics observed across the dataset. These codes were subsequently refined and grouped through an iterative process, resulting in the development of **81 sub-themes**. The 81 sub-themes were organised into a hierarchical structure, culminating in identifying of **6 overarching themes**. These themes reflect the broader conceptual categories emerging from the data and provide a comprehensive view of the research topic.

The main objective of this study was to examine the prevalent fatigue stressors and countermeasures within the military operations at the selected air base. The highest-order themes were arranged to convey the organisational and operational overall understanding, including fatigue precursors and consequences within a selected air unit. This made it possible to illustrate the peculiarities of work arrangements and how each one affects fatigue stressors and consequences. The themes are displayed in a Table 5-2 with a description.

Table 5-2. Themes identified in Study 1 of this thesis

Number	Name	Description
1	Overall views	Feelings and issues on general attitudes about organisational and operational arrangements.
2	Organisational arrangements	Details of organisational issues.
3	Fatigue management	Details on how fatigue risk is managed including fatigue consequences and countermeasures used.
4	Stressors influencing fatigue	Details on physical, psychological fatigue
5	Deployments	Arrangements of deployments in various environments and operational context.
6	Trainings	Details on which trainings are available and their frequency and effectiveness.

Under each theme, sub-themes are provided in the order that respondents referenced the sub-themes and according to the correlations between fatigue-related factors. For example, interviewees have experienced fatigue in different forms such as “psychological” and “physiological” fatigue and, moreover, “fatigue countermeasures” respond to fatigue with a number of “strategies and routines” both “on the ground” and “in-flight”.

Finally, the information discussed and displayed was obtained exclusively from the interviews, and it represents the respondents’ experiences and perception of fatigue by the interviewees in the selected air base and do not represent the Air Force as a whole, due to different operational and organisational requirements referring to several air units with different operational context. Issues with fatigue risk management should be expected across the industry due to the constant reduction in military budget and the

aim to accomplish more with less resources available and the lack of fatigue-related regulations.

5.3.1 Theme 1: Overall views

This theme identifies the various attitudes and viewpoints of the interviewees with reference to fatigue in military aviation. Figure 5-1 illustrates the findings from thematic analysis focusing on theme 1, overall views, and its sub-themes and associated codes.

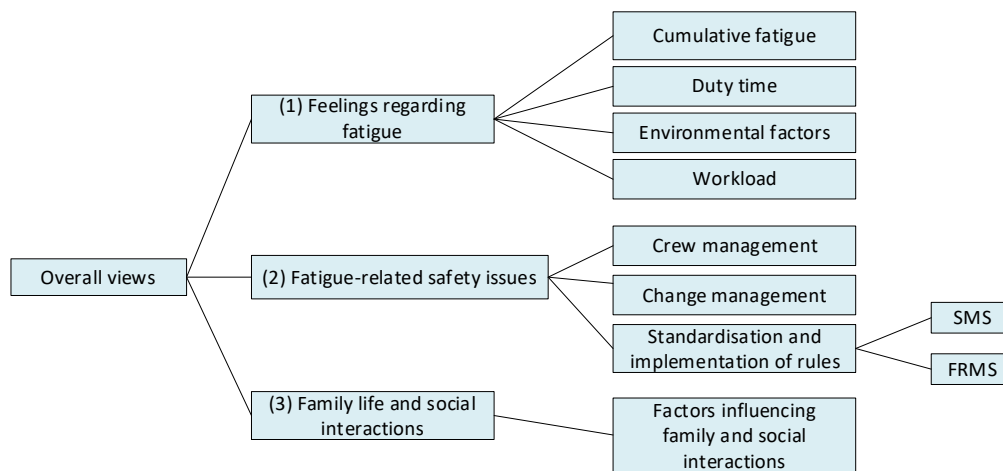


Figure 5-1. Overall views systematic diagram

(1) Feelings regarding fatigue

The interviewees perspectives towards the fatigue varied between cumulative fatigue, duty time, environmental factors, and workload. There were eight interviewees who generally experienced fatigue as a cumulative fatigue, including not having enough opportunities to rest and sleep during the circadian low with consequent cumulative sleep debt. This was also due to extended duty hours across a series of days, as well as the mission stress, for example, “Duty hours are not planned, there is a lot of schedule changes, and evening and night-time duties are really exhausting” (Interviewee (I) 4). Alternatively, inadequate sleep facilities and mission stress facilitate serious sleep deprivation leading to impaired performance of an aircrew; for example, “Mission stress is related to environmental conditions and several other disturbing factors such as sleep loss that affect my performance” (I9) and “When I am deployed, I stay in a small single

room and sometimes it is very noisy and too hot and I cannot sleep properly” (I6). Moreover, activities following trans meridian deployment may cause increased daytime sleepiness and impaired performance, therefore, an adequate rest should be provided by the Air Force to an aircrew to be fully rested and ready for a mission. For example, “Operational fatigue is not a one-dimensional problem, it’s a complex issue including a circadian misalignment, unpredicted duty hours, nighttime flying, crossing number of time zones, and operational pressure” (I7).

Duty time issues related to fatigue were stated by nine interviewees. They were complaining about constantly changing schedules and unpredicted duty hours that influence their stress levels, performance decrement and personal life, and overall well-being, which would then lead to the reduction of operational effectiveness and, moreover, safety. For example, “At the end I am very tired, continuous change of the schedule, no planning at all. The Air Force tries to do everything with less, and the plan is changed every few minutes. I have a feeling I work all day and there is no result at the end, it is frustrating” (I15).

A similar number of interviewees (6 interviewees) stated environmental factors influence the level of being fatigued. For example, “We are exposed to the climatic changes, weather, and long working hours.” (I11). Moreover, “I was very fatigued on a really long mission, under difficult environmental conditions, no proper nutrition and a lot of disturbing factors that affected my performance on that mission and made me fatigued.” (I9).

There were four interviewees, all of them loadmasters, who stated that the workload affected their performance and consequently made them fatigued after all. One of them stated “There is a mission for three people to load the cargo and we are only two available and this affects my workload performance and makes me fatigued.” (I9), moreover, “If we have to land three, four or even five times then the fatigue level increases because the workload is higher, and we need to sustain the performance much

longer” (I1). Finally, workload was identified also as one of the biggest fatigue stressors, “Workload is the biggest stressor that makes me nervous” (I2).

(2) Fatigue-related safety issues

Safety culture as a robust leading indicator or predictor of safety outcomes reflects attitudes, values and behaviours concerning safety and can enable efficient measures to preserve and enhance organisational safety. Fatigue-related safety factors indicated in the qualitative study are associated with crew management, change management, and standardisation and implementation of rules relating to safety management system and fatigue risk management.

Crew resource management is crucial for improving aviation safety, and interviewees generally had a positive attitude towards crew management. For example, “In our unit we are much more aware of working as a team than in any other Air Force units” and “It is important to share information and decisions with each other” (I11).

Another factor concerning safety Change management in the organisation. One of the front-line interviewees stated that “Change management in the Air Force always faces the resistance to changes” (I11). For example, an issue is one of the regulations, which is outdated and dates to 2004 and, therefore, it is not meeting the European military aviation regulation. Change management issues in the Air Force that were identified in a qualitative study are associated with non-aviation management or civilian aviation management which is not familiar with and do not fully understand the military aviation environment and military culture. Moreover, standardisation and implementation of rules should be one of the management priorities as fragmentation of rules, and standing orders may represent an issue toward an effective safety system due to inconsistencies in common European military aviation regulatory requirements. This, consequently, prevents an active safety system. Therefore, the introduction and implementation of military-specific SMS and FRMS, blended as necessary, would improve safety in the organisation. For example, “The FRMS would improve the current system” (I11), and “If we improve fatigue then we would also improve safety, and this

would change the procedures and culture as well” (I11). Whenever possible, military aviation regulations are underpinned by the ICAO set of principles, therefore, when discussing fatigue, it is crucial to address regulations and policies attempting to reduce the level of fatigue and meet the needs and complexity of military aviation industry through several regulatory fatigue-preventive measures such as SMS, FRMS, flight time limitations. When implementing civilian aviation regulations into the military aviation industry, they should be blended as necessary, to meet the needs and complexity of military aviation industry, as well as military culture. One of the interviewees stated that he is concerned about such transformation of the regulations from the civilian into military aviation environment, for example, “My worry is that the SMS in the civilian aviation is substantial and formal, which cannot be applied in the military aviation because we have missions, which are not always predicted and related to the formal part and I am afraid we will no longer be able to perform our job properly” (I11). Moreover, “If they (the Air Force) apply too many formalities we would lose money and life” (I11). The interviewee was referring to the reality that implementing the aforementioned regulations would be effective only in a normal mission but would not be effective in an unplanned mission. Also, another interviewee stated that “More standardisation is beneficial but on the other hand we have to carry out missions which cannot follow the civilian aviation standardisation” (I10).

(3) Family life and social interactions

Interviewees identified fatigue as a factor influencing their family and social lives. Most interviewees (11 interviewees) feel the biggest impact is regarding family, for example, “It’s difficult and important that my family understands my job and my wife knows its unpredictable and she understands that” and “Sometimes I come home really tired or late and it is not easy for the family. Family has to be stronger than me” (I4). Moreover, “My wife is pregnant, and I have a two-year-old child at home and the last-minute tasks disturb me a lot” (I7). When interviewees are fatigued, some of them prefer to take time at work after and relax before going back home (e.g., “Usually when I’m really fatigued after my duty, I take my time in a squadron to relax, to watch tv or take a half an hour

rest before going back home” (I2).) For only one interviewee fatigue does not influence his family life, for example, “I do not experience many problems with that, I try to divide my job from personal life” (I2). For another interviewee who does not have his own family, yet his job influences only his social life regarding planning his time off (e.g., “I cannot plan my annual leave or a trip in a specific moment” (I5)). Family and social life were exposed as one of the overall issues crew members have as the military environment represents a barrier to organising their private life, considering family, events planning, and other social interactions. There are a number of unexpected missions crew members have to be ready to join, along with last-minute and continuous changes to their planned schedule, operational and organisational changes of information that cause confusion and stress, and many other factors that influence their family and social life interactions.

5.3.2 Theme 2: Organisational arrangements

This theme discusses the organisational arrangements in the selected unit relating to a number of issues such as management and financial issues, unpredictable duty schedule and experiences of the interviewees on this subject, a lack of organisational and operational support and sources of information where the crew receives education and knowledge on fatigue and sleep hygiene. The associated sub-themes and the theme *Organisational arrangements* are presented visually in a hierarchical manner in Figure 5-2.

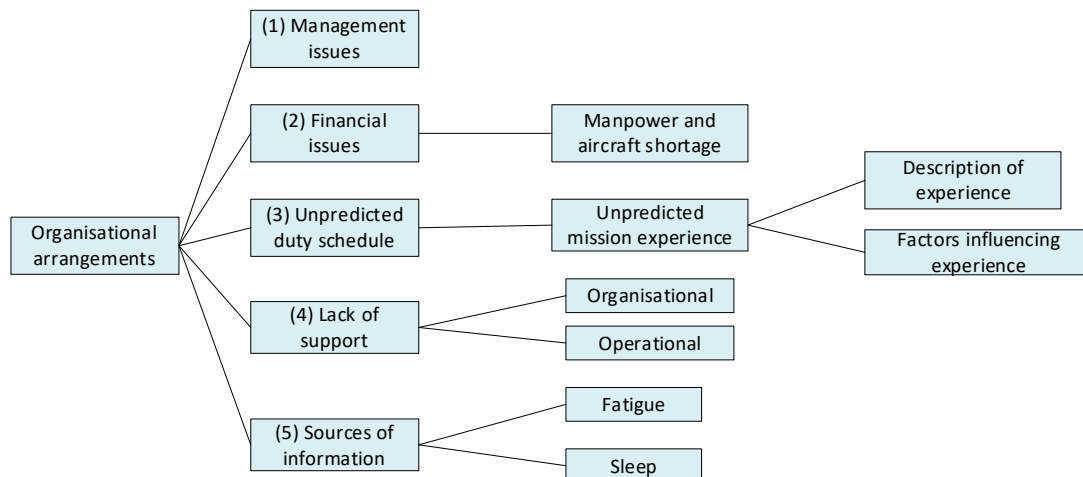


Figure 5-2. Organisational arrangements systematic diagram

(1) Management issues

Management issues can influence the overall safety of an organisation and should focus on organisational and operational needs and complexity and should work towards continuous safety assessments and improvements in all operational areas of an industry. Generally, an opinion of the Air Force interviewees exposes additional managerial attention to the particular squadrons such as Air Force fighter squadrons by investing more financial resources available and more top management attention in those units. Therefore, some interviewees stated there should be more attention and understanding by the management on fatigue in the selected unit as well. The crew mentioned financial obstacles towards the overall safety improvements, for example, “We have to be ready for everything, when we are deployed in Africa, we need to be vaccinated properly but we are not, they (the Air Force) cannot do everything at the last moment. The problem is money actually” (I15). Moreover, “It happens that the organisation does not clearly understand, which are our needs and because we fly low and slow the management believes that we do not experience any issues, that is easy for us to work” (I11).

(2) Financial issues

Constant cutbacks in military spending could seriously affect the overall performance and safety of an industry. The Air Force is struggling to deal with a shortage of manpower

and aircraft; therefore, mission readiness levels could be compromised and could also impact the readiness of the entire force. “We do not have enough resources such as manning and aircrafts to prevent problems” (I15) and “The Air Force tries to do everything with less, and they (the Air Force) change plans every few minutes. I have a feeling that I work all day and there is no result at the end” (I15). Moreover, “In the last few years we have a shortage in aircraft availability and the activity has become more difficult sometimes because things change a lot and people (crew) in our air base can be scheduled for multiple events in the same day, we are assigned to office work such as planning, training, or any other office activities and we also have to prepare for the mission next day” and “There are more things to do at the same time and that is a challenge” (I18). Interviewees stated that they feel pressure due to money savings which makes them stressed and fatigued. “I believe the top management is aware there are a lot of tasks people have to complete and there is a lack of resources, therefore, there is a big imbalance and the worst thing is that some commanders think they can do a lot with less and even better” and “There are issues due to a low efficiency of the aircrafts, there is not enough aircrafts and other resources needed” (I14). Additionally, one of the interviewees stated that “When there is a mission for three people to load the cargo and there are only two available then this affects the workload performance and causes fatigue” (I19).

(3) Unpredicted duty schedule

An unpredictable duty schedule is one of the biggest fatigue stressors identified in military operational settings. All interviewees stated that unpredicted duty schedule is the main source of stress, causing a feeling of uncertainty and consequently fatigue. There is no planned schedule available but just a draft of predicted duties due to the nature of the military operations. For example, “We have specific activities like courses that are scheduled but each day may bring unpredicted missions, and it can happen that we don’t know what tomorrow brings. When we fly relief missions such as flying after the earthquake, the schedule is not the same anymore. This is the nature of the operation itself.” (I11) and “This uncertainty is quite stressful and can cause fatigue as

well" (I11). Moreover, an unplanned mission is part of normal military daily operations "Usually I have a schedule on a daily basis one day before but in case of an unplanned mission I have to be very flexible." (I2). One such experience of an unpredicted mission stated "I had to fly one aircraft from our home base to the theatre, which took 12 hours of flight but the mission itself 15 hours. We landed in a different time zone and the flight was at night, not scheduled. I had to wake up in the morning and finally the flight was delayed so much that we had to fly in the night. Upon our arrival in the theatre, we were used as a crew because the other two crew in the theatre went out of duty hours. We actually did not expect that we would have to act as a flying crew when we landed. We immediately tried to acclimatise to the new time zone, going for lunch and having some rest. We were told to be used as crew at around 9 p.m. the same day after arrival in a theatre but the actual take-off time was at 1 a.m. and at that point we were awake for about 36 hours, which was 16 hours of flying. We had 8 hours to rest from the last flight but due to a different time zone the fatigue has reached a high level. After taking-off at 1 a.m. the mission took 15 hours and the morning after it was really difficult because of the fatigue." (I10). Some interviewees stated that organisation of an unplanned mission is not always clear and well organised, for example, "Organisation is not clear, especially with an unplanned mission, like now we are intervening due to the earthquake in Southeastern Europe and organisation of the operation is not good and clear enough. The problem is that there is a lot of different information available, and it is not clear which one is correct." (I1). Moreover, "The main stressor are changes that happen after the activities are already running" (I5). Due to continuous schedule changes people feel stressed and uncertain on a daily basis, which may cause fatigue in the long term. "There is a lot of changes that make me stressed because it is frustrating to cancel the mission just before it should take place", and "Due to a number of changes and other relevant issues there are delays, maintenance problems that push me very close to the limit of the crew rest period and I feel fatigued" (I8). A number of different factors influencing an interviewees' experiences of an unplanned mission refer to not well-organised operations, family, time zone changes. Therefore, there is an experience of circadian misalignment and sometimes difficulties with adapting to the new environment. For

example, “The continuous rescheduling is a sign of not good, organised operation” (I4). Furthermore, “It was a long mission, difficult environmental conditions, no proper nutrition, and there were a lot of other disturbing factors, which affected my performance and made me fatigued” (I9). What was indicated in a qualitative study is that more experienced interviewees experience less stress related to circadian misalignment and environmental changes. “When I was in New Zealand, I did not experience any issues with the circadian rhythm but when I came back home it took me 6-7 days to recover from a jet lag” (I13). “I was flying to California (USA), and flights were divided in different legs. According to our regulation we had to stay acclimatized to our home base timing and I experienced the biggest effect of the circadian misalignment when I came back home” (I7). Interviewees stated that unplanned missions affect their personal and social life, not allowing them to plan their personal appointments and holidays in advance, for example, “Usually, I am assigned to the mission just a day before the mission starts and this creates some sort of stress. It affects my personal and family life. I cannot plan some activities in my personal life in advance and it also affects my health appointments” (I12).

(4) Lack of support

As a result of operations not being well-organised operation there is a lack of operational and organisational support identified through the statements of the interviewees. Only two interviewees did not mention any lack of support in operational settings. Others stated that organisational and operational support could be improved referring to unplanned mission, training, workload, schedule planning, maintenance, manpower, and the general lack of support in a transport service operation. “The Air Force is more focused on fighters; they have more attention than the transport support service. Therefore, it happens that organisation does not clearly understand what our needs are and because we fly low and slow the management believes we do not experience any issues” (I11). Also, when there is a lack of support in terms of delivering an effective and updated regulations, “Change management in the Air Force always faces the resistance to changes” (I11). As already mentioned before, organisation is not clear, especially

when referring to an unplanned mission with too much information available at the same time. Therefore, this causes confusion among the crew who is trying to understand which information is correct and who are trying to adapt to continuous changes in a mission planning that need to be executed. For example, "Organisation is not clear, especially with unplanned missions, like now we are intervening due to the earthquake in Southeastern Europe. The problem is just when there is a lot of different information available, at the end it is not clear which one is correct" (I1). Moreover, "Things are not easy to organise in an operational centre because things come up unexpected like an emergency transport and there is a limited number of resources and there is a need to reschedule everything, and continuous rescheduling is seen as a not good organisation. This is because of the nature of military operations" (I4). They stated that safety could be improved by implementing SMS and FRMS into their operations "Implementing SMS would be beneficial. Now we manage safety in a way to wait for bad things to happen and then we react" (I4). This misses proactive and predictive risk management processes to ensure continuous improvement of safety. Some interviewees stated they wished to receive more information on fatigue either through training or briefings and debriefings "Some additional briefings would be helpful and would also motivate people to speak more about fatigue. If the time permits, we could have debriefings about the mission" and "It is important to speak more to each other about any concern relating to fatigue" (I12), "I believe lessons and briefings are important" (I14). Lack of support in terms of maintenance issues "Organisation in our air base has problems due to the aircraft shortage and poor maintenance due to financial issues and shortage of people and this is the greatest part that causes fatigue in the long term" (I8), indicated as one of the fatigue stressors in operational settings. Moreover, workload was another fatigue stressor identified by loadmasters only "Workload is high, and organisation is important to put more people on duty when the workload is higher than usual" (I9). One interviewee stated there is also a lack of support by older commanders "Some old commanders that are not flying often may not be familiar with the newest trends and ideas, therefore, for that reason there is a young co-pilot and combat pilot with him as

a crew to fill out the missing knowledge of a commander to perform the best. Old commanders are out-of-date in terms of crew management” (I10).

(5) Sources of information

Each crew is trained on fatigue and sleep hygiene which is important for keeping crew aware of and focused on any signs of fatigue and sleep issues they may be experiencing. The training includes considering what the causes are, which countermeasure to take, and why it is important to speak out and report any issues related to that. In the selected unit, a crew is trained on fatigue and sleep hygiene through the crew resource management (CRM) trainings, which take place first in a flight school. Then there is an advanced CRM training when people join the selected unit for the first time. Recurrent training is scheduled every two years focusing just on a single subject such as flight safety reports, decision-making, communication, etc. depending on the operational issues identified. Most interviewees stated they did not receive enough information on fatigue and sleepiness, for example, “CRM is more about communication rather than recognising fatigue and training is too theoretical. I believe there is not much interest from the pilots to be trained on that (fatigue)” (I10). Furthermore, “I received information on fatigue only once in the past, five or six years ago. I wish I could train more often on fatigue. I can get information now just through some briefings where we talk about sleep, power nap but this does not happen often. Training on fatigue would be beneficial” (I12). “We do not have particular trainings on fatigue, but we may get some information on fatigue during our regular courses such as CRM, through stress management. I am not familiar with where I can find information on fatigue, I am not aware of any posters, bulletins, newspapers, intranet” and despite this “I am very well informed about fatigue due to my experiences working in the military” (I1). On the other hand, the flight safety officer of the unit stated that the crew is trained enough on fatigue and sleep hygiene through the CRM and additional training with the flight surgeon. “During the conversion course in the unit the flight surgeon talks about fatigue and fatigue management strategies. When we do the flight safety stand downs, the flight surgeon always gives them a briefing during that day, he often speaks about

fatigue. So, there are many occasions when crew can get information and knowledge about fatigue, but there are just lessons and not training” (I11). The flight surgeon of the unit stated that people are not interested in listening about fatigue and sleepiness, during his courses, that they get bored when talking about fatigue. He believes it would be good to have more lessons on fatigue and sleep hygiene and it must be improved in the future.

5.3.3 Theme 3: Fatigue management

Fatigue management is a complex spectrum combining several different factors related to fatigue risk consequences and countermeasures, fatigue risk assessment, reporting on fatigue and its software for monitoring and fighting against fatigue. The associated sub-themes and the theme *Fatigue management* are presented visually in a hierarchical manner in Figure 5-3.

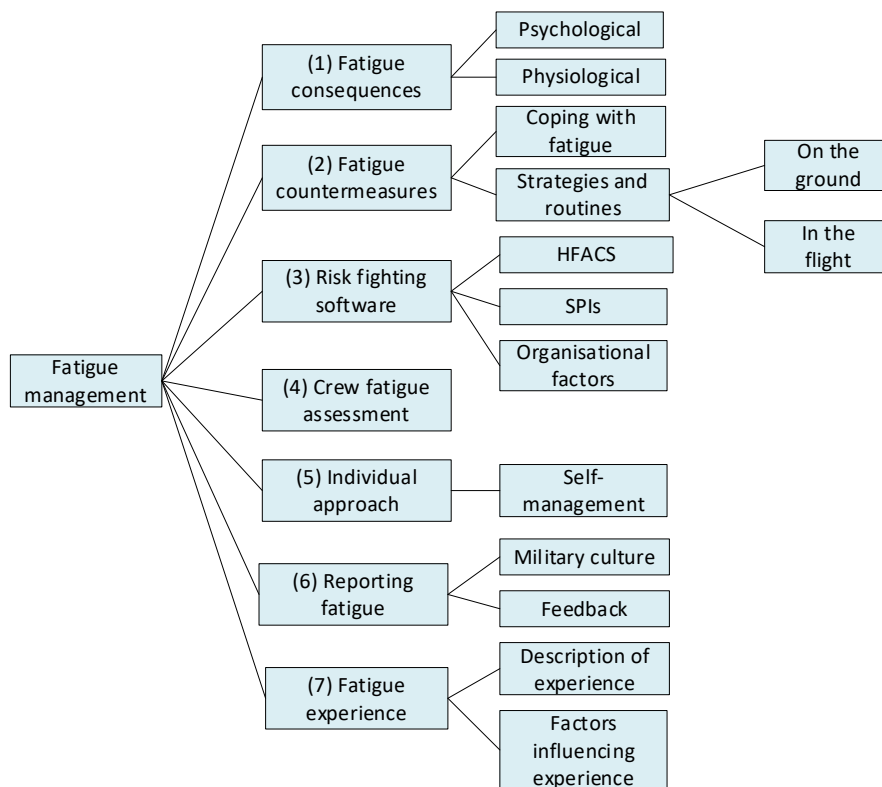


Figure 5-3. Fatigue management systematic diagram

(1) Fatigue risk consequences

Fatigue risk consequences are related to various psychological and physiological consequences on human performance, with the most identified behavioural changes being: tiredness, anger, mental stress, frustration, forgetfulness, eye-closure, sleepiness, backache, body pains, confusion, longer decision-making process, and attention decrement among interviewees. Interviewees stated a number of consequences experienced due to fatigue such as, "Fatigue influences my mental readiness, I do not feel physically tired, but my cognitive capability is decreasing, my decision-making process takes longer time, it can be decreased and not always the best" (I 11). "There are times when I feel really mentally stressed, they used to teach us stress is helpful in a way that we will work better under the pressure" and "When I am fatigued, I become tired and angry, and I take the anger back at home and affect my family life" (I 15). Therefore, fatigue may influence various aspects of human performance including family and social well-being. Moreover, "I feel tired, pains in legs and back, difficulties with reading or to fill out some form and to concentrate" (I 3), "When I am fatigued, I feel the same way as when I am thirsty or hungry, I feel sleepy and slow, eyes are closing, mental capacity decreases, and I feel stressed" (I 7). Sleepiness may cause negative impacts on situation perception, decision-making and overall human performance, and well-being. Moreover, decreased cognitive, behavioural, and physiological functions are the most common consequences of the lack of sleep. What is worrying is the following statement "Even if I am fatigued and tired, I will not bring this out because we are used to coming to work and being strong" (I4) and "The accompanying fatigue is something normal, we have to finish the mission" (I 1). Therefore, it is crucial to be educated and have some knowledge about fatigue risk indicators and consequences as well as which countermeasures may be useful to fight against fatigue. Some interviewees' statements relating to fatigue indicate how military culture may influence the way of perceiving fatigue. A flight safety officer of the selected unit and the CRM instructor stated "The mentality of the nation is a problem as people believe they can do more than they actually can. They have an issue to admit they may be affected by the fatigue. They feel

too proud” and “The culture is still that if you feel fatigued you are not a real man” (I 11).

(2) Fatigue risk countermeasures

Existing countermeasures and mitigation strategies are usually divided into in-flight countermeasures, (such as breaks and strategic naps) and pre-/post- flight countermeasures and strategies, (such as health screening and treatment, adequate manning, appropriate training and education, monitoring number of hours worked, sleep monitoring, fatigue-proofing, and fatigue reduction strategies). As already mentioned before, an effective approach integrates mitigation strategies in order to reduce the possibility that workers will become fatigued at work and lowering the possibility that fatigued workers will make a mistake leading to safety issues. Interviewees stated different countermeasures and strategies they use to mitigate fatigue risk, for example, “As a CRM instructor I always recommend to my colleagues to refer to CRM tools even when facing fatigue” and “As a commander I always make a strategy of resting and napping in at least demanding flight phase” (I 11). “I usually fight against fatigue by talking to my colleagues to give me some time like thirty minutes to rest during the flight or I have some coffee” (I 3) and “When I am fatigued, I try to self-control, pilot mental setting and try to relax, to take a break for ten minutes or to have a coffee” (I15). What is more, “When my attention starts decreasing I usually start to walk in the aircraft, look outside and drink water, talk to my colleagues” (I 2) and “When I feel tired I talk to the crew and I take a power nap” (I 4), “I fight against fatigue with the coffee first and I speak to others and use the power naps but due to vibrations and noise it is not really helpful” (I 12) and “When I realise I am fatigued I try to relax for at least ten minutes to focus my mind just on my private things, just thinking about my car or any other personal problem and I breathe deeply. After that I feel better, it is important to know our body when it is experiencing fatigue and to react to that, if not this can lead to making mistakes” (I 1). The majority of the interviewees stated their first fatigue countermeasure is having coffee and talking to other members of a crew. They

try to maintain their performance level to complete the mission assigned to them as expected.

(3) Risk Fighting Software

Risk fighting software of the selected unit includes Human Factors Analysis and Classification System (HFACS), Safety Performance Indicators (SPIs) and Organisational arrangements of the unit. The flight safety officer explained that the risk fighting software is used for analysing mishaps and is based on the HFACS. The system is ready to analyse, as well as organisational factors and is also ready to produce appropriate SPIs trends. Furthermore, the system is able to run analysis with further recommendations on existing processes, procedures, systems, and rules of engagement, if appropriate. Although the SPIs are being developed or identified on a regular basis the system experiences difficulties when applying appropriate risk controls and mitigation strategies due to the military environment and military culture.

(4) Crew fatigue assessment

Aircraft commanders are responsible for assessing crew readiness for the flight and the primary duty of each crew member is a responsibility of being aware of fatigue risk precursors and consequences and to recognise any signs of fatigue or any other condition that could make them unfit to perform an assigned duty. Interviewees stated that they are generally well-aware of their body capabilities and are able to recognise fatigue. One aircraft commander stated “I also need to take care of other crew, I treat them like a family, I am familiar with their private life and I have to pay a lot of attention on what I am doing and saying” (I 15) and “If I see my colleague is tired I take care and send him back home if that person is really fatigued but at the same time I have to assign another person to perform the duties” (I 15). Moreover, “When I am fatigued, I recognise the symptoms and I am able to react on time” (I 14) and “I like that we are like a family and we take care of each other, there is always an invitation by the safety officer to report any concerns relating to fatigue and whatever is not safe” (I 10). On the other hand, “The flying surgeon usually explains what fatigue and stress is but nothing

particular. We get advice on how to manage fatigue, but I would like to get more information” also “Fatigue could be experienced differently by individuals and if people are familiar with some particular symptoms they can react before the fatigue escalates” (I 5). The Interviewees stated different opinions on crew fatigue assessment. Generally, they are well-aware of their own psychological and physiological capabilities to perform duty effectively as expected. “I think it is important to speak more to each other about any concern relating to fatigue” (I 12) and “If someone is really fatigued, he should just raise his hand and say he needs some rest and that is never a problem because we are always three pilots, so we manage these kind of situations” (I 8).

(5) Individual approach

Self-management of the fatigue risk is a common approach used by the interviewees; therefore, mitigation strategies should be applied according to the operational needs and individual physiological and psychological condition, including the operational environment. Individuals differ in susceptibility and adaptations to changes. For example, “When I have any doubt about fatigue, I take a look at operational manual where there is a chapter dedicated to fatigue. I refer to the EATC flight operational manual, Chapter 6” (I 7). Moreover, “I can manage fatigue by keeping in my mind that the mission has to be performed and finished” (I 1). “If fatigue is too high then I ask for the replacement but usually I try to manage fatigue myself to concentrate more on what I do because it is not easy to ask for the replacement. I try to motivate my colleagues to do the same when they feel fatigued” (I 12). As previously discussed, the operational environment influences individual’s perception of fatigue, for example, “Night work makes me fatigued, NVGs (i.e., Night Vision Googles) have an impact on me, especially the weight and this is the most significant fatigue for me” (I 12). Interviewees stated that deployments are classified as the most affected by the perception of fatigue, and more fatigue-related lessons would be helpful to sustain performance in different operational environments, such as “There are many factors accompanying every day duties like weather and stress” (I 2) and “It would be helpful to get information on fatigue to have particular lessons and to be trained in the real world to know what I can and what I

cannot do when I feel fatigued” (I 6). Interviewees have experienced various situations when being fatigued and how to mitigate fatigue on their own, therefore, a majority of them wish to be more informed on particular fatigue risk countermeasures they could use to sustain the performance while on duty. More longitudinal studies that research individual differences and genetic predictors of performance impairment vulnerability are needed to understand each individual, as well as their tolerance to different working conditions and environment.

(6) Reporting fatigue

Reporting fatigue is crucial in the process of estimating, assessing, and predicting fatigue in operational settings, as well as creating a military specific FRMS framework. The important part of a communication plan, as a part of the FRMS promotion processes within the overall FRMS, includes feedback which is crucial for effective communication within an organisation. The nature of the military culture could be identified in the process of reporting fatigue, as several interviewees stated they do not report on fatigue due to their beliefs that reporting is assigned to personal weakness and they would not expect any feedback on their report and could not change anything through fatigue reporting, for example, “I know I can report fatigue but I do not think it’s easy and I believe that even if I would report on it there would be no difference, no feedback and nothing would be changed” (I 6). Moreover, “My priority is to complete the mission even though I feel fatigued, I do not want to create any problem for the squadron” (I 12). On the other hand, some interviewees are well-aware of fatigue reporting benefits, “Self-critic is crucial, and it is important to speak out, in this way we can react. Just culture is important” (I 15). They try to motivate the crew to speak out as this is the only way to solve an issue related to performance and behavioural changes, and consequently safety. “I report fatigue to the safety officer, and I feel free to report any minor problem as well” (I 5) and “Reporting fatigue is very important in terms of safety of a mission, tasks, and the crew itself. I have never reported on any safety concerns, but I believe that the idea of being a “macho” in the cockpit is not present anymore” (I 10). While the flight safety officer of the unit stated “As a safety officer I do not receive many reports

on fatigue, less than I expected. The mentality of the nation is a problem as people believe they can do more than they actually can. They have an issue admitting they may be affected by fatigue; they feel too proud. The culture is still that if you feel fatigued then you are not a real man” (I 11). Therefore, there is a military culture issue as one of the identified obstacles is reporting fatigue. The Air Force has not yet developed a fatigue report form to enable crew to report any concerns relating to fatigue and some interviewees stated this form would be helpful in reporting fatigue, “A fatigue report form would be beneficial” (I 9).

(7) Fatigue experience

Interviewees have several different fatigue experiences, some are related to deployments, NVGs, and some to home base operations including training, emergency operations and personal life. Most of the interviewees stated they have experienced fatigue while flying with NVGs, for example, “The weight and unbalance gives a lot of stress on the muscles of the neck and head. It causes mental stress because the vision is narrower and the environment must be mentally adapted to the NVGs, which is not easy” (I 11) and “NVGs stress my eyes and at the end of the flight I feel a bit dizzy” (I 13).

Furthermore, fatigue experienced during the emergency operations, “I was called on duty for a medical flight and I finished my duty after 23 hours” (I 2). Moreover, “During the last part of the mission of the night flight, I fell asleep without being aware that I was sleeping and that was really not a good feeling” (I 6) and “I experienced fatigue on a really long mission, under difficult environmental conditions, without proper nutrition, there were a lot of disturbing factors that affected my performance” (I 9). The flight safety officer of the unit stated that “When there are a lot of tasks with many difficulties and changes then this takes a lot of mental effort and staying on board for many hours can cause a physical fatigue. This refers especially to the loadmasters who do fewer mental tasks during the flight but are very busy before and after the flight. It is very demanding, and they are physically more tired” (I 11).

Fatigue during deployments refers to various missions which could be predicted or not. One interviewee stated his experience as very fatigued and stressful during the unpredicted mission - "The flight to the theatre took 12 hours and the mission itself 15 hours. We landed in a different time zone, it was a night flight, not scheduled and I had to wake up early in the morning, but the flight was delayed until the evening. When we finally landed in the theatre, we were not aware that we did not have much time to acclimatize to the new time zone as we had to act as flying crew after eight hours of rest. The mission took us again 15 hours and the morning after it was difficult because I was fatigued" (I 10).

Finally, one of the statements raised a concern over the age limit for performing the assigned duties properly, for example, "I believe people experience fatigue differently depending on age and I think the older people cannot perform this job as good as young people 22 to 23 years old. The age limit should be 40 to 45 years for the loadmasters" (I 2).

5.3.4 Theme 4: Stressors influencing fatigue

Fatigue could be influenced by a number of stressors causing psychical and psychological stress. The environment in the military aviation industry is very unpredictable with an unpredicted duty schedule. Important factors that relate to this include uncertainty, cumulative fatigue, sleep disturbances, workload, deployments, family life, and anxiety. The associated sub-themes and the theme *Stressors influencing fatigue* are presented visually in a hierarchical manner in Figure 5-4.

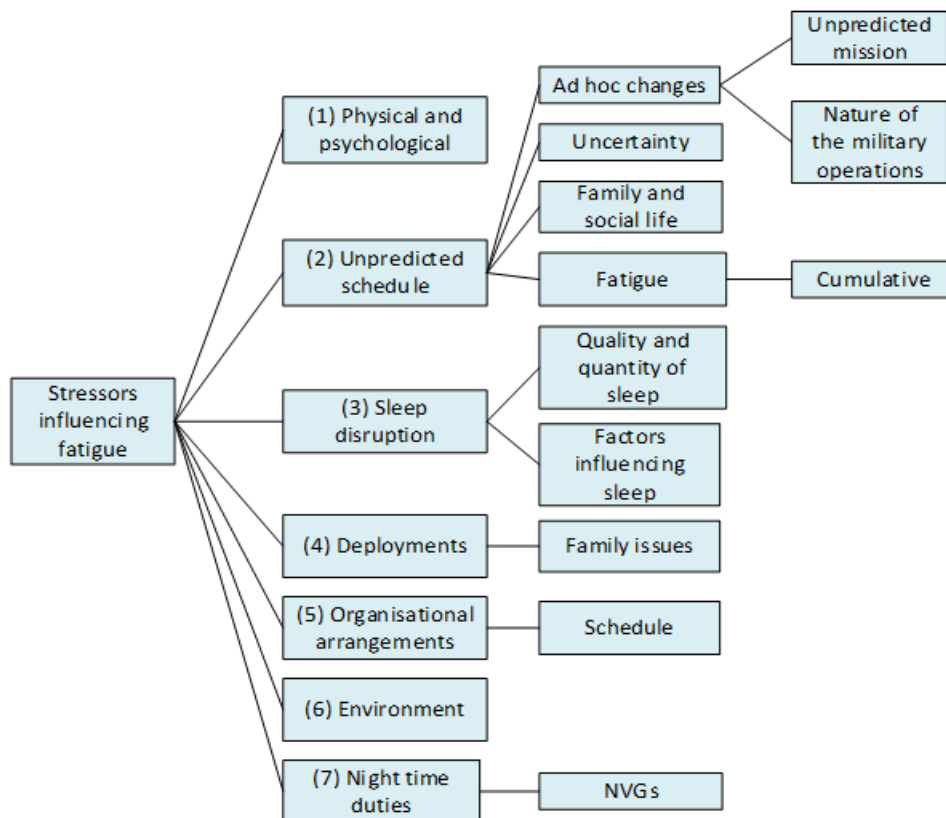


Figure 5-4. Stressors influencing fatigue systematic diagram

(1) Physical and psychological stress

Stress is a part of a human life and fatigue has several negative impacts on operational safety and well-being arising from stressors. The ability to cope with fatigue and stress depends on an individual's characteristics, therefore, research on individual factors and differences is crucial for further and enhanced comprehension of human behaviour and an effective fight against fatigue and stress.

Interviewees have experienced and stated several psychological and physiological stressors identified during their duty time as well as personal life, which is influenced by unpredicted military environment. Some interviewees stated they feel more stressed when deployed and others when they stay at their home base, for example "I feel working at home is much easier than in Afghanistan", stress related to workload and organisational arrangements, "Workload and waiting time are the biggest stressors but

they depend on organisational factors. If organisation works well, I am able to offload and upload the aircraft quickly, otherwise it takes time" (I 2), moreover, "Unstable schedule impacts my personal life, this happens in emergency and unpredictable cases like the earthquake in Southeastern Europe" (I 2).

"They teach us that stress is helpful in a way that we work better under pressure" and "Mental stress is pretty high. It is a problem and even if the crew is a good team when I get stressed and feeling fatigued my tolerance decreases and I become tired and angry" (I 15). Working under pressure and stress is one of features of a military culture, and people are trained to work under the hard-working conditions so that they sustain their performance at the highest level possible and finish the assigned duties as expected, independent of their feelings and how stressed they are.

Trainings are related to survival topics where crew's cognitive and physiological limits are tested, "Trainings stress my body and mind and make me fatigued" (I 13). Moreover, "Each day may bring unpredicted missions, and it can happen that we do not know what tomorrow brings. Uncertainty is quite stressful and can cause fatigue" (I 11). Pilots are more psychologically stressed than loadmasters. For example, one of the pilots stated, "When I realise, I am mentally fatigued I have to concentrate in order to make the right choice, decision-making time gets longer" (I 11). "The most frustrating thing for people is that things are not planned, and this is stressful" (I 4), which refers to an organisational arrangement causing stress and consequently fatigue.

Personal life could be affected as well due to working environment, "Usually I experience a stressful period for a long time and my family is involved in this situation, and I am aware I may not recognise this, but my family members can. I need time to relax but I have responsibilities to my family like taking children to different activities and school and it is difficult for me to relax. Also, everyday life is a bit stressful" (I 1).

(2) Unpredicted duty schedule

A duty schedule that is not planned or constantly changed due to the operational environment could be a disturbing factor that causes various issues such as stress, uncertainty, and anxiety in a daily life. It can also affect family and social life, as well as overall well-being. An unpredicted duty schedule in military operations is expected activity and military personnel should be familiar with it and able to cope with all disturbing factors. Interviewees have stated various disturbing factors arising from constant operational and unplanned changes. Some of those disturbing factors and examples have been introduced in Theme 2 (i.e. Organisational arrangements) and some more are stated in this section. For example, “I experienced during the last period, some pressure because my wife is pregnant, and I have a small child at home and the tasks that came up the last minute disturbed me” and “I asked for 2-3 months for some more flexibility, and it was not a problem” (I 7). Last minute changes can be stressful and undesirable, “In our air base, there is a manpower shortage, and we are assigned to manage more duties at the same time” (I 8), which means that more operational personnel have assigned additional paperwork duties in the offices, “It is very stressful when I have to do something unpredictable. There is not enough time to plan the mission and take care of the family” (I 8) and “I cannot plan my life, or I have to change my plans” (I 1). Moreover, “Unstable schedule impacts my personal life, but I do not experience many problems with that” (I 2).

“This is not about that people not being able to manage operations, but this is because of the nature of military operations” (I 4). Identifying the nature of the military operations itself, which should be familiar to the military personnel, “A mission can come up at any time and we have to be ready, this creates some sort of stress for me” (I 12). Furthermore, “Uncertainty is quite stressful and can cause fatigue” (I 11). In the long-term, fatigue can be cumulative, affecting a person’s health and causing several sleep issues. “What is more stressful is accumulating fatigue caused as such by delays. With lost time like waiting or organisation, we perceive different fatigue” (I 11). Overall, “Unpredicted schedule, fatigue, stress, all these factors influence my personal and social life” (I 5) and “Air force should improve the system to reduce the stress” (I 15).

(3) Sleep disruption

Most interviewees have no sleep issues related to quantity of sleep, but rather with quality of sleep which is related to young children in their families and in the long-term low quality of sleep may cause various health issues. Interviewees sleep on average 6.5 hours a night, which may not be enough, but the actual amount of sleep required varies between and within individuals. Sleep may be easily disrupted by various conditions, for example, “I previously had some health problems and for that reason I could not sleep well, I had dental issues, but now I sleep well” (I 15) and “I am aware I should sleep more, sometimes I have thoughts, and I cannot sleep immediately. I accumulate fatigue also through the lack of sleep, but I try to sleep more on the weekend and sometimes I need to take 20 to 30 minutes nap when I can” (I 11). Moreover, “I had training about sleep apnea, and they instructed me how to focus on the present time, which comes from mindfulness. The most important thing is to body-scan, to be able to focus on a present moment only, to relax muscles, legs, shoulders, etc.” (I 11).

Interviewees stated that quality of a daily sleep is different than a night sleep, for example, “Sleeping in a day is not the same as sleeping at night, I do not like to sleep during a day” (I 9). One interviewee stated his experience with sleep issues “I always sleep in a single room when I am deployed and sometimes it’s very noisy and too hot, not very comfortable environment and I feel disrupted, and I cannot rest well, and I do not feel comfortable. Then, at home I do not sleep well because I have a small baby and I am interrupted by his crying” (I 6). Moreover, “The real problem is that I do not sleep enough and the consequences I experience are shorter memory and decreased attention” (I 6). Individual differences, related to both genetic factors that are of great importance and the usefulness of genetic predictors of performance impairment vulnerability due to sleep loss, are still not well determined.

Furthermore, “Once after the night flight it happened that I fell asleep without being aware of that. I wish I could get more tips on how to sleep better” (I 6). Younger crew members experience more sleep quality and quantity issues due to young family

members and consequently they feel more fatigued at their work. Finally, crew develop their personal strategies to combat fatigue, and a good sleep habit are one of the basic strategies to enhance sleep quality and quantity.

(4) Deployments

Family issues may influence deployments and cause stress for a crew, which cannot focus effectively on the assigned task during deployments. Most interviewees stated that “A mission can come up at any time and we have to be ready. Usually, we are assigned to the mission just a day before the mission starts and this makes me stressed, it affects my personal and family life because I cannot plan some activities in advance and it affects also my health appointments” (I 12) and “The only stress that I experience when deployed is being away from my family and that fact that I cannot communicate with family” (I 12). Therefore, people are stressed due to being unable to control the situation at home and the inability to help if necessary. For example, “The only stressor is being away from my family and if something happens at home, I am not able to help and that is very stressful” (I 9).

Crew may refuse to be deployed due to personal and family reasons but not often, “People can refuse to be deployed if there is a personal issue. They can refuse one time, but more is a problem, this is then an issue for a human resource management” (I 11). Moreover, “I can refuse to be deployed if there is any serious reason for that such as family problem” (I 5) and “I could refuse to be deployed for family reason, but the squadron is like a family for me and I know if I refuse to be deployed there will somebody else be deployed instead of me and may cause that colleague a problem. Therefore, I cannot refuse to be deployed” (I 13). One interviewee stated his experience as a chief crew of deployed crew as “One of the loadmasters received a call from his wife that she had an emergency and needed surgery. I asked him if he wanted to return home or not” (I 15). There is flexibility if the crew experience any personal issues before or during deployments, and the Air Force tries to manage an issue not to affect the assigned mission.

(5) Organisational arrangements

Organisational arrangements in the operational process are discussed in Theme 2 of this qualitative research study and are a great concern causing additional stress that interviewees experience throughout their operational performance. One of the main frustrations is that the Air Force does not well understand the importance of all squadrons and gives priority and more attention to the selected ones, for example, “the concerned Air Force and other Air Forces are more focused on fighters, they put more attention to them than to our squadron. Therefore, it happens that the organisation does not clearly understand, what our needs are and because we fly low and slow the management believes that we do not experience any issues” (I 11).

Organisational arrangements related to schedule are one of the biggest stressors among interviewees, “If I do not know what to do and how to organise my life then I am stressed” and “The main stressor are changes that happen after the activities are already running (I 5). Moreover, “There should be less administrative work and more practical work” (I 10), “If organisation works well then, I can be more successful performing my job because I can focus only on my duties. If everything is scheduled, I can perform my duty better because I know how to also organise my private life” (I 9) and “I often have to change plans or to postpone some duties or projects in my personal life and that is not easy” (I 6). “The schedule affects my personal and family life, and I cannot plan activities in advance, and it affects also my health appointments” (I 12).

Finally, some interviewees stated that organisational arrangements often depend on unexpected missions and cannot be planned, for example, “Things are not easy to organise in operational centres because things come up unexpectedly like emergency transportation, and there are a limited number of resources and there is a need to reschedule everything” (I 4). Furthermore, “Organisation is not clear, especially with unplanned mission. There is more different information available at the end and it is not clear which one is correct” (I 1) and “There are a lot of changes that make people

stressed because it's frustrating to cancel the mission just before it should take place. It is stressful when I have to do something unpredictable" (I 8).

(6) Environment

Environmental factors may influence the performance level of a crew, interviewees stated a number of environmental stressors that degrade their performance level. For example, deployments are exposed to various destinations and crew may experience different cultures and environment, which sometimes either have benefits or disadvantages depending on an individual's perception of an environment, "I have experienced the reality in other operational environments and tried to improve my abilities and technical skills" (I 7). Environmental elements such as temperature, humidity, noise, and circadian misalignment, among others, may have negative impacts on operational performance and overall well-being, for example, "I find that high temperatures influence my level of fatigue" (I 12). Moreover, "When I am deployed, I stay in a small single room and sometimes it is very noisy and too hot, not very comfortable environment. I am disrupted because of the building which is not sound-proof, and I cannot sleep and rest well and I do not feel comfortable" (I 6). Furthermore, "When I am deployed, I am used to adapting my body to the new timing and climate changes, therefore, I have no problem with that" (I 6). "Difficult environmental conditions and a lack of proper nutrition affects my performance and makes me fatigued" (I 9), and "In Iraq we were in a camp and the environment was good but at the beginning we were sleeping in a tent very close to the helicopter ramp so sleeping at night was disrupted. Generally, I have no problems with the circadian misalignment or adjusting to the new environment" (I 5). What is more, "Temperature of the environment is stressful, for example, I was in Dubai in July and temperature was very high and it made me fatigued" (I 3).

When the crew is deployed to different environmental conditions, they perceive fatigue differently. "Previously I was in the UAE (United Arab Emirates) and the environment is different than in the USA (United States of America), where organisation is really good

and there is a lot of support. I can also meet locals, and this makes me feel good. Social life is important for me, I had an opportunity to meet different cultures and environment" (I 14), or "When I was deployed in Afghanistan the weather conditions were really difficult, it was sunny and hot and stressful due to the threat of the mission. For example, working 16 hours a day at home is much easier than in Afghanistan" (I 2).

Finally, "We are exposed to climatic changes, weather, and long working hours. The rule states that the flight crew must rest in a single and quite room when deployed. But sometimes we have to sleep on stretchers all together in the same room. There may be deployments where officers and loadmasters sleep separately and this may be an issue, which can affect crew morale, especially the morale of the loadmasters" (I 11).

(7) Night-time duties, NVGs

Night Vision Googles (NVGs) may cause psychological and physiological fatigue and stress. Interviewees stated that the weight of the NVGs is the first factor influencing their performance when flying at night. For example, "The weight and unbalance give a lot of stress on the muscles of the neck and head. It causes mental stress because the vision is narrow and the environment has to be mentally adapted to the NVGs, which is not easy" (I 11). Moreover, "NVGs require proper rest, we use them mostly when we fly tactical operations. It is not comfortable, the physical aspect of the helmet is the balance, the most weight is in front, so it is not properly balanced, and it impacts the neck and vision. I feel exhausted really quickly when flying with the NVG" (I 7).

Interviewees stated they have to be more concentrated and focused when using NVGs, "When I fly at night, I need to adjust my body and flying with NVGs is not easy, I have to be more precise, and I talk to myself when I do not feel comfortable so that I can manage to do my duties. I convince myself that I can do it" (I 15) and "Night flying with the NVGs is fatiguing and stressful, NVGs causes me problems with eyes, I usually need more rest afterwards" (I 3). Furthermore, "Resting after the NVGs flight is more difficult than the usual flight because of the pains" (I 6) and "NVGs are uncomfortable, heavy but they give very good tactical advantages. They allow us to spot the threat, features and

enemies” (I 10). “Usually, NVGs are needed in Kabul and similar places, and we use them from the top of descent until the landing, I mean 20-30 minutes” (I 8). Night vision goggles may be used for a limited time only with the maximum of six hours of continuous flight.

5.3.5 Theme 5: Deployments

Deployments are a regular part of the operational activity, and interviewees perceive deployments individually. This is mostly related to the location of deployments including accommodation, organisational arrangements, factors influencing sleep quality, performance and mood, family and social life, and other factors influencing fatigue. The associated sub-themes and the theme *Deployments* are presented visually in a hierarchical manner in Figure 5-5.

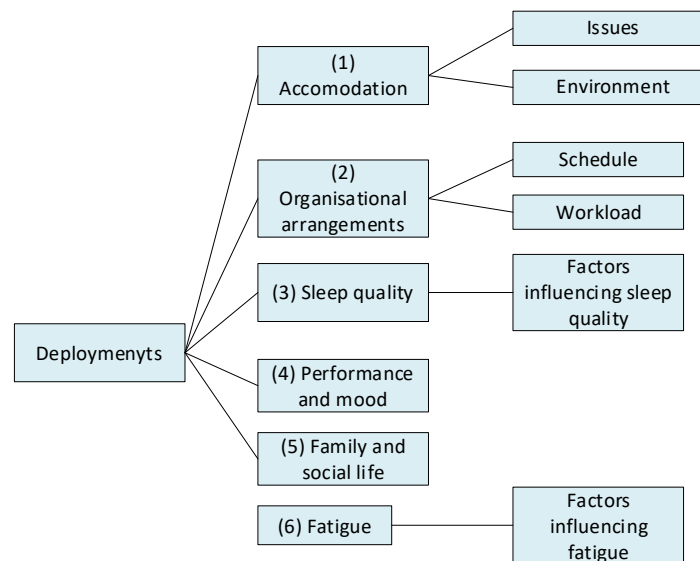


Figure 5-5. Deployments systematic diagram

(1) Accommodation

While being deployed, interviewees stated that accommodation was one of the important aspects to proper sleep and rest. Many of them exposed the importance of location, for example, “When we are deployed in less comfortable areas where we have to share the place of sleep, it may be hard at the beginning but then we get used to

having no privacy. We spend more time together” (I 15) and “When I am deployed and the accommodation is in the tent with 20 other colleagues, sleeping is not good enough because we are disturbing each other. There are rules prescribing the silence between 11 p.m. until 8 a.m. but I am disrupted by my colleagues who finish their duty after 11 p.m. and who are having dinner, showering, smoking cigarettes, and I am trying to sleep” (I 3). Moreover, “Sometimes accommodation is different for pilots and loadmasters because the pilots are officers and loadmasters are not. The rule states that the flight crew has to rest in a single and quiet room. When we are deployed and they sort officers and loadmasters separately then this may be an issue, which can affect crew morale, especially the morale of loadmasters” (I 11).

“When I was in Qatar and Kuwait, we were accommodated in American air bases and accommodation, food, and everything else was perfect. In Iraq, we stayed in our camp and the accommodation was good but, in the beginning, we were sleeping in a tent very close to the helicopter ramp, so sleeping was disturbed” (I 5). On the other hand, “Deployment accommodation is good, also sleeping in a tent, I can rest well” (I 4).

Finally, accommodation is related to the deployment location, which influences a crew’s quality of sleep, and generally the interviewees do not experience much issues with the environment where they are deployed, “In Minhad Airbase (i.e. in the UAE) we have our own camp and the only places with poor accommodation are Erbil (i.e. Kurdistan region in northern Iraq), Baghdad (Iraq) where we have to sleep under the tent but, nevertheless, I sleep well” (I 8).

(2) Organisational arrangements

Usually, deployments are scheduled in advance with an exemption of an unplanned emergency and ad-hoc missions, therefore, the crew has to be very flexible and ready whenever necessary. Most of interviewees stated that they are satisfied with the deployment schedule due to its organisational arrangements, which are better than the home base schedule. For example, “If the mission is planned, then also a schedule is planned. For example, during the mission in Afghanistan workload was always planned

and there was a schedule the day before" (I 1). Moreover, "In Minhaj, I was assigned just to specific types of flights. Organisation was managed better than at home. I was just a pilot there and had enough time to prepare for the mission. There were no additional assignments such as work in the office. In our air base, there is a manpower shortage, therefore, we are assigned to manage more duties at the same time. I am more productive when I am deployed" (I8).

Furthermore, "It is better when I am deployed because there is only activity, and we do only that. We do not have other things to do or at least the activities do not change much. For example, when I was deployed, I was a pilot and a flight safety officer and I was also working in a security office for a classified file, so I actually had three roles there. But it was easy to manage that because there was no family, no need to go back home and take care of a child after duty was completed. Deployments are less stressful" (I 4), and "When I am deployed, the work is easier because the only duty that I have is flying and I also know what the mission is a day after. When I am at home base, I have also other duties to perform and complete, not only flying" (I 12). Interviewees stated they generally prefer being deployed due to better organisational arrangements, they may focus better on their assigned job role without being worried about their families.

On the other hand, some interviewees stated that whenever unplanned missions arise there are more organisational misunderstandings such as, "Organisation is not clear, especially with unplanned mission. For example, like now we are intervening due to the earthquake in Southeastern Europe. In such cases the organisation is not good enough, not clear" (I 1). What is more, "When we are deployed in Africa, we need to be vaccinated properly but we are not. The Air Force wants to do everything the last moment and then it's too late. The problem is money actually" (I 15).

(3) Sleep quality

Sleep quality and quantity differ when crew is deployed compared to when they are on duty at their home unit. When deployed, they may experience various sleep accommodations and environments preventing good sleep quality. Interviewees stated

that sleep quality depends on the place they are deployed to. For example, “When we are deployed in a less comfortable area, we have to share the sleeping space. At the beginning it may be hard but when people get used to having no privacy things get better” (I15). Moreover, “When I am deployed, and we sleep in a tent with twenty colleagues, sleeping is not easy because we disturb each other. There are rules prescribing silence between 11 p.m. and 8 a.m. I am disrupted by my colleagues who finish their duty after 11 p.m. coming into the accommodation and having dinner, taking a shower, smoking a cigarette and so on, while I am trying to sleep” (I 3).

“In Iraq, we were based in our camp and the overall situation was good but at the beginning we were sleeping in a tent placed very close to the helicopter ramp and sleep quality at night was disturbed” (I 5). Generally, crew prefer to sleep in their own accommodation, either in a hotel or in some other accommodation without being disturbed by others or by external factors influencing their sleep quality. Some interviewees stated they sleep better when deployed, due to being away from families and disturbing factors related to family and social life. For example, “I sleep better when deployed because at home I have a daughter who does not sleep properly yet” (I 4) and “I have a one-year-old son at home and my sleep quality depends on his sleep hygiene” (I 2).

(4) Performance and mood

As previously mentioned, the interviewees feel more productive and focused on an assigned mission when deployed due to needing to perform a single task rather than many. It is also because there are better organisational arrangements in place which results in a less stressful environment and a better performance of a mission. In addition, social life is important during deployments, and it influences the mood and the overall well-being. For example, “When we are not accommodated in a hotel, we spend more time together. We have more social life” (I 15), and “Maybe there is someone who likes to stay alone but I try to involve him to be a part of a crew” (I 15). Interviewees are aware that performance and mood are an important part of

deployments as they have to work with each other and spend their free time together when off duty. They try to make a comfortable and productive environment where everyone would feel highly productive.

(5) Family and social life

Families of the interviewees are well-aware of the nature of the military operation itself and generally they support the interviewees and their working conditions and requirements, although, it is not always easy to accept unpredicted missions. Some interviewees stated that, "Being away from my family is stressful and if something happens at home, I am not able to help" (I 9), and "The only stress that I experience when I am deployed is being away from my family, that I cannot communicate with the family" (I 12). Moreover, "It is difficult and important that my family understands my job and my wife knows that my job is unpredictable, and she understands that" (I 4). Deployments and a number of other factors such as workload, psychological stress, unpredicted schedule, and psychological and physiological fatigue influence the interviewees' families and social life. Therefore, there is a need to analyse each component of the previously mentioned disturbing factors separately.

(6) Fatigue

Factors influencing fatigue during deployments mostly depend on the environment where deployments take place. For example, "Sometimes logistic arrangements are good, it is more relaxed, and when we are deployed in less comfortable areas, we have to share the space to sleep" (I 15). Therefore, the level of fatigue arises due to the type of sleep quality and quantity decrement, as well as the lack of privacy.

According to interviewees, weather is one of the most frequent factors influencing human level of fatigue. For example, "When I was deployed in Afghanistan the weather conditions were difficult, sunny, hot with higher stress levels due to the threat of the mission requirements. Fatigue in this kind of condition is high and on average we work while deployed 16 hours per day" (I 2). Moreover, "When I was in Dubai in July, the

temperature was the most stressful factor that made me fatigued” (I 3). Fatigue disrupts the interviewees’ attention because they need to stay focused and perform an assigned duty professionally, and at the highest level.

Furthermore, “I was deployed in the United Arab Emirates, and it was different than when I was deployed in the USA where organisation is good and there is a lot of support. We can also meet local colleagues, and this makes me feel good because social life is important. I can meet different cultures in a different environment” (I 14).

On the other hand, some interviewees find working at the home base more stressful due to additional work they have to perform. For example, paperwork makes them fatigued, “Most fatiguing for me is office work, sitting behind a computer for eight hours” (I 10). The Air Force is trying to improve the level of performance through fatigue awareness trainings and fatigue-related lessons, as well as with a development and implementation of the FRMS as a stand-alone system.

5.3.6 Theme 6: Trainings

One of the elements of the promotion process, relates to training and education, while the other component to the communication plan. Training programs are a documented and validated process which aim to identify training requirements and training effectiveness. Therefore, each training program should be tailored to meet the needs and complexity of a particular operation, organisation, or a group of employees. Moreover, there are several different trainings available such as an initial, recurrent, annual training, etc. Training requirements, type, frequency and aims form the basis of an individual training. The associated sub-themes and the theme *Trainings* are presented visually in a hierarchical manner in Figure 5-6.

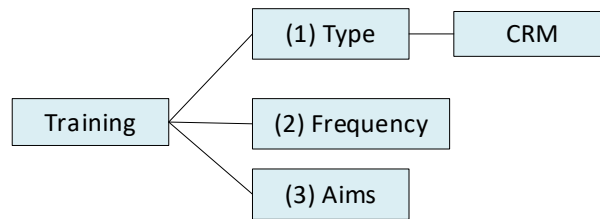


Figure 5-6. Training systematic diagram

(1) Type

The most common training currently available within the Air Force is Crew Resource Management (CRM) is training performed by the Air Force itself. According to the interviewees' responses the assigned base is more aware of working as a team than other Air Force bases, for example, "I believe that the crew in our base is strongly aware of working as a team, much more than a crew in other bases" (I 11). Firstly, CRM training is required in a flight school and then later on, advanced CRM training is required when people join the assigned base. Every two years there is recurrent training, which may focus on just one particular subject that has been raised due to an operational aspect. Furthermore, "We can also discuss fatigue-related safety issues through the specific briefings or any other events such as flight safety stand downs" (I 11).

There is no fatigue specific training available. Despite that, the Air Force believes that employees receive enough fatigue-related information through different communication channels such as briefings and de-briefings, flight surgeon lessons on fatigue and fatigue management. "I believe that, generally, crew may complain of not having enough information on fatigue but there are many occasions when crew can get information and knowledge about fatigue" (I 11). Most interviewees stated they receive just theory on fatigue, for example, "We receive just theory on how to recognise fatigue and its consequences and countermeasures. I wish I could get more information on fatigue" (I 8). Moreover, "We do not have individual training on fatigue but we get some information during other courses such as CRM, through stress management" (I 1), and "I believe it would be helpful to get information about fatigue to have fatigue-related

lessons and it would be good to be trained in the real world about what we can and cannot do when fatigued” (I 6).

(2) Frequency

Crew Resource Management training courses are available every two years, although some interviewees stated that they do not receive training regularly. For example, “The last training on fatigue I had three or four years ago” (I 8), moreover, “I had CRM training only twice, once in a flying school and the other a few years ago” (I 13), and “I completed my CRM training in the navy and so far I had no opportunity to get the CRM training in the Air Force” (I 10). As indicated by the interviewees, there is no regular fatigue-related training available.

(3) Aims

Training programs should aim to provide justification for specific actions taken or explain why fatigue-related safety procedures are introduced or modified. Furthermore, it should aim to ensure that all people are aware of fatigue-related precursors and consequences within a safety management system. Training courses should also aim to convey good-to-know information and improve fatigue-related knowledge of all employees. What is more, there are currently no fatigue-related publications available in the Air Force, except a flight safety magazine where some information about fatigue, sleep, and human factors is available. Finally, feedback is an essential part of a communication plan. Without any feedback there is no effective communication possible.

5.4 Discussion

The semi-structured interview protocol was diligently prepared to allow the exploratory inductive approach to researching three separate parts of the interview. These parts were; organisational arrangements, individual job requirements and responsibilities; fatigue risk management processes and tools; and demographics. All of the data gathered reflects the more pertinent topics that were found, and the semi-structured

interviews allowed to investigate and develop the themes and sub-themes that were discovered throughout the interviews. A review of the existing literature on fatigue and FRMS in military aviation revealed that it is very limited. On the other hand, the literature is very rich in general fatigue science (Dean et al., 2007b; Fletcher et al., 2015; McCulloch, Baker, Ferguson, Fletcher, Dawson, Marcil, Booth-Bourdeau, Laurence, 2007) but limited by a number of methodological issues such as the lack of validity and reliability of objective and subjective fatigue measurement tools along with other issues (Williamson et al., 2011) and with a significant gap in exploring fatigue relationship with human genetic factors (Fletcher et al., 2015), which is an important aspect of fatigue.

The semi-structured interviews conducted in a Study 1 of the thesis facilitated an exploratory inductive approach to investigating key aspects such as organisational arrangements, individual job requirements and responsibilities, fatigue risk management processes and tools, and participant demographics. Through this approach, themes and sub-themes were identified, capturing the core characteristics and patterns present in the data. By determining the key characteristics and their relationships, the inductive thematic analysis arrangement fully demonstrated its ability to analyse the data that was gathered.

Because of the linkages between the issues and the practice of operational activities, it was challenging to arrange the lower-order themes. For instance, fatigue is influenced by deployments, organisational and operational arrangements, family and social interactions, and the experience of being unexpectedly called for an unplanned mission. Due to the intricacy of comprehending the interrelationships among the various elements, the development and implementation of a military-specific FRMS framework for fatigue risk research in military aviation is essential.

A negative association between fatigue and general attitudes has been found, most likely due to duty time issues, environmental factors, workload, and cumulative fatigue. Another important factor is the management of change, which constantly faces resistance to changes. Moreover, the standardisation and implementation of rules that

are fragmented may represent an issue toward an effective safety system. Furthermore, family, and social life has one of the biggest impacts on being fatigued among interviewees, as family does not always necessarily understand the nature of the military operations.

Organisational arrangements have exposed unpredictable duty schedules and associated experiences of the interviewees as one of the biggest fatigue stressors, as there is no planned schedule available due to the nature of the operation itself. Moreover, an unplanned mission is part of normal military daily operations. Some interviewees stated that operations are not well-organised, therefore, sometimes they have experienced circadian misalignment and difficulties adapting to the new environment. As a result of the operations not being well-organised, the lack of operational and organisational support has been identified. The lack of organisational support in the selected Air Force base may cause different frustrations as what was revealed throughout the interviews, as crew members feel less important than colleagues from other squadrons. This may further lead to a lack of confidence and work stimulation (Thomas et al., 2005). Furthermore, the crew does not seem to feel confident in reporting any concerns related to fatigue, which may be due to the military nature. They believe that the person who reports fatigue is weak, and that kind of personality in their opinion does not belong in military operations.

Management and financial issues were represented as sub-themes, which can influence and seriously affect the overall safety and performance of an organisation. Some interviewees stated that there's a lack of attention and understanding by the management. They also mentioned financial obstacles towards the overall safety improvements, as well as a shortage of manpower and aircraft, which could compromise and impact the readiness of the entire air force. Most of the interviewees complained about fatigue and sleep hygiene awareness received through the current training in place. Most of them wished to get more lessons on the related topics they could use to sustain performance while on duty.

Fatigue management, a complex spectrum of a number of different fatigue-related factors, is another theme in this thesis qualitative study, and it relates to fatigue consequences, countermeasures, risk assessment, fatigue reporting mechanisms and associated feedback including software for monitoring and fighting against fatigue. A common approach of the interviewees is to fight fatigue as a self-management of the fatigue risk, where individuals differ in their susceptibility and adaptations to changes. However, as already mentioned before, more longitudinal studies researching individual differences and genetic predictors of performance impairment vulnerability are needed to understand each individual, and it is important to explore the crew members' strategies in the following research study of this thesis as it helps to develop an appropriate fatigue report form. That is, a fatigue report form that considers the relevant fatigue countermeasures and identifies the potential need for more training on this subject (Van Dongen, Maislin and Dinges, 2004).

In addition, fatigue reporting mechanisms and associated feedback are crucial in an effective and efficient communication plan, which is part of safety promotion, as well as in a process of estimating, assessing, and predicting fatigue. One of the characteristics of the military culture is weakness. If a crew member feels fatigued then he believes he is not a real man, therefore, the culture is one of the identified obstacles in reporting fatigue.

The analysis of the interviews showed that fatigue could be influenced by several stressors causing psychological and physiological stress. Most interviewees stated that stress has several negative impacts on operational activities, as well as on well-being which is usually influenced by unpredicted military environment. Therefore, an unpredicted duty schedule could be a disturbing factor causing stress, anxiety, uncertainty, as well as disturbing the overall well-being of interviewees and their family and social life. The crew members' responses exposed accommodation, organisational arrangements, factors influencing sleep quality, performance and mood, family, and social life, as aspects that influence fatigue (Bonnefond et al., 2006; Kubo et al., 2007; Liu et al., 2017).

Interestingly, a majority of interviewees have not experienced any sleep disturbing factors but what has been noticed is that younger crew members have experienced more sleep quality and quantity issues due to their young family members, and that may also be a contributing factor to deployment stress they have experienced. Regardless of crew member age, deployments may be stressful for all crew members due to different culture and environmental factors such as temperature, humidity, noise, circadian misalignment. Moreover, during deployments crew members are often unable to communicate with their families. On the contrary, some interviewees find working at home base more stressful than being deployed due to additional work, mostly office work, that they perform.

Finally, training on fatigue and sleep hygiene could improve fatigue and sleep awareness among crew including developing countermeasures techniques and an understanding of the importance of fatigue reporting. The interviewees stated they wish they would get more information on fatigue and sleep hygiene which could be done through the relevant training and promotional material. Currently, training on fatigue and sleep hygiene is partly implemented and delivered through CRM and training given by a flight surgeon, but currently there is no fatigue-specific training available.

The analysis of the semi-structured interviews supports the findings identified from the literature review. For example: performance while under stress; fatigue management during operations; sleep hygiene; individual differences; perception of fatigue; and mitigation strategies (Åkerstedt et al., 2014; Dolan and Ender, 2008; Van Dongen and Belenky, 2009; Mairesse et al., 2014; Miller, Matsangas and Shattuck, 2007; Sharpe and Bartlett, 2000). Moreover, the unpredictability of military environment and consequential anxiety affects the crews' sleep hygiene, performance level and behaviour (Miller et al., 2011, 2012). The unpredictability of the military environment does not always allow the crew to prepare for their duties nor plan family and social activities, which may cause anxiety and consequently fatigue among crew members. Moreover, the anxiety and fatigue affect the workers' sleep quality and quantity (Kalmbach et al., 2015), operational performance level, behaviour, and inevitably safety.

Similar results have been obtained in at least one other study regarding effects on fatigue and operational performance level decline, as well as the relationship between fatigue stressors, mediating factors (i.e., sleep quantity and quality, individual differences, health and physical condition, task characteristics) and performance level (Miller et al., 2011, 2012). Furthermore, studies in the United States Naval Aviation have found a relationship between a pilots' performance decline and an increased level of fatigue, while sleep deprivation was a frequent occurrence identified in deployments in Haiti, Bosnia, Kuwait, and Somalia, where task features and complexity were principal mediators in the effect of sleep deprivation on task performance. Similarly, interviewees mentioned that the complexity of a task affects their performance level and quality and quantity of sleep, whereas unpredicted tasks are the major cause (Liu et al., 2017; Pilcher & Huffcutt, 1996; Ramakrishnan et al., 2015). The study has identified fatigue countermeasures that extend and enhance cognitive performance and endurance in operational context. Overall, the general themes that represent the experience and perception of fatigue by the interviewees were identified and discussed.

Study 1 aimed to investigate the objectives of this thesis and to make an effort to answer the research questions associated with each objective. These are duplicated below:

O1: To examine the prevalent fatigue stressors and countermeasures within military operations at the selected air base.

- RQ1: Do unpredicted operations and family issues impact sleep hygiene compared to other factors among military personnel?
- RQ2: What is the prevalence of using swapping roles with colleagues, coordinated inflight naps, exercise, and caffeine intake as fatigue countermeasures compared to other strategies?

This semi-structure interview study successfully answered the research questions related to this study. The second research study for this thesis is covered in the next chapter, which describes in full the planning, carrying out, analysing, and outcomes of the survey conducted with the selected Air Force base.

Chapter 6 - Study 2. Fatigue Questionnaire

6.1 Chapter Introduction

This chapter examines and elucidates the second fatigue research study, a survey questionnaire, in the air unit selected for this thesis. Chapter 4 describes the preparation, implementation, data capture, and analysis by using R software to analyse the results of the questionnaire performed with the Air Force crew members of the selected air base. The findings of this quantitative study are discussed considering expectations and forecasts derived from this thesis qualitative study and the literature review. The conclusions of this chapter's findings are discussed in relation to future research.

6.2 Methods

A web-based questionnaire survey was developed to collect data from the selected Air Force base. The purpose of this study, which was a follow-up to the first study exploratory interviews, was to confirm the generalisability of Study 1 findings and offer more information about the peculiarities of the factors that were found, including fatigue stressors, operational arrangements, fatigue reporting mechanisms, sleep hygiene, and training. The same data identified the lack of operational and organisational support, for example, an effective fatigue reporting mechanism in place in the selected Air Force base.

A large amount of data was swiftly gathered by a questionnaire survey, which proved to be the best method for investigating the generalisability of the data collected in Study 1. It was decided, in agreement with the Air Force front line personnel, that the survey questionnaire would be published on the Air Force intranet page. Because it was available to every crew member on the chosen base, it made the survey easier to access and allowed crew members to respond whenever it was convenient for them. Additionally, participants were invited via email, by the flight safety officer of the selected base, to participate in this study, which allowed participant anonymity and encouraged their frankness.

The five sections of the questionnaire were designed to evaluate various aspects of fatigue that crew members at the chosen Air Force base encountered. General demographic data was covered in section one, crew members' experiences with sleep hygiene were evaluated in section two, crew members' experiences with fatigue and how they perceive it during operations were evaluated in section three, and current reporting procedures and related feedback were discussed. Additionally, fatigue and sleep hygiene training were assessed in the fourth section, and any additional observations made by participants were examined in the fifth section of the questionnaire. For further information, refer to Chapter 4, where methodology is covered in more detail. Appendix B, the Fatigue Questionnaire, contains the whole questionnaire.

6.2.1 Selection method

Participants involved in this study were crew members, i.e., pilots and loadmasters, at a selected Air Force base, whose participation was voluntary and anonymous. An invitation of participation was posted on Air Force base intranet, moreover, it was sent out via email to all crew members of the selected air base. In compliance with the Cranfield University Research Ethics System (CURES), the collected data was treated in a strictly confidential way. This study's sampling was non-probabilistic. The participants for all studies in this thesis were selected by the Air Force unit itself, where the selection process was not disclosed to the researcher due to military security and safety reasons unknown to the researcher.

6.2.2 Hypotheses

In order to generate a list of hypotheses, the questionnaire was designed in the second study to investigate the generalisability of the results from Study 1 and the literature review. Interviewed crew members complained about not having received effective training on fatigue consequences, fatigue causes and countermeasures as well as not on sleep hygiene. Moreover, commonly used fatigue countermeasures among crew members relate to swapping roles with colleagues and using a coordinated inflight nap.

Furthermore, the biggest stressors at work are family issues and unpredicted operations, which both influence sleep hygiene. Relating to fatigue reporting mechanisms and associated feedback, interviewees stated there is no effective feedback on reporting fatigue, therefore, crew members are not motivated to do so. Therefore, the following hypotheses are developed for this study:

Hypothesis 1. Unpredicted operations and family issues have significant impacts on sleep hygiene.

Study 1 interviewees recognised family issues and unpredicted operations as the biggest stressors at work and which impacts the sleep hygiene as there is no time to plan activities when off-duty and family may not understand the nature of military operations.

Hypothesis 2. Swapping roles with colleagues, coordinated in-flight naps, exercise, and caffeine intake are the most utilised fatigue countermeasures among all crew members.

In-flight fatigue countermeasures integrate mitigation strategies to lessen the possibility that people will become fatigued and the possibility that they will make mistakes, leading to adverse issues. The majority of participants do not report being fatigued while on duty due to a lack of reporting confidence. An effective reporting mechanism with associated feedback, is not in place, which does not improve organisational and operational systems, processes, and procedures. Therefore, current fatigue and safety-related issues could not be identified through reporting mechanisms. Additionally, interviewees in Study 1 stated there is no feedback on reporting fatigue and they feel it is useless to report it.

Hypothesis 3. Sleep is positively related to fatigue and to countermeasures.

Sleep is usually disrupted by several factors such as night duties, family, circadian misalignment, deployments, psychological and physiological fatigue, a poor sleep environment, workload, off-duty leisure activities, and unpredicted operations. Sleep

deprivation may cause several issues leading to negative impacts on decision-making, situation perception, and overall well-being (Fulcher et al., 2010; Lavie, 1986; Lieberman et al., 2002, 2012; Pilcher & Huffcutt, 1996; Schnyer et al., 2009), therefore, a better understanding of sleep hygiene in relation to safety, performance, health, and overall well-being, helps recognise fatigue-related behaviour and how to prevent and mitigate it.

Hypothesis 4. There is no difference in the frequency of crew members who have not received any training on fatigue and crew members who have received fatigue training.

Interviewees in Study 1 stated there is no specific training available on sleep hygiene and fatigue causes, consequences, and countermeasures, most commonly these themes are discussed in CRM training, which is available every two years. Crew members receive just a brief theory on fatigue and sleep hygiene. What is more, crew members wish to get more information on this subject, for example, via safety bulletins, magazines, or any other form of safety promotion. Interviewees expressed their wish to get more information particularly on fatigue.

Hypothesis 5: There is no difference in the frequency of crew members who have not received any training on sleep hygiene and crew members who have received sleep hygiene training.

As identified in Study 1 semi-structured interviews, crew members are satisfied with training through which they receive information concerning sleep hygiene and have also developed their own strategies in different environments to assure good quality sleep. Training on sleep hygiene may improve fatigue and sleep awareness among crew, including countermeasure technique development and understanding of the importance of fatigue reporting.

6.3 Data analysis

General demographic information, Sleep hygiene, Fatigue experience and fatigue reporting mechanisms and Fatigue and sleep hygiene training were analysed and reported according to the hypotheses of this thesis. The sections are organised under the same headings as the questionnaire, which provided a functional logic for the results' presentation. *General demographic information*, followed by the data on sleep and fatigue and how crew members report them (e.g., *Sleep hygiene and Fatigue arrangements*), and lastly, data reflecting training received on sleep and fatigue and any additional comments participants may have had.

After the survey was completed, all the data was immediately imported from the Qualtrics website into R and arranged for analysis using the steps outlined below.

Step 1: Data gathering. Over the course of eight weeks, all data were gathered using the web-based questionnaire survey tool Qualtrics.

Step 2: Preparing data for analysis. After being directly imported into R, all the data was ready for analysis in the data and variable views.

Step 3: Descriptive data analysis. At first, all variables were analysed using the explore and describe commands. A description of the results found was done and some predictions about cause and effect were made, which would link to the hypotheses of this Study.

Step 4: Statistical tests. At this step, the data were examined for relationships between the various variables and for the impact that each variable had on the impacts identified in the fatigue model framework. Therefore, the data were tested for the existence and strength of relationships between variables.

Hypotheses 1 and 2:

To address hypotheses H1 and H2, **Friedman's ANOVA** was used. The rationale for selecting this test is rooted in the data characteristics. Specifically, the measurements for these hypotheses were related (i.e., repeated measures on the same subjects). Moreover, the assumption of normality, which is often a prerequisite for traditional parametric tests such as the one-way ANOVA, was not met for these data sets, as indicated by the **Shapiro-Wilks** test. Traditional ANOVA assumes that the data are normally distributed; given the non-normality of the data, this assumption would have been violated, rendering the results potentially inaccurate. Therefore, the non-parametric counterpart, Friedman's ANOVA, was more appropriate for this analysis.

To further analyse differences between specific related measurements post-hoc, the **Durbin-Conover** test was applied. This test provides pairwise comparisons following the Friedman's ANOVA, while adjusting for multiple comparisons.

Hypothesis 3:

For H3, **structural equation modelling** (SEM) was employed using the Lavaan package in R. SEM was deemed appropriate as it offers the ability to examine and simplify complex relationships (or correlations) and to specify a hypothetical model based on the observed variables. Lavaan also provides measures of how well the hypothesized model fits the observed data.

In addition to the SEM, the following metrics were computed:

- **Variance Extracted** (AVE): This was computed to assess convergent validity, ensuring that the constructs are distinct and measure what they are purported to measure.
- **Composite Reliability** (CR): This metric was calculated to gauge the reliability of the constructs, ensuring that they are consistent and stable.

Additionally, semPaths was used to illustrate the specified model diagrammatically, providing a visual representation of the interrelations among variables.

Hypotheses 4 and 5 (H4 & H5):

For hypotheses H4 and H5, the **chi-square test of equality of two proportions** was employed. This test was chosen based on the nature of the data: specifically, the analysed variable was nominal (with categories without any order). By leveraging the chi-square test, it was possible to ascertain whether observed differences between the two categories were statistically significant.

6.3.1 Sample description

Once the data collection period ended, 122 replies had been registered from which 83 (68.03%) responses had been completed and 39 (31.97%) uncompleted. All participants were male; 51 pilots (61.45%) and 32 loadmasters (38.55%) gave their informed consent and completed the questionnaire. With the oldest participant being 58 years old and the youngest being 28 years old, the participants' average age was almost 42 years of age (SD=8.19). In their current working position, they have worked for an average of thirteen years. Most respondents (67.9%) had been flying C-130J aircraft while 32.1% C-27J SPARTAN.

6.3.2 Demographics

Crew members in the selected base are defined as pilots and loadmasters and fly two aircraft types C-130J and C-27 SPARTAN. The air base which is the largest air transport association of the concerned Air Force has a fleet of 32 aircraft, from which are 20 four-engine airlifter C-130J Super Hercules which played a fundamental role during the recent long health emergency, and 12 C-27 SPARTAN which is mostly used for tactical operations, medical evacuation, aerial spraying, and firefighting.

Among all the respondents (N=83), 61.4% reported that their job role is 'Pilot', while 38.6% reported being a 'Loadmaster' (See Figure 6-1).

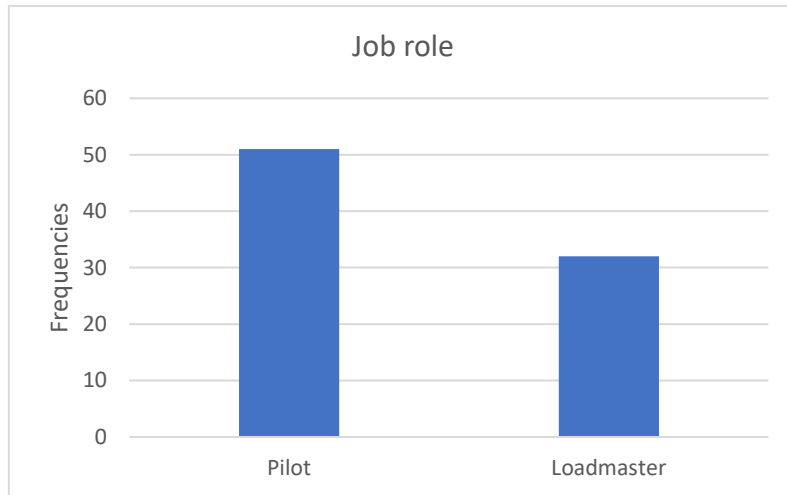


Figure 6-1. Job role

The average age of respondents was approximately 42 years, with a standard deviation of about 8.19 years (See Figure 6-2). The age range of the respondents was from 28 to 58 years of age.

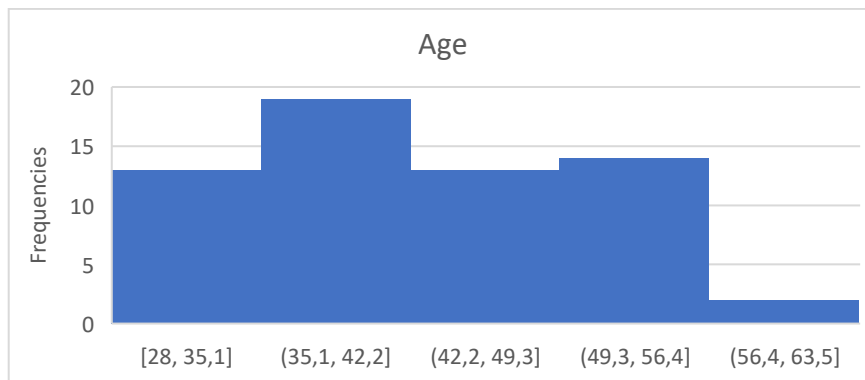


Figure 6-2. Age

Furthermore, 67.9% of the respondents are currently flying C-130J, while 32.1% are flying C-27 SPARTAN (See Figure 6-3).

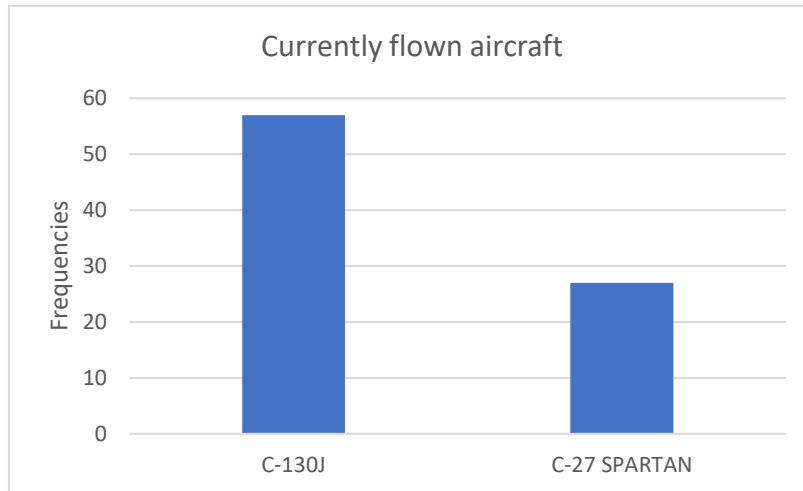


Figure 6-3. Currently flown aircraft

The average duration of flying the current aircraft was around 13 years, with a standard deviation of about 7.38 years (See Figure 6-4). The duration ranged from 1 to 40 years.

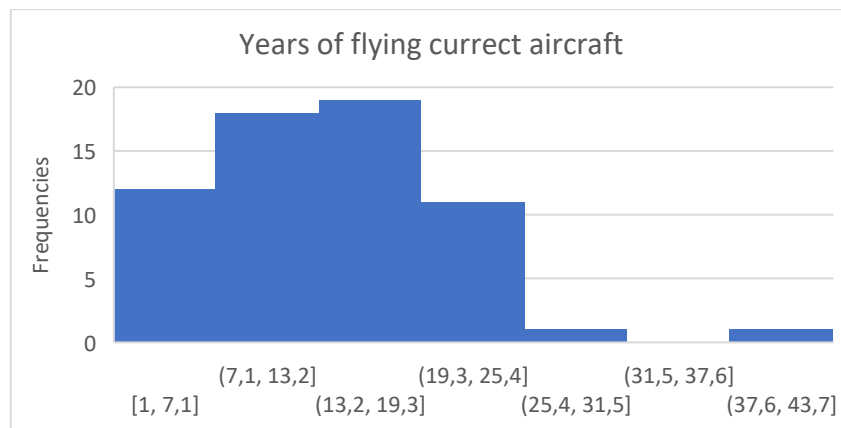


Figure 6-4. Years of flying current aircraft

6.3.3 Hypothesis testing

This section provides hypotheses testing using the above-mentioned methodology.

H1. Unpredicted operations and family issues have a greater effect on sleep hygiene than other reasons.

The next step was to analyse the principal factors affecting sleep, which led to the hypothesis H1 assessment, where the impact of unpredicted operations and family issues on sleep hygiene was hypothesised. This was derived to the two separate

alternative versions (denoted with subscripted *a*) of the sub-hypothesis (with their *null hypothesis versions* denoted with subscripted *0*).

H1.1_a: Unpredicted operations have a greater effect on sleep hygiene than other reasons (except family issues).

H1.1₀: There is no difference in effect on sleep hygiene between unpredicted operations and other reasons.

H1.2_a: Family issues have a greater effect on sleep hygiene than other reasons (except unpredicted operations).

H1.2₀: There is no difference in effect on sleep hygiene between family issues and other reasons.

To test both null hypotheses, the data from the questionnaire was used, where the participants were provided with a range of potential sleep disruptors and asked to rate the likelihood of each from 1 (always) to 5 (never). These were:

- Unpredicted operations
- Family issues
- Poor sleep environment (e.g., too hot, cold, noisy, bright)
- Night-time duties
- Workload
- Off-duty leisure activities (e.g., movies, sports)

Then a frequency table and chart were assembled to display the distribution of the participants' rankings. Among the sleep-disrupting factors, 'Nighttime duties' and 'Poor sleep environment' were reported as 'Sometimes' by most respondents (70.4% and 63.0% respectively). 'Family issues' and 'Workload' also sometimes interfered with sleep for 58.0% and 53.1% of respondents respectively. 'Unpredicted operations' and 'Off-duty leisure activities' were least likely to always disrupt sleep (1.2% and 0% respectively). Table 6-1 and Figure 6-5 present frequency of sleep disturbing factors. Table 6-1 shows detailed numbers.

Table 6-1. Frequency table of sleep disturbing factors

	Unpredicted operations		Family issues		Poor sleep environment		Nighttime duties		Workload		Off-duty leisure activities	
	N	%	N	%	N	%	N	%	N	%	N	%
Always	1	1.2	2	2.5	0	0	1	1.2	2	2.5	0	0
Most of the time	2	2.5	2	2.5	3	3.7	0	0	4	4.9	2	2.5
About half the time	4	4.9	6	7.4	10	12.3	7	8.6	6	7.4	6	7.4
Sometimes	43	53.1	47	58.0	51	63.0	57	70.4	43	53.1	38	46.9
Never	31	38.3	24	29.6	17	21.0	16	19.8	26	32.1	35	43.2

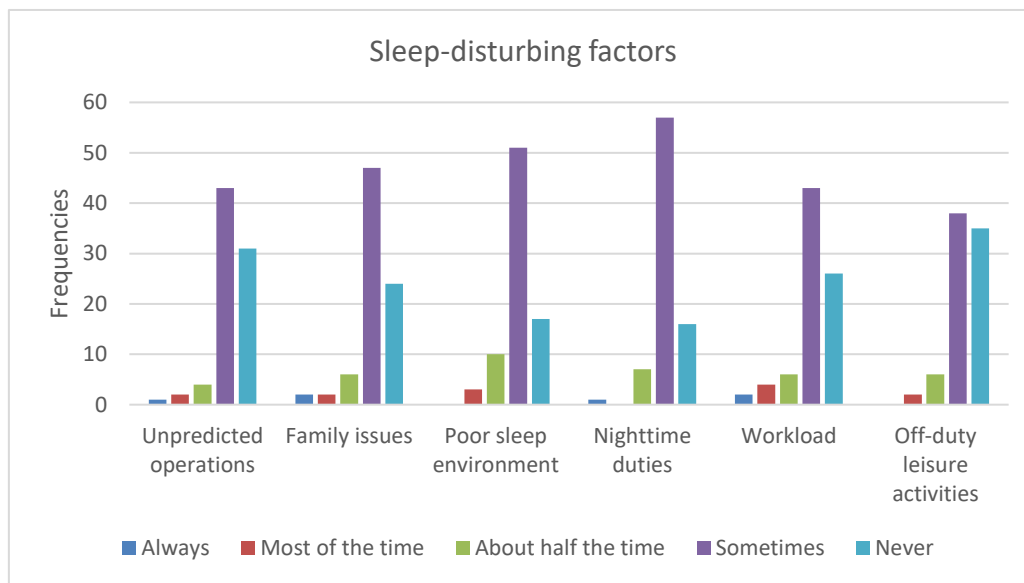


Figure 6-5. Frequency of sleep disturbing factors

Because the analysis was done with ordinal values, these ranks were used in the analysis, leading to the descriptive statistics (see Table 6-2) for each potential sleep disruptor.

Table 6-2. Descriptives of reasons affecting sleep (N=81)

	Mean	Median	SD	Min	Max
Unpredicted operations	4.25	4.00	0.767	1	5
Family issues	4.10	4.00	0.831	1	5
Poor sleep environment (e.g., too hot, cold, noisy, bright)	4.01	4.00	0.698	2	5

	Mean	Median	SD	Min	Max
Nighttime duties	4.07	4.00	0.628	1	5
Workload	4.07	4.00	0.905	1	5
Off-duty leisure activities (e.g., movies, sport)	4.31	4.00	0.718	2	5

The chart below (see Figure 6-6) shows the mean and standard deviation (whiskers), where the statistical differences with unpredicted operations and family issues and other reasons denoted on the horizontal axis.

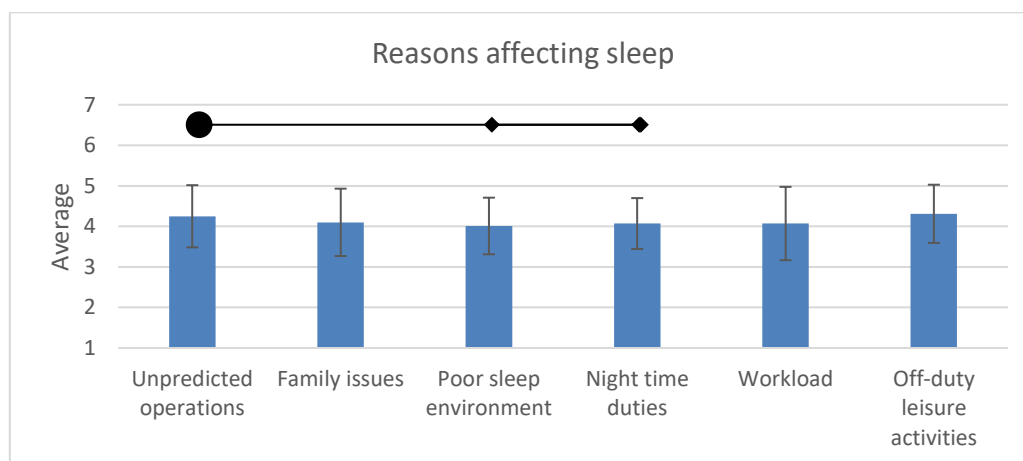


Figure 6-6. Reasons affecting sleep

However, given the nature of the data, certain conditions, or prerequisites for using a parametric test cannot be met. Specifically, the measurements are ordinal, which presents challenges for most parametric methods as these typically assume interval or ratio data. Ordinal data, with its rank order but unequal intervals between levels, does not meet these requirements. Therefore, to make an appropriate and robust comparison, the parametric repeated-measurements ANOVA cannot be used, therefore its non-parametric equivalent was used: Friedman's ANOVA. The reason for choosing non-parametric Friedman's ANOVA and not, non-parametric Kruskal-Wallis's test, is that the measurements are repeated (each participant answered to multiple reasons, thus null hypotheses were tested if there are significant differences between

related/repeated measurement) and are not in different non-overlapping and independent groups (as is needed for either one-way ANOVA or Kruskal-Wallis test). Friedman's ANOVA test is also, the only one suitable for our purpose as it does not require the stringent assumptions of a parametric test and is designed to work with ordinal data like ours. The results (see Table 6-3) of this analysis are outlined here:

Table 6-3. Friedman's ANOVA

χ^2	df	p
19.3	5	0.002

The analysis using Friedman's ANOVA revealed statistically significant differences in how participants ranked the factors affecting sleep ($p = 0.002$). This result indicates that the observed differences are unlikely to have occurred by chance and suggests that participants perceived certain factors as more impactful on sleep than others. These findings underscore meaningful variation in participant rankings, providing insights into the relative importance of different factors in shaping sleep quality. This suggests that there are significant differences in the impact of various reasons on sleep, although the exact reasons that differ significantly, are not yet clear. The Kendall's W effect size test with a sample size of 81, demonstrated an effect size of 0.0478. In accordance with Cohen's classification, this effect size is considered 'small'. This indicates that there is a minor level of agreement among participants on the rankings of the factors affecting sleep. Although Friedman's ANOVA showed a significant difference in the rankings assigned to these factors, the relatively small effect size suggests that the consensus on the ranking order of these factors is somewhat limited. To identify which factors had statistically significant differences, a post-hoc analysis was proceeded. This involved conducting a pairwise comparison of related/repeated measurement of each sleep disruptor using the non-parametric Durbin-Conover test (see Table 6-4) (which already includes a correction for multiple comparisons).

Table 6-4. Post-hoc pairwise Comparisons (Durbin-Conover)

			Statistic	P
Unpredicted operations	-	Family issues	1.7648	0.078
Unpredicted operations	-	Poor sleep environment	3.2402	0.001
Unpredicted operations	-	Nighttime duties	2.8931	0.004
Unpredicted operations	-	Workload	1.7937	0.074
Unpredicted operations	-	Off-duty leisure activities	0.1447	0.885
Family issues	-	Poor sleep environment	1.4755	0.141
Family issues	-	Nighttime duties	1.1283	0.260
Family issues	-	Workload	0.0289	0.977
Family issues	-	Off-duty leisure activities	1.9094	0.057
Poor sleep environment	-	Nighttime duties	0.3472	0.729
Poor sleep environment	-	Workload	1.4465	0.149
Poor sleep environment	-	Off-duty leisure activities	3.3849	< 0.001
Nighttime duties	-	Workload	1.0994	0.272
Nighttime duties	-	Off-duty leisure activities	3.0377	0.003
Workload	-	Off-duty leisure activities	1.9384	0.053

The results of the Durbin-Conover post-hoc test indicate that unpredicted operations and family issues did not show statistically significant differences in their impact on sleep when compared to any other factors. This suggests that these two factors were perceived as having a similar level of impact on sleep disruption as the other variables examined. Specifically, unpredicted operations were not found to affect sleep hygiene, more than workload and off-duty leisure activities, in addition to family issues. Similarly, family issues did not appear to have a significantly greater affect than any of the other potential sleep disruptors.

Given these findings, neither of the null hypothesis H1.1₀ or H1.2₀ can be rejected. Consequently, neither of the alternative hypothesis (H1.1a or H1.2a) can be accepted, and thus even the main **H1 hypothesis cannot be accepted**.

H2: Swapping roles with colleagues, coordinated inflight nap, exercise, and caffeine intake are the more utilised than other fatigue countermeasures.

Next, the hypothesis H2 was analysed, where swapping roles with colleagues, coordinated inflight nap, exercise, and caffeine intake were explored. These are really the most utilised fatigue countermeasures. Again, this hypothesis can be deconstructed into several alternative sub-hypotheses (with their null hypothesis variants):

H2.1_a: Swapping roles with colleagues is more utilised than other fatigue countermeasures (except coordinated inflight nap, exercise, and caffeine intake).

H2.1₀: There is no difference in utilisation between swapping roles and other fatigue countermeasures.

H2.2_a: Coordinated inflight is more utilised than other fatigue countermeasures (except swapping roles with colleagues, exercise, and caffeine intake).

H2.2₀: There is no difference in utilisation between coordinated inflight nap and other fatigue countermeasures.

H2.3_a: Exercise is more utilised than other fatigue countermeasures (except swapping roles with colleagues, coordinated inflight nap, and caffeine intake).

H2.3₀: There is no difference in utilisation between exercise and other fatigue countermeasures.

H2.4_a: Caffeine intake is more utilised than other fatigue countermeasures (except swapping roles with colleagues, coordinated inflight nap, and exercise).

H2.4₀: There is no difference in utilisation between caffeine intake and other fatigue countermeasures.

The responses examined for this hypothesis fall under a group of statements about fatigue countermeasures that participants evaluated on a scale ranging from 1 (very likely) to 5 (very unlikely). The statements that form the basis of this hypothesis are as follows:

- Swapping roles with colleagues
- Taking an inflight nap coordinated with other crew members
- Engaging in conversation with others
- Consuming caffeine (for instance, coffee or energy drinks)
- Performing physical activity (such as moving around or stretching legs)

The analysis includes a frequency table (see Table 6-5), followed by a bar chart (see Figure 6-7) depicting the frequencies of the responses.

Table 6-5. Frequency table of fatigue countermeasures

	Swap the role with colleagues		Take an inflight nap coordinated with other crew members		Talk to others		Caffeine intake (e.g. coffee, energy drinks)		Exercise (e.g. move around, stretching legs)	
	N	%	N	%	N	%	N	%	N	%
Very likely	18	23.4	23	29.9	19	25.0	20	26.0	16	20.8
Moderately likely	27	35.1	23	29.9	35	46.1	24	31.2	29	37.7
Neither likely nor unlikely	13	16.9	13	16.9	13	17.1	16	20.8	19	24.7
Moderately unlikely	10	13.0	9	11.7	7	9.2	11	14.3	10	13.0
Very unlikely	9	11.7	9	11.7	2	2.6	6	7.8	3	3.9

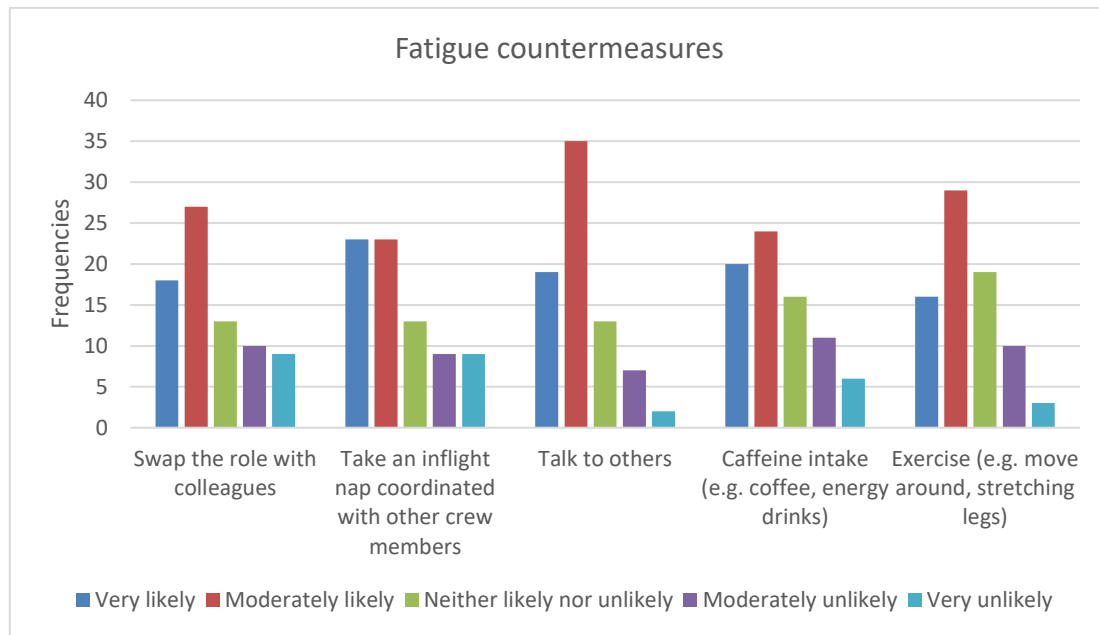


Figure 6-7. Frequency of fatigue countermeasures

As the data under consideration are ordinal, the subsequent statistical analyses were conducted using ranks. Therefore, the upcoming table (see Table 6-6) displays the descriptive statistics of the ranks for each of these statements.

Table 6-6. Descriptives of fatigue countermeasures

	N	Mean	Median	SD	Min	Max
Swapping roles with colleagues	77	2.55	2.00	1.30	1	5
Taking an inflight nap coordinated with other crew members	77	2.45	2.00	1.34	1	5
Engaging in conversation with others	76	2.18	2.00	1.00	1	5
Consuming caffeine (for instance, coffee or energy drinks)	77	2.47	2.00	1.24	1	5
Performing physical activity (such as moving around or stretching legs)	77	2.42	2.00	1.08	1	5

Following is the bar chart (see Figure 6-8) of means with whiskers for standard deviations. As there are no statistically significant differences among the fatigue countermeasures, there are no indications for statistically significant differences.

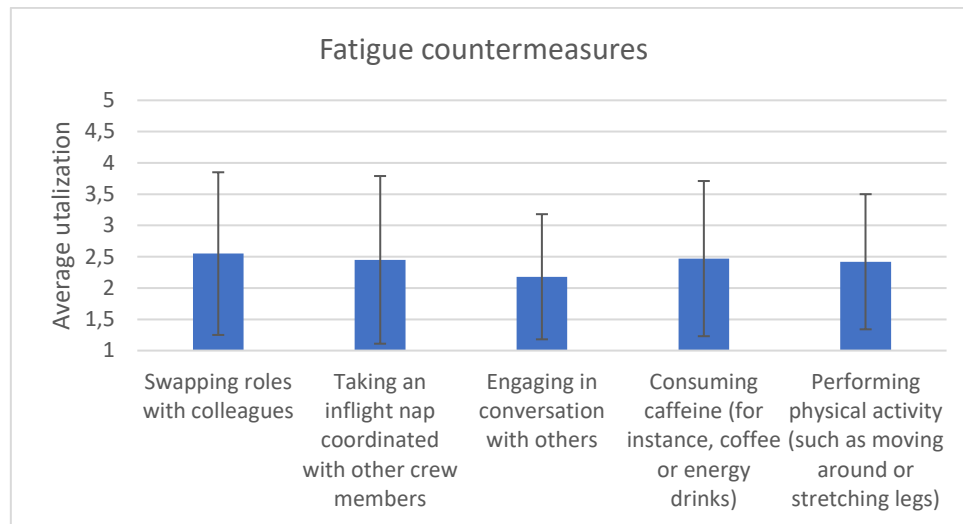


Figure 6-8. Means and SDs of fatigue countermeasures

The analysis proceeds by comparing the likelihood of all the provided responses. This involved a comparison of multiple related measurements. As once again ordinal data is used, one prerequisite for using the parametric test to compare multiple related samples is not met. Consequently, again the non-parametric Friedman's ANOVA was employed for testing this hypothesis. The results (see Table 6-7) of this test are provided here:

Table 6-7. Friedman's ANOVA

χ^2	df	p
3.56	4	0.469

The results from Friedman's ANOVA suggest that there are no statistically significant differences in the utilization of any of the given responses. This is indicated by the value of statistical significance p , which is not below the threshold of 0.05 ($p=0.469$). The results from Kendall's W effect size test with a sample size of 76, revealed an effect size of 0.0117. According to Cohen's conventions, this effect size is categorised as 'small'. Thus, while there is a consistency in rankings across the different judges, the degree of agreement is not particularly strong. This finding further reinforces the results of Friedman's ANOVA, suggesting that the differences in responses are not statistically significant. Based on this finding, it was concluded that swapping roles with colleagues,

taking coordinated inflight naps, exercising, and caffeine intake are no more popular than any other fatigue countermeasure.

In accordance with these findings, neither of the null hypothesis (H2.1₀, H2.2₀, H2.3₀, or H2.4₀) can be rejected. Consequently, none of the alternative hypothesis (H2.1_a, H2.2_a, H2.3_a, and H2.4_a) can be accepted, and thus even the main **H2 hypothesis cannot be accepted**.

H3: Sleep is positively related to fatigue and fatigue countermeasures.

In the analysis of the hypothesis H3, the relationship between sleep and two other factors, fatigue, and fatigue countermeasures, were explored. Once again, this hypothesis can be deconstructed into two alternative sub-hypotheses (with their null hypothesis variants):

H3.1_a: Sleep is positively associated with fatigue.

H3.1₀: Sleep and fatigue are significantly related.

H3.2_a: Sleep is positively associated with the use of fatigue countermeasures.

H3.2₀: Sleep and fatigue countermeasures are significantly related.

Thus, it was sought to examine a direct relationship between sleep and fatigue, and a reciprocal relationship between countermeasures and sleep. Thus, the analysis incorporates a multitude of measures. For sleep, all the identified factors impacting sleep hygiene were included, where participants rated the frequency of each factor on a scale of 1 (always) to 5 (never):

- Unpredicted operations
- Family issues
- Poor sleep environment (e.g., too hot, cold, noisy, bright)
- Nighttime duties
- Workload

- Off-duty leisure activities (e.g., movies, sports)

For fatigue countermeasures, participants rated the frequency of the following activities, again on the scale of 1 (always) to 5 (never):

- Swapping roles with colleagues
- Taking an inflight nap coordinated with other crew members
- Engaging in conversation with others
- Consuming caffeine (for instance, coffee or energy drinks)
- Performing physical activity (such as moving around or stretching legs)

For fatigue, the following measures were included:

- Unintentional sleep (1-never, 4-always)
- Average number of hours slept per day (actual hours)
- Formally reporting fatigue on duty (1-yes, 2-no)

As noted during the measurement review, the scales of the measurements were not uniform. Therefore, to ensure consistency and interpretability, all measurements were standardized to have a mean of 0 and a standard deviation of 1. Subsequently, a structural equation modelling (SEM) analysis was conducted with the architecture illustrated in Figure 6-9, where fatigue was modelled as a function of sleep, and sleep and countermeasures were modelled to interact bidirectionally.

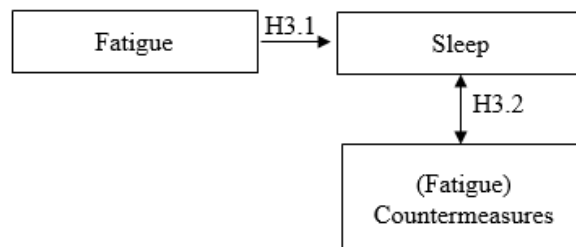


Figure 6-9. The architecture of SEM

The outcomes of the structural equation modelling are presented in the following table (see Table 6-8) and illustrated in the chart below.

Table 6-8. Latent variables

Latent Variables	Estimate	Standard Error	z-value	p
Fatigue				
Sleep Quantity	0.577	0.092	6.295	<0.001
Reporting	0.337	0.094	3.569	<0.001
Unintentional Sleep	0.710	0.106	6.681	<0.001
Sleep				
Unpredicted Operations	0.862	0.092	9.329	<0.001
Family Issues	0.739	0.099	7.433	<0.001
Poor Sleep Environment	0.775	0.098	7.886	<0.001
Night time duties	0.819	0.095	8.666	<0.001
Workload	0.827	0.094	8.757	<0.001
Off-duty leisure activities	0.728	0.100	7.264	<0.001
Countermeasures				
Swap Role	0.504	0.120	4.212	<0.001
Inflight Nap	0.490	0.120	4.085	<0.001
Talk to Others	0.617	0.116	5.311	<0.001
Caffeine	0.612	0.116	5.263	<0.001
Exercise	0.682	0.114	5.972	<0.001

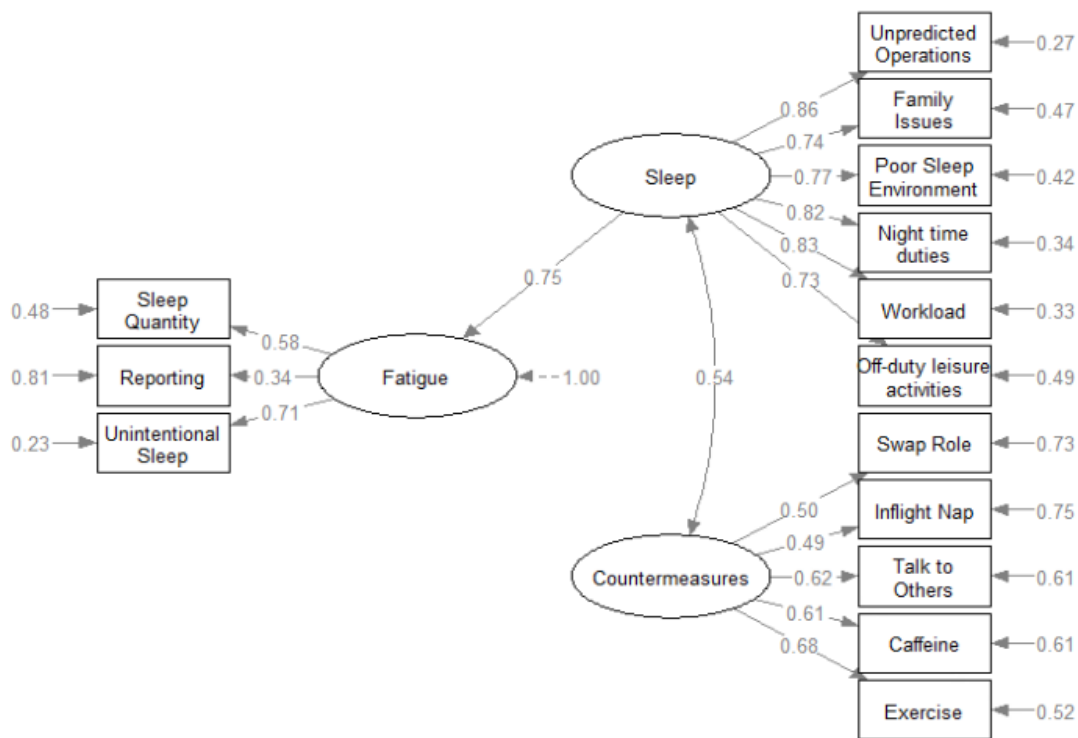


Figure 6-10. Structural Equation Model

The resulting model (see Figure 6-10) also has a good fit to the data as indicated by the chi-square test. The test statistic is 100.262, with degrees of freedom 75, and the p is 0.027, which is below the significance level 0.05. The loading of each observable variable on their corresponding latent variable is estimated. Also, all loadings are statistically significant ($p < 0.05$ for all), suggesting that each of the observed variables are significant indicators of their respective latent variables (see Table 6-9).

- Fatigue is measured by three different measures (with loadings ranging from 0.34 to 0.71).
- Sleep is measured by six different measures (with loadings ranging from 0.73 to 0.86).
- Countermeasures are measured by five different measures (with loadings ranging from 0.49 to 0.68).

Table 6-9. Regressions and Covariance

Path	Estimate	Standard Error	z-value	p
Fatigue ~ Sleep	0.747	0.180	4.153	<0.001
Sleep ~ Countermeasures	0.535	0.105	5.076	<0.001

The results show that sleep is a significant predictor of Fatigue, with a standardized regression coefficient of 0.747; $p < 0.001$. This indicates a significant positive relationship between Sleep and Fatigue, which rejects H3.1₀ and thus H3.1_a can be accepted.

The covariance between Sleep and Countermeasures is 0.535, which is statistically significant ($p < 0.001$). This again implies a significant positive relationship between Sleep and Countermeasures, which rejects H3.2₀ and so H3.2_a can be accepted.

Next are the tests which test the model's validity. If the model is not appropriate, the hypothesis cannot be accepted. The researcher started with the variances (see Table 6-10) for the residuals (unexplained variance) for each indicator variable.

Table 6-10. Variances

Variable	Estimate	Standard Error	z-value	p
Sleep Quantity	0.485	0.112	4.323	<0.001
Reporting	0.811	0.134	6.031	<0.001
Unintentional Sleep	0.233	0.127	1.842	0.065
Unpredicted Operations	0.273	0.057	4.745	<0.001
Family Issues	0.467	0.083	5.653	<0.001
Poor Sleep Environment	0.424	0.077	5.51	<0.001
Nighttime duties	0.337	0.065	5.173	<0.001
Workload	0.33	0.064	5.124	<0.001
Off-duty leisure activities	0.486	0.085	5.7	<0.001
Swap Role	0.734	0.131	5.62	<0.001
Inflight Nap	0.747	0.132	5.67	<0.001

Variable	Estimate	Standard Error	z-value	p
Talk to Others	0.607	0.121	5.033	<0.001
Caffeine	0.613	0.121	5.066	<0.001
Exercise	0.522	0.116	4.481	<0.001
Fatigue	1.000			
Sleep	1.000			
Countermeasures	1.000			

The variances for the residuals, along with the variances of the latent variables, are estimated and are found to be significant at the 5% level. This suggests that not all the variability in the observed indicators can be explained by the latent variables. For latent variables (Fatigue, Sleep, Countermeasures), the variances are all set to 1. This is standard practice in SEM, as it helps with model identification. By fixing the variance of the latent variables to 1, they are essentially scaled, and this allows the model to estimate the loadings of the observed variables onto the latent variables.

Convergent Validity was tested, which is important to verify that different measures of the same construct are indeed related. This was accomplished by calculating the Average Variance Extracted (AVE) for each construct, which should ideally be 0.5 or higher to indicate good convergent validity.

The AVE measures the level of variance captured by the construct in relation to the amount of variance attributable to measurement error. If the AVE is above 0.5, it means that, on average, the construct explains more than half of the variance of its indicators, signifying good convergent validity.

In this case the AVE for **fatigue** is 0.494, which is slightly below the recommended threshold of 0.5. This suggests that the measures used to represent *fatigue* might not be sufficiently capturing the construct. Further investigation into the measurement model or more refined measurements may be needed. The AVE for **sleep** is 0.629, which is above the 0.5 threshold. This suggests good convergent validity for the *sleep*

construct, meaning that it captures more than half of the variance of its indicators. This construct appears to be well measured in the model. The AVE for countermeasures is 0.343, which is below the 0.5 threshold. This suggests that the convergent validity for the *countermeasures* construct is not ideal, as it's not capturing more than half of the variance of its indicators. Similar to *fatigue*, this might necessitate further investigation or refinement of the measures used for this construct. In summary, the construct *Sleep* seems to have good convergent validity while the constructs *Fatigue* and *Countermeasures* might need to be refined or re-evaluated to improve their convergent validity.

Discriminant Validity was tested next. This is critical to confirm that different constructs are indeed distinct and not highly correlated. Discriminant validity refers to the extent to which a construct is truly distinct from other constructs. In this case, each of the constructs (*Fatigue*, *Sleep*, and *Countermeasures*) is distinct from each other. To establish discriminant validity, that the square root of the AVE for each construct was verified as greater than its correlation with any other construct. The results indicate that all three constructs *Fatigue*, *Sleep*, and *Countermeasures* passed the test for discriminant validity. Each construct shares more variance with its associated indicators than it does with the other constructs in the model. This is a good sign in the context of the structural equation model, as it indicates that each construct measures a different phenomenon, and they are not merely reflections of each other. In other words, these constructs can be interpreted as independent factors in this model, and the relationships observed between these constructs in the structural model are meaningful and not due to overlapping content between constructs. So, these results support the validity of the SEM model (see Figure 6-9), as it's important that each latent variable, measures a unique construct. This also strengthens confidence in any subsequent analysis of the relationships between these constructs. Furthermore, these findings suggest which data is important to consider when developing the fatigue report form for the selected Air Force base.

Lastly, *Construct Reliability* was evaluated, which is necessary to confirm that the measures of a construct are consistent and reliable. This was done by calculating the Composite Reliability (CR) for each construct, which should ideally be 0.7 or higher to indicate good reliability. Construct reliability is a measure of the internal consistency of the indicators within each construct. It reflects the degree to which the indicators of each latent variable co-vary. If the indicators of a latent variable are highly correlated, then they are consistently measuring the same construct, indicating high construct reliability.

Fatigue has a construct reliability of 0.73. This is considered acceptable, as it is above the commonly used threshold of 0.7, showing that the indicators for Fatigue are reliably measuring the same underlying construct. **Sleep** has a construct reliability of 0.91. This is excellent and suggests that the indicators for Sleep are consistent in measuring the same underlying construct. **Countermeasures** has a construct reliability of 0.72. This is considered acceptable, as it is above the threshold of 0.7, suggesting that the indicators for Countermeasures reliably measure the same underlying construct. In conclusion, all three constructs in the model display good internal consistency, reinforcing the validity of the structural equation model. It means that each latent variable is well represented by its observed variables, and this gives confidence in the interpretation of the relationships between these constructs in the structural model. With these results, the acceptance of both sub-hypotheses can be retained. Consequently, **hypothesis H3 can be accepted.**

H4: There is no difference in the frequency of crew members who have not received any training on fatigue and crew members who have received fatigue training.

Next, it was investigated, if the participants have received any fatigue training, which is directly related to hypothesis H4 (first, in alternative form, then in its null hypothesis variant):

H4_a: Crew members have received some type of training on fatigue.

H4₀: Crew members have not received any type of training on fatigue.

The participants' responses about the four possible (multiple choice) fatigue training options were used in the analysis:

- Crew Resource Management (CRM) training
- Fatigue training provided by a flight surgeon
- None
- Other

The ensuing table (see Table 6-11) and bar chart (see Figure 6-11) display the frequencies of each of the potential responses. It must be noted that this question allowed for multiple responses, so the proportions do not total to 100%, as each participant could select none, one, or more responses simultaneously.

Table 6-11. Frequency analysis

	Crew Resource Management training		Fatigue training provided by a flight surgeon		No training received		Other (please specify)	
	N	%	N	%	N	%	N	%
Not selected	13	17.6	63	85.1	63	85.1	72	97.3
Selected	61	82.4	11	14.9	11	14.9	2	2.7

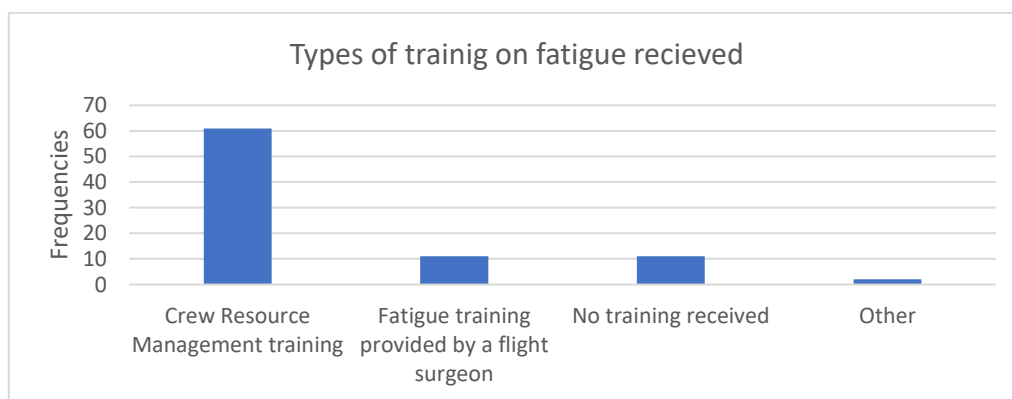


Figure 6-11. Frequency of fatigue training course

For the analysis of the hypothesis, these answers were transformed in the following way: First, if the participant answered, "Crew Resource Management (CRM) training" or "Fatigue training provided by a flight surgeon" it was denoted, that they received

training and denoted the answers as “Received fatigue training”. Next, the answers “No training received” were retained and discarded the participants who only answered with “Other”. There was one participant, who answered both (that they did not receive any training, and that they have received at least one type of training). They were removed from the analysis. Following are the results of the frequency analysis for the new variable.

Table 6-12. Frequency analysis

	N	%
Received fatigue training	62	86.1
No training received	10	13.9

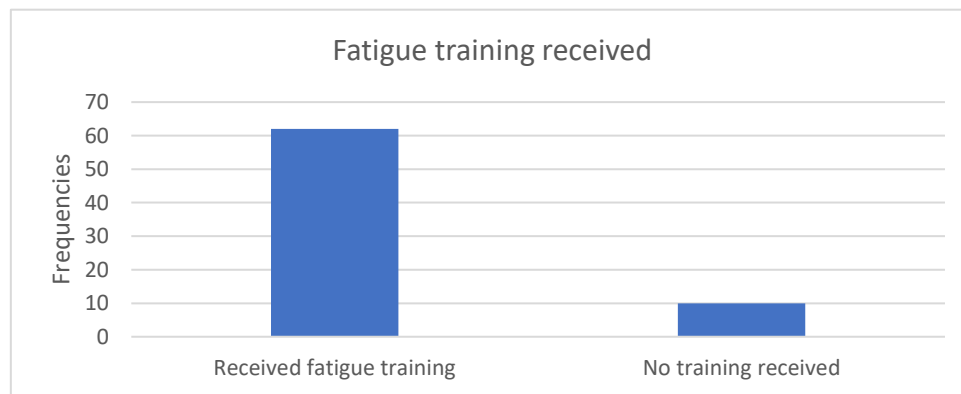


Figure 6-12. Fatigue training received

The differences in frequencies and proportions in fatigue training received can be seen from the frequency table (see Table 6-12) and the frequency bar plot (see Figure 6-12). This was continued with a chi-square test of equality of two proportions to check whether the differences in frequencies are due to chance (these differences are not a reflection of a real-world sample; if $p \geq 0.05$) or whether the differences are statistically significant (such differences in frequencies occur in the real world; if $p < 0.05$). The results of this test are given in the table (see Table 6-13) below.

Table 6-13. Chi-square test of equality of two proportions

χ^2	df	p
37.6	1	< 0.001

The results of the chi-square test show that there are indeed statistically significant differences in frequencies on the answers about if any fatigue training was received by a participant. This is indicated again, by the value of statistical significance p , which is below 0.05 ($p < 0.001$). The results indicate that participants most frequently received some type of fatigue training, which rejects the null-hypothesis H_{0} and thus, **H4 can be accepted**.

Additionally, the majority of the respondents agreed (strongly or somewhat) that they had received effective training on the causes (75.7%), consequences (75.7%), and countermeasures (70.3%) of fatigue (see Table 6-14 and Figure 6-13).

Table 6-14. Frequency table of 'I have received effective training on fatigue'

	Causes		Consequences		Countermeasures	
	N	%	N	%	N	%
Strongly agree	19	25.7	19	25.7	13	17.6
Somewhat agree	37	50.0	37	50.0	39	52.7
Neither agree nor disagree	9	12.2	11	14.9	12	16.2
Somewhat disagree	3	4.1	4	5.4	4	5.4
Strongly disagree	0	0.0	3	4.1	6	8.1

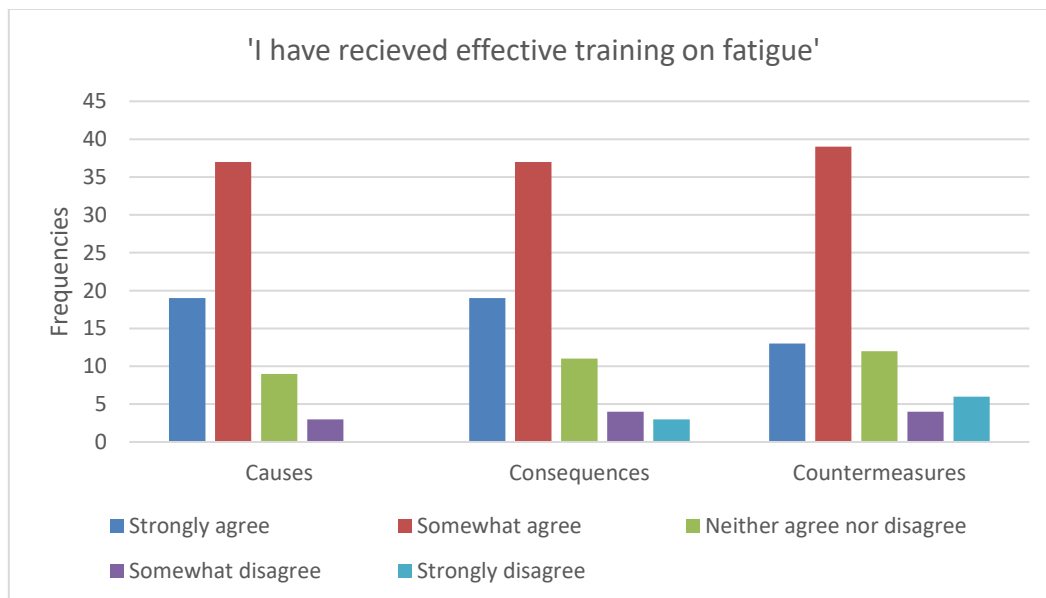


Figure 6-13. Fatigue training on fatigue causes, consequences, countermeasures

H5: There is no difference in the frequency of crew members who have received some training on sleep hygiene and crew members who have not received sleep hygiene training.

Finally, it was analysed, if the participants had received effective sleep hygiene training, directly tests hypothesis H5. This hypothesis is repeated in the following, firstly, in alternative form, then in its null hypothesis variant:

H4_a: Crew members have received some type of training on sleep hygiene.

H4_o: Crew members have not received any type of training on sleep hygiene.

The following are the participants' responses about the four possible (multiple choice) sleep hygiene training options presented:

- Crew Resource Management (CRM) training
- Sleep hygiene training provided by a flight surgeon
- None
- Other

The following frequency table (see Table 6-15) and frequency bar chart (see Figure 6-14) show the frequencies of each of the presented responses. Again, it should be noted that due to the multiple responses, some of the proportions may not total to 100%.

Table 6-15. Frequency table of 'What type(s) of training on sleep hygiene have you received?'

	Crew Resource Management training		Sleep training provided by a flight surgeon		No training received		Other	
	N	%	N	%	N	%	N	%
Not Selected	30	40.5	58	78.4	54	73.0	71	95.9
Selected	44	59.5	16	21.6	20	27.0	3	4.1

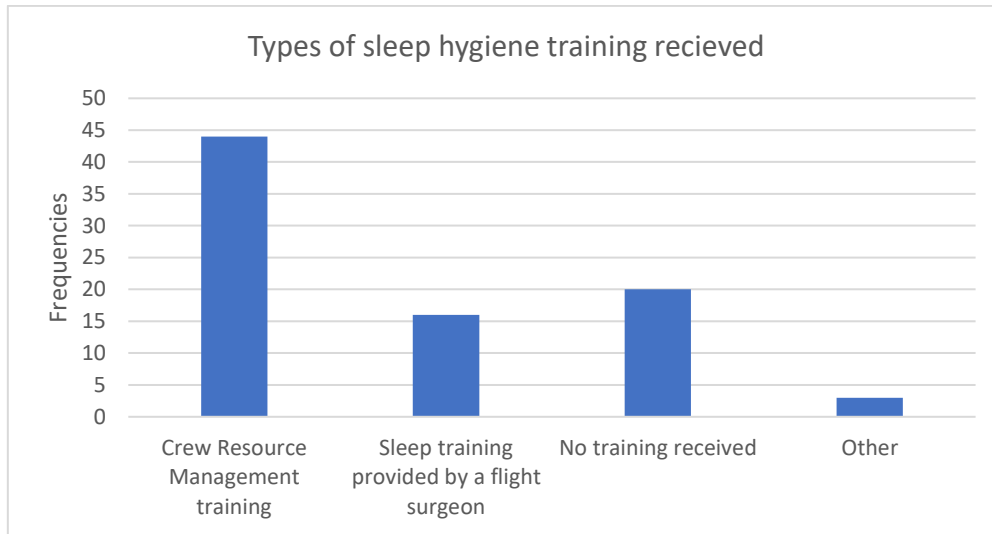


Figure 6-14. Type of sleep hygiene training received

Again, the answers were transformed as the following: First, if the participant answered, “Crew Resource Management (CRM) training” or “Sleep training provided by a flight surgeon” it was denoted, that they received training and the answers as “Received sleep hygiene training” were denoted. Next, the answers “No training received” were retained and discarded the participants who only answered with “Other”. In this case, there were no participants, who answered both, as in, that they did not receive some type of training, and that they have received no type of training. Following, are the results of the frequency analysis (see Figure 6-15).

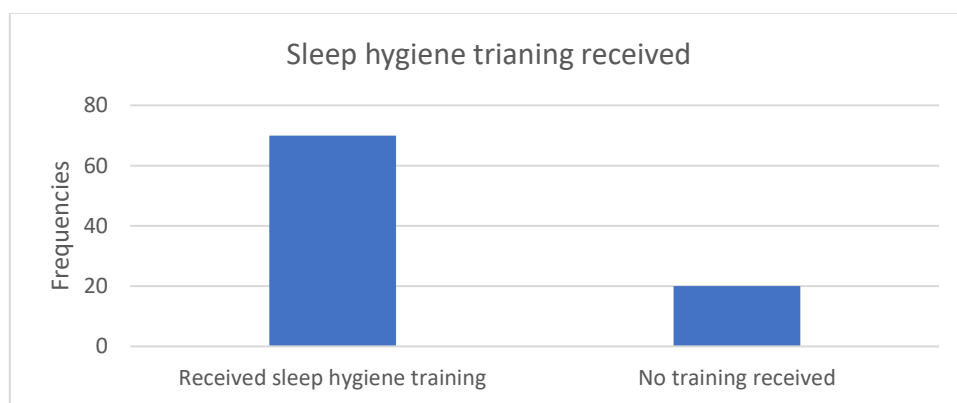


Figure 6-15. Sleep hygiene training received

Again, the differences in frequencies in received sleep hygiene training can already be observed from the frequency bar chart (see Figure 6-15), but again, chi-square of

equality of two proportions was conducted to check whether there are statistically significant differences in frequencies or not (see Table 6-16).

Table 6-16. Chi-square test of equality of two proportions

χ^2	df	p
12.9	1	< 0.001

Finally, the results of the chi-square test show that there are indeed statistically significant differences in frequencies on the answers about if any sleep hygiene training was received or not, as the value of the statistical significance p is below 0.05 ($p < 0.001$). The results indicate that more than not, participants received some type of sleep hygiene training, which rejects the null-hypothesis H_{50} and **H5 can be accepted**.

6.4 Other comments

The last question in the questionnaire gave respondents the opportunity to write their opinions, concerns, advice, or any other comments relevant to the questionnaire. Six respondents gave brief comments, such as 'Fatigue is not measurable with flight hours, or extra hours at work. Fatigue is not easy to measure and to find a solution to. Sometimes the work that we need to perform in the office has a big impact on flight performance'. This comment confirms previous findings throughout Study 1 and Study 2 of this thesis, where participants mentioned that office work is one of the potentially disturbing factors and may influence flight performance. The other comment stated: 'Over the years, we have seen a decrease in the number of pilots and loadmasters. The number of tasks remains unchanged, on the contrary, many new forms of flight involve greater crew commitment. The average age of loadmasters has risen, consequently the perception of fatigue is greater', which addresses the issue of reduced manpower and increased workload without proper management intervention. During Study 1 a few interviewees mentioned that older loadmasters are less productive than younger ones and the Air Force management should consider age limitations for loadmasters. Another comment stated 'We can talk about it (fatigue) but in the end, you must complete the

mission. Must change the way of planning the mission, which reflects the military culture aiming at completion of the mission regardless of potentially pre-existing fatigue or sleepiness or any other disturbing factor'. Furthermore, 'Constant work to organise flight activity then having to change it every day at 16.30 because urgent needs came out (all priority 1). Often have increased payload for others not doing their job (planning flights as training flights for brigade needs, evaluate conditions of an aircraft for a certain flight because job control doesn't do it or doesn't know the real limitations of different aircrafts)'. This statement refers to unpredicted operations identified throughout Study 1 and Study 2 and last-minute changes due to internal organisational issues and unpredicted operations. The following comment states there is unrealistic comparison between real life and training regarding fatigue, crew management and safety, which may indicate the lack of practical experience on how to manage fatigue in real operations and which may affect the overall safety 'I feel there is a big difference between what we train and study about fatigue, crew management and safety and reality but we are improving'. The last comment in the questionnaire 'Despite a constant increase in fatigue imposed on crews, leaders keep demanding more effort, establish more tasks without equally improving personnel (which is actually always decreasing), infrastructure facilities (old computers and unhealthy work environments regarding the quality of the air conditioners in summer or heating in winter, poor hygiene in restrooms) and the overwhelming bureaucracy, which is frustrating and generates stress during everyday activities. Inability to plan deployments at least three months in advance causes a great deal of stress family wise. Crews sacrifice too much time abroad without an adequate rest between deployments, often less than four months spent at home before the next deployment', indicates previous findings throughout both studies of this thesis relating to the lack of manpower, increased workload, and organisational issues.

6.5 Discussion

The results of Study 2 support most findings of Study 1, the literature review and add the strength to the correlations identified between fatigue and sleep, between countermeasures and sleep, and the associated variables.

The main objective of this study was to investigate fatigue in military aviation transportation and logistics base. Which factors have the greatest influence on fatigue and by which indicators they are affected, taking into consideration two constructs affecting fatigue, sleep hygiene and fatigue countermeasures, using SEM (see Figure 6-10).

Fatigue in military aviation cannot be measured using the same instruments for measuring fatigue in civilian aviation or other transportation settings due to the nature of military operations themselves. Many defence forces have adopted a civilian-based approach to Safety Management Systems (SMS) and developed and implemented Fatigue Risk Management System (FRMS) mostly as a stand-alone system, which represents a holistic approach to safety and addresses variables that are not addressed in SMS and enables operators to continuously assess and improve the impact of operational and organisational changes on overall safety and promote safe operations (McCulloch, Baker, Ferguson, Fletcher, Dawson, Marcil, Booth-Bourdeau, Laurence, 2007; Whittemore, 2019).

Moreover, fatigue is not easily measurable, there are various objective and subjective measurement tools but there is still no common definition on what fatigue is, therefore, measuring fatigue in military aviation is more likely performed in a laboratory or simulator.

Furthermore, sleep is one of the main factors influencing fatigue in this study as it addresses the quantity and quality of sleep and relevant disturbing latent indicators, for example, unpredicted operations, family issues, poor sleep environment, night-time duties, workload, and off-duty leisure activities.

On the other hand, fatigue countermeasures and mitigation strategies are decreasing the likelihood that fatigued individuals in the workplace will make an error leading to safety issues and reduce the likelihood of people being fatigued at work. Individuals take different approaches to preventing fatigue or reducing the level of fatigue using various fatigue mitigation strategies and countermeasures which depend on individual psychological and physiological conditions. However, more longitudinal studies are needed to investigate individual differences and genetic predictors of performance impairment vulnerability.

Fatigue in this research was influenced by several individual and organisational factors. Crew members in the selected base mostly experienced fatigue at home base due to organisational arrangements and other base-related operational arrangements including training and unpredicted operations when there is not enough time to plan the mission and take care of the family.

Sleep quality and quantity in this study depends on environment, complexity of a mission, individual factors, personal life, and circadian rhythm.

Furthermore, crew members prefer not to report perceived fatigue due to personal constraints and military culture as several interviewees stated they do not report fatigue due to their beliefs that reporting is assigned to personal weakness, moreover, they believe they would not receive any feedback from the organisation and therefore, in their opinion reporting is useless.

Sleep hygiene is an important factor influencing and affecting operational fatigue perceived by crew members. Indicators affecting sleep are defined as a combination of work-related and non-work-related indicators. Unpredicted operations (Miller et al., 2014; Miller, Shattuck and Matsangas, 2011; Thomas et al., 2015) may cause disturbances in a private life and increased level of uncertainty, stress, and sleep hygiene issues.

Crew members may experience various environments and accommodation preventing good sleep hygiene (i.e., sleep quality and quantity). Mostly, poor sleep environmental factors are experienced by crew members when being deployed, which again depends on individual perception of an environment. Furthermore, night-time duties may cause psychological and physiological fatigue mostly due to the use of Night Vision Googles (NVG) as indicated by the interviewees in a previous semi-structured interviews study. Moreover, flying in a circadian low is another contributing factor to increased level of fatigue and sleep disruption (Casini et al., 2013; Motamedzadeh et al., 2017; Petru et al., 2005).

As mentioned previously, individual differences and genetic predictors are of great importance when predicting fatigue and performance impairment vulnerability due to the low levels of sleep quality and quantity (Åkerstedt, Knutsson, et al., 2004; Roach, Zhou, et al., 2017). However, these factors are still not well determined and needed for future research activities and better understanding of individuals and their tolerance to different working conditions and environment.

Countermeasure variables assessed individual approaches to managing or reducing fatigue in the workplace and influence the level of sleep hygiene and consequently fatigue. Indicators of fatigue countermeasures selected for this study originate from previous study, semi-structured interviews, and literature review. The most used inputs or independent variables include swapping roles with colleagues (Caldwell et al., 2009b; Miller, 2014b; Phillips, 2016; Williamson & Friswell, 2013), taking an in-flight nap coordinated with other crew members (Bonnet, 2015; Hartzler, 2014; Hilditch et al., 2016; Kubo et al., 2007), talking to others, caffeine intake (e.g., coffee, energy drinks) (Burdan, 2014; Lieberman et al., 2002; Puckeridge et al., 2011; Vital-Lopez et al., 2018; Wesensten et al., 2005), and exercise, for example, moving around and stretching legs (LeDuc et al., 2000).

Results about fatigue and sleep training showed most participants received some type of training on fatigue and sleep hygiene, most commonly through Crew Resource

Management training. Similarly, Study 1 showed participants received related training through Crew Resource Management training.

The first vital gap is a lack of agreed definition on what fatigue is, in other words, there is no unified definition of fatigue. The second gap is how fatigue is currently monitored and reported in military aviation. Numerous fatigue measurement tools are available which are not validated or reliable for assessing the actual level of fatigue, especially in military aviation where most measurement procedures must be performed in a laboratory due to the military operational environment. Furthermore, an affective reporting system would allow confident reporting with appropriate feedback which could motivate people to report more often any fatigue-related issues.

The aim of Study 2 was to explore the objectives of this thesis described in section 1.2 Aims and Objectives of Chapter 1 and to attempt to answer the research questions related with each objective and replicated below.

O2: To construct a military-specific fatigue model that encapsulates the fatigue stressors and countermeasures identified.

- RQ3: How is sleep quality connected with perceived fatigue levels and the implementation of fatigue countermeasures in the military setting?

O3: To explore the current fatigue and sleep management training.

- RQ4: What proportion of crew members have undergone training that addresses fatigue management?
- RQ5: How widespread is the training on sleep hygiene among crew members, and what are its perceived effects on sleep quality?

This next chapter discusses in detail the method of developing a military-specific fatigue report form. It shows which items are important and an inevitable construct of the form, discussing their implications for this thesis and future studies, and discussing proposed

fatigue report form for the selected Air Force base using heuristic evaluation methodology.

Chapter 7 - Study 3: Military-Specific Fatigue Report Form

7.1 Chapter Introduction

This chapter discusses the development of a military specific fatigue report form for the selected Air Force base. It details the use of results of the previous two studies of this thesis, semi-structured interviews, and the questionnaire survey and as well as the literature review to construct an appropriate fatigue report form, which shall contain all relevant factors identifying fatigue levels and its reasons and consequences including countermeasures taken for combat reported fatigue. This chapter concludes with the development of a military specific fatigue report form and methodological implications for future studies.

7.2 Method

Study 1 and Study 2 of this thesis are considered as a base for the development of a military-specific fatigue report form for the selected Air Force base considering their findings concerning fatigue causes and countermeasures, sleep hygiene and training on sleep and fatigue. This fatigue report form was designed based on previously mentioned factors and evaluated using heuristic evaluation methodology. The fatigue report form was designed based on ICAO fatigue report form and modified in accordance with the results of Study 1 and Study 2. The first draft shared with the selected Air Force base did not include the section about fatigue and sleep training and it was just the researcher's suggestion to also include the mentioned training section as it is important to understand the type and frequency of received training on fatigue and sleep hygiene. The selected base agreed on adding the proposed training section and they suggested reorganising some information in the form such as importance of a rank. The second draft was shared with the selected base for their professional revision and comments where no comments were received, and they agreed with the proposed fatigue report form that may be used in a pilot phase when implementing fatigue reporting mechanisms and maybe show some additional changes necessary according to their operational environment and which were not identified during this study.

7.2.1 Procedure

The literature review including the results of Study 1, Study 2 is considered as an appropriate approach on developing a military-specific fatigue report form. Before developing an appropriate fatigue report form, a remote meeting with the flight safety officer of the selected Air Force base took place in January 2023 where the potential structure of the form was discussed in detail based on results of Study 1 and 2 of this thesis including the literature review, and the flight safety officer's experience on fatigue-related issues in selected Air Force base. The flight safety officer emphasised the importance of environmental factors affecting sleep and increasing fatigue and base's operational and organisational needs related to fatigue issues. The highest concern related to environmental issues in relation to sleep and fatigue, are deployments in areas with high temperatures, humidity, windchill effect, noise, and sleep disturbing factors.

7.3 Developing a Military-Specific Fatigue Report Form

The proposed fatigue report form (see Figure 7-1) was finally structured in 6 sections providing detailed information of the event namely: Personal details, Fatigue feelings details, Sleep information and potential fatigue causes, Fatigue countermeasures, Fatigue and sleep training and suggested corrective actions. Primarily, the military-specific Fatigue Report Form did not include the Fatigue and sleep training section, and it was added at a later stage as the importance of fatigue and sleep training information was emphasised by the researcher.

7.3.1 Personal details

Personal details, time, and location of occurrence are aimed at identifying who the reporter is with an option to choose whether the reporter wishes to keep his identity confidential. Furthermore, grade and job title information are required in this section including information on duty (e.g., in-flight, on ground-office, deployment), if an in-flight sector or on ground location information is required when fatigue occurred with specifying the aircraft type, date, and time of occurrence.

7.3.2 Fatigue feelings details

In this section, the reporter provides information about fatigue feelings, how a reporter felt or what he observed when perceiving fatigue by circling the level of alertness in Samn-Perelli fatigue scale where 1 indicates Fully alert, wide awake, 2 Very lively, somewhat responsive, but not at peak, 3 okay, somewhat fresh, 4 A little tired, less than fresh, 5 Moderately let down, tired, 6 Extremely tired, very difficult to concentrate and 7 Completely exhausted. Chapter 2.6.2 further describes the seven-point self-assessment of Samn-Perelli Fatigue Scale values (Dahlgren et al., 2012; Samn & Perelli, 1982).

7.3.3 Sleep information and potential fatigue causes

The reporter is asked to answer questions regarding potential fatigue causes, where the first question is: 'How long had you been awake when the event happened?', the second question: 'How much sleep did you have in the 24 hours before the event?', third question: 'How much sleep did you have in the 72 hours before the event?', fourth question: 'Coordinated in-flight napping? If yes, when? Start and End'. Furthermore, the reporter needs to select potential fatigue causes such as unpredicted operations, workload, environment (temperature, humidity, windchill effect), night-time duty, sleep deprivation, family issues and off-duty activities. The reporter may also identify other fatigue causes not listed in the form.

7.3.4 Fatigue countermeasures

Under this section the reporter provides information on countermeasures taken to fight fatigue issues. The countermeasures listed in the form are based on the results of this thesis's studies 1 and 2, including a literature review, namely: swap the role with colleagues, coordinated in-flight nap, talk to others, caffeine intake and exercise. The reporter also has the option to write any other countermeasures taken and not listed.

The form concludes with the section giving an opportunity to the reporter to write any comments or corrective actions he/she may have.

Figure 7-1.Developed Fatigue Report Form

All identified sections should help to understand an event reported including information on fatigue and sleep level. Based on information received, the data analyst can inform the management, and further preventive measures can be put in place if needed or data can be used for potential fatigue and sleep training topics, CRM, or any other safety communication.

7.4 Heuristic Evaluation Checklist

Heuristic evaluation is a method to find usability of the reporting form in user interface design according to (Jackson & Cheng, 2018). This method was used to evaluate the proposed fatigue report form at the beginning of the development process and identify usability problems based on five chosen heuristics which are described further below. As the evaluators were end-users of the fatigue report form, heuristic evaluation and usability testing were performed at the same time. Issues found with usability testing represent the real issues of the proposed fatigue report form while potential issues are identified during the heuristic evaluation (see Figure 7-2).

List of heuristics chosen for the proposed form, based on Jakob Nielsen's 10 heuristics:

1. Match between system and the real world
2. Flexibility and efficiency of use
3. Aesthetic and minimalistic design
4. Consistency and standards
5. Recognition rather than recall

Furthermore, each heuristic in the heuristic evaluation checklist is described by individual questions to offer clear understanding to the participant of what each of the heuristics means, as they were not professional heuristic evaluators and might have issues with understanding the meaning of selected heuristics. Participants in this study were end-users of the proposed form, both pilots and loadmasters. Each heuristic had to be evaluated by the participants by selecting the rate of impact- severity of usability problems that end-users may face when filling in the form. The following impact rate was offered to the participants:

- 1= No problems at all
- 2= Minor cosmetic problem
- 3= moderate cosmetic problem
- 4= Severe cosmetic problem: recommended to be fixed
- 5= Minor usability problem
- 6= Moderate usability problem
- 7= Severe usability problem: important to fix before the use of the Form
- 8= Extreme usability problem
- 9= Usability catastrophe: must be fixed before the use of the Form

The participants had to select one of the above rating impacts for each of the heuristics.

7.4.1 Match between system and the real world

Match between system and the real-world heuristic was first addressed in the heuristics checklist where the participants were asked a specific question under the heuristic to be more friendly to understand it as the following 'Is the language of the form, words, phrases and concept familiar to you?' The participants which are the end-users of the form (crew members) had an opportunity to evaluate the proposed form based on the before mentioned question with rating the impact (i.e., severity of usability problems) and to write any recommendations for the improvement of the form they may have.

7.4.2 Flexibility and efficiency of use

The second heuristic of the evaluation form describes users' interfaces which should be flexible and efficient, allowing quick and easy completion of the form. The participants were asked this specific heuristic under the following question allowing a more friendly understanding 'Could the form be effectively used by both new and experienced users?'. Again, the participants had an opportunity to rate the impact of this heuristic and as well as write any additional comments and recommendations.

7.4.3 Aesthetic and minimalistic design

An aesthetic and minimalistic design heuristic was chosen to check for a style of the form's design by focusing on minimalistic necessary elements, visual harmony, and layout to be user friendly. The participants were asked to rate this heuristic by answering the following question: 'Is the form focused on necessary elements with simple layout and visual harmony?'. The participants rated the impact of the heuristic by 1 to 9 including the opportunity of writing additional comments and recommendations for the improvement of the proposed fatigue report form.

7.4.4 Consistency and standards

The participants were asked the following question: 'Is the language and design familiar with other related reporting forms in the field?', trying to understand if the language and the elements of the form are the same or like other reporting forms in the field, for example, the Safety Report Form. Participants rated the impact of this heuristic on the form and had an opportunity to write comments and recommendations for the improvement of the form.

7.4.5 Recognition rather than recall

The last heuristic by Jakob Nielsen used in this heuristic evaluation checklist 'Can inexperienced users interact with the form without previous interaction with the form?', namely recognition rather than recall was trying to identify if the proposed form is clear, consistent, and familiar to end-users/participants.

Heuristic Evaluation Checklist for Fatigue Report Form

Please answer the questions 1-5 by rating the impact of severity of usability problems, describe an issue and write recommendations (if any) for the improvement of the Fatigue Report Form.

	Step 1	Step 2	Optional
Heuristics	Describe issue	Rate impact (severity of usability problems)	Recommendation (how the form could be improved)
1. Is the language of the form, words, phrases, and concept familiar to you? (i.e., Match between the system and the real world)			
2. Could the form be effectively used by both, new and experienced users? (i.e., Flexibility and efficiency of use)			
3. Is the form focused on necessary elements with simple layout and visual harmony? (i.e., Aesthetic, and minimalistic design)			
4. Is the language and design familiar with other related reporting forms in the field? (i.e., Consistency and standards)			
5. Can inexperienced user interact with the form without previous interaction with the form? (i.e., Recognition rather than recall)			

Rate impact

(severity of usability problems)

1= No problems at all (1)

2= Minor cosmetic problem (2)

3= Moderate cosmetic problem (3)

4= Severe cosmetic problem: recommended to be fixed (4)

5= Minor usability problem (5)

6= Moderate usability problem (6)

7= Severe usability problem: important to fix before the use of the Form (7)

8= Extreme usability problem (8)

9= Usability catastrophe: must be fixed before the use of the Form (9)

Figure 7-2. Heuristic evaluation checklist

7.5 Data Analysis

The following data analysis and reporting were completed using the Fatigue Report Form and the Heuristic Evaluation checklist. The participants rated the impact of each selected heuristic and wrote comments and recommendations for the improvement of the Fatigue Report Form.

7.5.1 Sample description

The data from twelve participants was gathered at the start of the data analysis. Five loadmasters and seven pilots, all anonymous, have responded.

7.5.2 Analysis

Analysing the usability of fatigue report form aims to determine if the pilots and loading masters perceived the fatigue report form to be useful. Five questions were posed to the subjects:

- Is the language of the form, words, phrases, and concepts familiar?
- Could the form be effectively used by both, new and experienced users?
- Is the form focused on necessary elements with a simple layout and design?
- Is the language and design familiar with other related reporting forms?
- Can an inexperienced user interact with the form without previous training or instruction?

The responses available for each of the five questions were the following:

1. No problems at all.
2. Minor cosmetic problem.
3. Moderate cosmetic problem.
4. Severe cosmetic problem: recommended to be fixed.
5. Minor usability problem.
6. Moderate usability problem.
7. Severe usability problem: important to fix before the use of the Form.
8. Extreme usability problem.
9. Usability catastrophe: must be fixed before the use of the Form.

First, the answers were overviewed in two forms: the frequencies of answers for each question in the frequency table (see Table 7-1), and in the table of descriptive statistics (see Table 7-2), which analysed the answers based on their number values (ranks). Additionally, two charts accompany the tables: bar chart of frequencies illustrating the

frequency of each response for the questions (see Figure 7-3), and bar chart of means with standard deviation whiskers depicting the average ratings and the associated standard deviations (see Figure 7-4).

Table 7-1. Frequencies for each question

Question		Answers								
		1	2	3	4	5	6	7	8	9
Is the language of the form, words, phrases and concept familiar?	N	11	1	0	0	0	0	0	0	0
	%	91.7	8.3	0	0	0	0	0	0	0
Could the form be effectively used by both, new and experienced?	N	10	0	2	0	0	0	0	0	0
	%	83.3	0	16.7	0	0	0	0	0	0
Is the form focused on necessary elements with simple layout and design?	N	8	3	0	0	1	0	0	0	0
	%	66.7	25.0	0	0	8.3	0	0	0	0
Is the language and design familiar with other related reporting forms?	N	6	2	2	1	1	0	0	0	0
	%	50.0	16.7	16.7	8.3	8.3	0	0	0	0
Can inexperienced user interact with the form without previous training?	N	8	2	1	0	1	0	0	0	0
	%	66.7	16.7	8.3	0	8.3	0	0	0	0

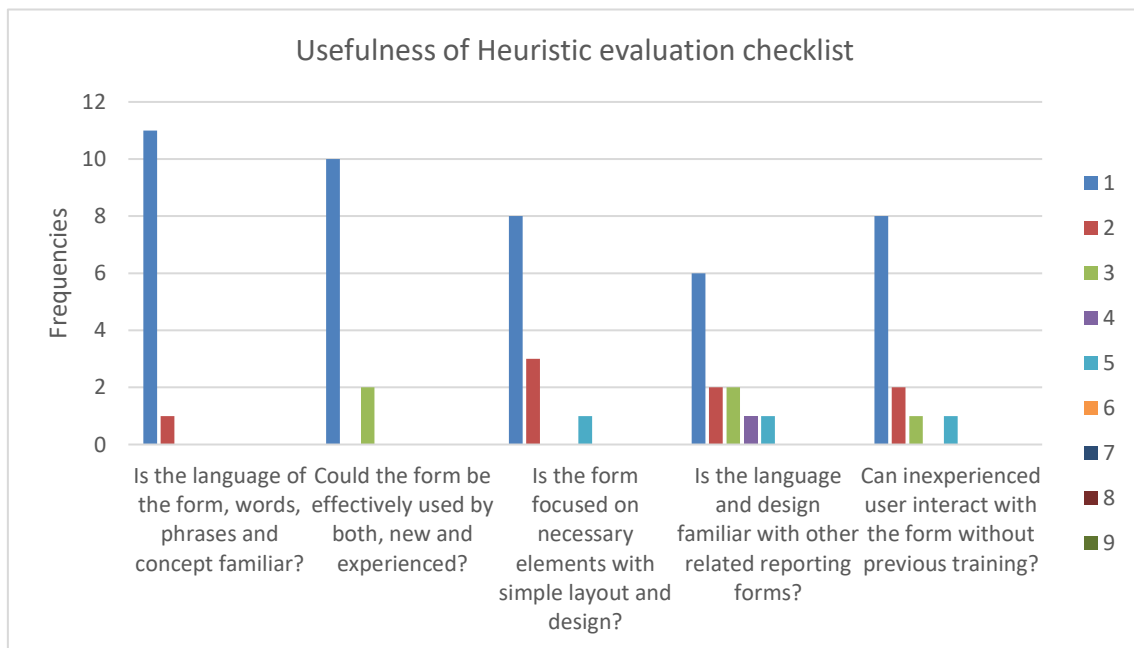


Figure 7-3. Usefulness of fatigue report form

Table 7-2. Descriptives for each of the five questions

	N	Mean	Median	Std. dev.	Min	Max
Is the language of the form, words, phrases, and concept familiar?	12	1.08	1	0.289	1	2
Could the form be effectively used by both, new and experienced users?	12	1.33	1	0.778	1	3
Is the form focused on necessary elements with simple layout and design?	12	1.58	1	1.165	1	5
Is the language and design familiar with other related reporting forms?	12	2.08	1.5	1.379	1	5
Can inexperienced user interact with the form without previous training or instruction?	12	1.67	1	1.231	1	5

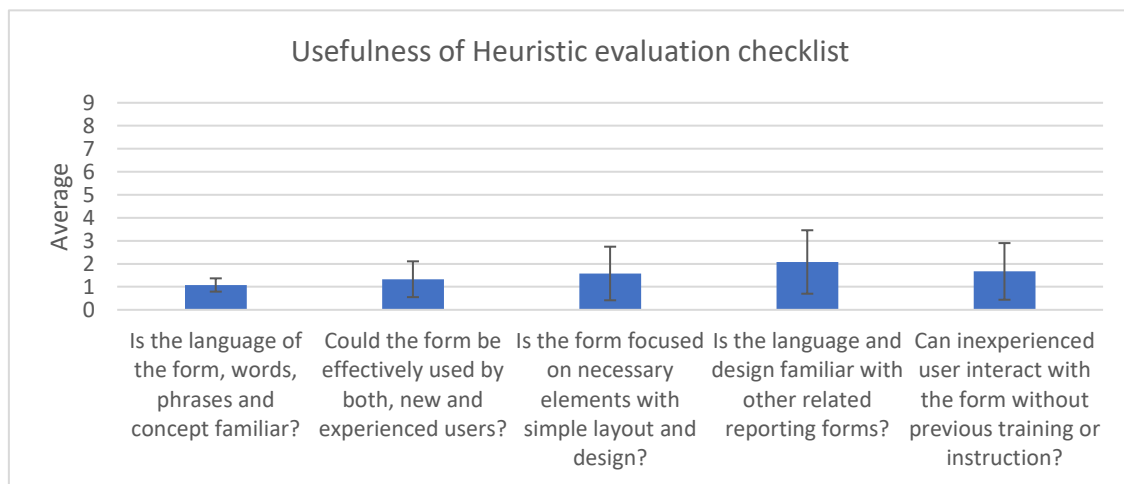


Figure 7-4. Average usefulness of fatigue report form

To assess the perceived usability of the form, it was essential to compute a singular measure derived from the five questions. Given that all questions were framed on the same scale and direction (higher values indicate a lesser usability score), the average of the five was used. The midpoint was crucial to analyse the usefulness, and thus averaging was the most appropriate method. Considering the low number of participants (N=12), conducting a Factor Analysis would not be appropriate, leading to low KMO (MSA) values.

The derived measure was named “General Perceived Usefulness of the fatigue report form”. Below are descriptive statistics for this new value (see Table 7-3 and Figure 7-5).

Table 7-3. Descriptives of 'General Perceived Usefulness of the fatigue report form'

	N	Mean	Median	Std. dev.	Min	Max
General Perceived Usefulness of the Heuristic Evaluation Checklist	12	1.55	1.4	0.639	1	2.6

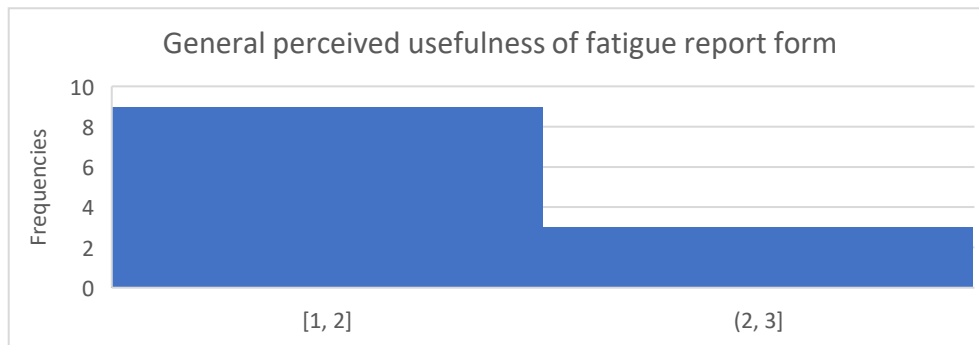


Figure 7-5. General perceived usefulness of fatigue report form

To evaluate the perceived usability, a one-sample test was employed. The reference value chosen was 5 (Minor usability problem), as lower numbers represent cosmetic issues or a complete lack of problems.

Prior to running the one-sample test, the data's distribution was assessed using Shapiro-Wilk's test of normality. In essence, the Shapiro-Wilk's test is one of the prerequisites for using the parametric t-test for one sample. The test examines whether the given measurements differ from a hypothetical normal distribution (when $p < 0.05$) or if it does not differ from a normal distribution (when $p \geq 0.05$; we conclude that the measurements are normally distributed).

As per the test's results ($W=0.793$; $p=0.008$), the data was not found to be normally distributed. Therefore, a non-parametric method was required – the Wilcoxon signed-rank test for one sample was conducted, comparing the sample with the reference value of 5. Given the study's objective (testing if subjects perceive the form as useful), a one-tailed version of the test was applied, checking if values were below 5.

The results of the Wilcoxon test conclusively indicate that the **subjects found the proposed fatigue report form useful**. This is evident from the p-value being below the threshold of $\alpha=0.05$ ($p<0.001$; $W=0$).

7.6 Discussion

The proposed fatigue report form was found useful by the participants, although the number of participants was 12, it was still possible to test the usefulness of the proposed form.

The language of the form, words, phrases, and concepts were familiar to almost all participants, which they also mostly agreed that the proposed Fatigue Report Form could be used without issues by both new and experienced users. The layout and design of the form focused on necessary elements, and the language and design were familiar with other related reporting forms. Finally, the participants agreed an inexperienced user could interact with the form without previous training on it.

Previous findings of this thesis identified sleep hygiene and fatigue countermeasures as having great impact on fatigue, sleep a direct and countermeasures an indirect impact. These two constructs influencing fatigue were taken into consideration, using SEM. Fatigue, in this thesis, was influenced by several organisational and individual factors, where participants in the selected air base experience fatigue mostly due to organisational arrangements, including training and unpredicted operations. Sleep and fatigue countermeasures in this thesis are correlated, having more than one indicator and the conceptual research model is presented and Lavaan graphical tool was used to develop the model (see Chapter 6). Operational and organisational arrangements such as unpredicted missions and manpower shortage were causing a great impact on participants' fatigue level along with other indicated fatigue stressors.

Participants in this thesis identified countermeasures they are using for maintaining the acceptable fatigue level and accomplishing their task safely and efficiently.

Currently, there is no specific fatigue report form available in the selected air base, which could help crew members to report any concerns related to fatigue and identify

the roots of fatigue and where fatigue has influenced behaviour and/or performance and consequently safety. The objective 4 of this thesis, 'To develop a military-specific Fatigue Report Form capturing the key fatigue-related factors and their interrelationships', identified that the fatigue report form would suit the nature of operations in the selected air base.

Fatigue report form in a commercial aviation enables crew to report any fatigue-related concerns as it is crucial to identify the root cause of fatigue which may influence performance and/or behaviour and consequently safety (Abd-Elfattah, Abdelazeim and Elshennawy, 2015, Anon, n.d.; Horrey et al., 2011). Some airlines have a specific fatigue report form to report fatigue while others use a safety reporting form through which flight and cabin crew can report fatigue related issues. The culture may be one of the biggest barriers in reporting fatigue as for example flight crew coming from the military aviation environment are less prone to report fatigue and are concerned about the possible consequences despite of the non-punitive policy in place, which is worrying.

Additionally, along with the proposed Fatigue Report Form, SAFTE-FAST biomathematical model which was developed for use in industrial and military contexts (Hursh & Balkin, 2004) and is currently also used by the United States Air Force (Mallis et al., 2004), could be used by the concerned Air Force for identifying potential fatigue factors such as recent sleep timing, continuous hours awake, cumulative sleep debt, time on task/workload and predicting fatigue which would increase the possibility of fatigue and sleep issues being identified and overall safety being improved.

The principal aim of developing a military-specific fatigue report form was to give an opportunity to all crew members to report any fatigue-related issues and to identify and analyse the role of fatigue in safety events, therefore, to improve the overall safety. This was achieved by exploring objective four of this thesis and attempting to answer the research question RQ6 described in Chapter 2, which is replicated below.

O4: To develop a military-specific Fatigue Report Form that captures key fatigue-related factors and their relationships.

- RQ6: What type of Fatigue Report Form would be suitable for the selected air base?

The development of the fatigue report form for the selected air base, according to previous findings, and intended to investigate the particular hypothesis, enabled the creation of the reporting form which would suit the needs and complexity of the selected air base and may be used in the selected air base future operations as a tool for fatigue identification and analysis.

Chapter 8 - Conclusion

8.1 Chapter Introduction

The overall outcome of the research done for this thesis is presented in this chapter. The conclusions drawn from the three studies are aligned with the objectives, aims, and research questions of this thesis. They also address the limitations of each study as well as the overall thesis constraints and the thesis's contributions, including the possibilities for further research.

8.2 Objective 1: To Examine the Prevalent Fatigue Stressors and Countermeasures within Military Operations at the Selected Air Base.

Study 1 and 2 participants provided detailed data; therefore, the objective's conclusions are derived from both studies. The first study of this thesis enabled the identification of prevalent fatigue stressors and countermeasures by crew members, which were later further explored through Study 2. The research questions related to this objective are listed and summarised below.

8.2.1 Do unpredicted operations and family issues impact sleep hygiene compared to other factors among military personnel?

Results of Study 1 showed that unpredicted operations and family issues affect sleep hygiene, especially young crew members who have young children may lack of sleep. On the other hand, Study 2 identified this is not the case as unpredicted operations were not found to be affecting sleep hygiene more than workload, off-duty leisure activities and family issues.

8.2.2 What is the prevalence of using swapping roles with colleagues, coordinated inflight naps, exercise, and caffeine intake as fatigue countermeasures compared to other strategies?

Findings from Study 1 revealed that swapping roles with colleagues, coordinated inflight naps, exercise, and caffeine intake are the most commonly used fatigue countermeasures. Study 2 could not confirm that swapping roles with colleagues, taking coordinated inflight naps, exercising, and caffeine intake were used more frequently

than other fatigue countermeasures. Since Study 2 found no statistically significant differences in the utilisation of any of the given responses, it was concluded that these countermeasures are not more popular than any other fatigue countermeasure.

Particularly, research findings from Study 1 and Study 2 of this thesis gave an important insight into the current organisational and operational arrangements at the selected air base, although, there is a need for further research in the area of fatigue and sleep perceived by crew members, individual approach to mitigation strategies and sleep hygiene. Study 1 examined the prevalent fatigue stressors and countermeasures within military operations at the selected air base, as a result, different themes and sub-themes were identified and suggested possible hypotheses to be tested in Study 2 which further investigated findings of Study 1 and constructed a military specific fatigue model that encapsulates the fatigue stressors and countermeasures identified.

Results of Study 2 showed factors having the greatest influence on fatigue and by which indicators they are affected, using SEM. Countermeasure variables assessed individual approach to managing or reducing fatigue and the level of sleep hygiene. Data collected throughout Study 1 and Study 2 enabled the design of a proposed fatigue report form which usefulness was evaluated using Heuristics evaluation checklist.

8.3 Objective 2: To Construct a Military-Specific Fatigue Model that Encapsulates the Fatigue Stressors and Countermeasures Identified.

A structural equation modelling (SEM) analysis was conducted, where fatigue was modelled as a function of sleep, and sleep and countermeasures were modelled to interact bidirectionally. Structural equation modelling analysis consisted of the following steps: determining the research model based on the theoretical framework and interpretation of the relationship between factors and their measures; to assess construct validity, i.e., convergent and discriminant validity; to determine the measurement model including the confirmatory factor analysis; to describe the estimated model coefficients and to perform the analysis.

The structural equation model indicated that each construct measures a different phenomenon, and they are not merely reflections of each other. Therefore, these constructs can be interpreted as independent factors in this model, and the relationships observed between these constructs in the structural model are meaningful and not due to overlapping content between constructs. Overall, all three constructs in the model displayed good internal consistency, reinforcing the validity of the structural equation model. It means that each latent variable is well represented by its observed variables, and this gives confidence in the interpretation of the relationships between these constructs in the structural model indicating that sleep is positively related to fatigue and fatigue countermeasures.

8.3.1 How is sleep quality connected with perceived fatigue levels and the implementation of fatigue countermeasures in the military settings?

This research question investigated how sleep relates to perceived fatigue and the implementation of fatigue countermeasures using SEM which showed a positive relationship between sleep, fatigue, and fatigue countermeasures.

8.4 Objective 3: To Explore the Current Management of Fatigue and Sleep Training.

This objective investigated training on fatigue and sleep hygiene as important information that shall be included in the Fatigue Report Form. Training on fatigue and sleep hygiene explored the current training management of these type of training which gave an important insight into the missing information on fatigue and sleep identified by crew members through Study 1, and it highlighted the need for this information to be part of the proposed Fatigue Report Form. First, training section in the Fatigue Report Form was not considered necessary but after a thorough discussion with the researcher's supervisors, this very important information on training was incorporated and explored in the research Study 2 of this thesis.

8.4.1 What proportion of crew members have undergone training that addresses fatigue management?

Study 1 showed there is no specific training currently available addressing fatigue management. The training currently in place is Crew Resources Management which includes topics related to fatigue management, but participants have highlighted that in this form they do not receive enough information, and specific training would be needed. Study 2 confirmed crew members did not receive any training on fatigue management. Training on fatigue management is important for crew members as it would help them better manage their fatigue issues and increase the overall safety. It is also important to include information on the fatigue/sleep training received in the fatigue report form, including the frequency as this would help the analysing process to understand the overall picture of fatigue reported and take measures in the improvement process if needed.

8.4.2 How widespread is the training on sleep hygiene among crew members, and what are its perceived effects on sleep quality?

Study 1 of this thesis identified that crew members are satisfied with information received on sleep hygiene through Crew Resource Management training, however the interviewees expressed the need for sleep hygiene particularly when training which would increase awareness about sleep management and appropriate countermeasures. Participants in Study 2 confirmed there is some type of training currently in place through which they get sleep hygiene information. Also, this information shall be included in the fatigue report form indicating how many hours a crew member slept before the fatigue event occurred, including the sleep training received and when the last training session was.

8.5 Objective 4: To Develop a Military-Specific Fatigue Report Form that Captures Key Fatigue-Related Factors and their Interrelationships.

The development of military-specific fatigue report form was the final outcome of research studies in this thesis. It is an important contribution to current scientific research, as it offers a fatigue a reporting form that can be used by several and different

stakeholders experiencing fatigue issues and seeking strategies to report fatigue. The proposed fatigue report form can be used for fatigue risk identification and further actions in preventing fatigue risks by applying appropriate fatigue countermeasures, communication channels, setting appropriate training and improving the overall safety of activities. As previously mentioned, the proposed fatigue report form in this thesis cannot be applied by all Air Force squadrons as well as other settings mentioned, as each of them has different operational and organisational management, operating environment, requirements, and consequences of fatigue. Therefore, the proposed fatigue report form and SEM of this thesis can be used as an example for future research activities.

8.5.1 What type of Fatigue Report Form would be suitable for the selected air base?

This research question focused on what fatigue report form would be suitable for the selected air base, one of the transportation and logistics bases of the concerned Air Force. The first two studies of this thesis gave an important insight into current fatigue management arrangements, and the results were used for the development of a military-specific fatigue report form structured in six sections, providing detailed information on: Personal details, Fatigue feelings details, Sleep information and potential fatigue causes, Fatigue countermeasures, Fatigue and sleep training and suggested corrective actions. Training section was first not considered important and after a thorough discussion of the researcher and supervisor, it was decided to include this information into proposed fatigue report form in its final version. Training section in the form gave information about fatigue and sleep arrangements and all sections should help to understand an event reported. A heuristic evaluation checklist indicated its effective use by both new and experienced users, with all necessary elements presented in a simple layout and visual harmony, including familiarisation of the report's language and design with other related reporting forms.

The aim of the development of a military-specific fatigue report form was to give all crew members an opportunity to report any fatigue-related issues and to Air Force

management to identify and analyse the role of fatigue in safety events, therefore, to improve the overall safety. The research studies of this thesis can be an important step towards developing a military-specific FRMS in a selected air base.

8.6 Limitations

Limitations apply in conducting any research, particularly in a complex real-world system such as the one under study.

The difficulty of investigating fatigue and sleep arrangements in the selected air base is based on the wide range of agreements, arrangements, and research provided in the selected air base. The unpredictability of military staff and the recent pandemic have further limited this research study leading to extended periods of research studies which are explained further below.

8.6.1 Study 1

Semi-structured interviews are a particularly helpful method to begin researching a topic because the participants' answers may bring up points the researcher had not thought of. Questions from the semi-structured interview were previously reviewed and approved by the selected air base without any additional question the researcher may have had. Therefore, the researcher had to respect the agreed questions without any further questions she may have followed by received answers. Another limitation of this study was that the selected air base provided participants for this study, so they may be briefed before starting interview. One of the interviewees was even so short in his answers that the researcher had to ask for another interviewee, besides he was just visiting the selected air base for some period and originally came from the United States Air Force, therefore he was not familiar with the subject of this study.

8.6.2 Study 2

Participatory bias was a clear limitation of quantitative research, although at the conclusion of the period spent gathering data, 122 replies had been registered from which 83 (68.03%) responses had been completed and 39 (31.97%) uncompleted. All participants were male and data regarding the role were collected, therefore, 51 pilots

(61.45%) and 32 loadmasters (38.55%) gave their informed consent and completed the questionnaire.

However, the greatest limitation of this study was the limited availability of military personnel for this research study while the sample size actually represents a very large proportion of the population and generalising to this specific population is really not an issue while generalising to other squadrons' populations, more studies should be done to investigate fatigue in military aviation in all squadrons and not limited to one. For example, this study is limited to one squadron, i.e., the transportation and logistics base.

8.6.3 Study 3

The main limitation of this study was again pre-selected participants by the air base who gave their answers concerning the proposed fatigue report form using the heuristic evaluation checklist. The number of participants was decided after the researcher's consultation with the supervisor as the most appropriate according to a relatively small size of the participating air base, which later showed that considering the low number of participants (N=12), the researcher could not conduct a Factor Analysis as initially planned, as it would not be appropriate, leading to low KMO (MSA) values.

8.6.4 Overall issues

The three studies that were presented also have broad issues with the conclusions' external validity. The greatest challenge was a change of three supervisors which was something positive as the researcher was able to see different perspectives. Challenges of having a part-time PhD caused difficulties in balancing work, part-time PhD and family life.

Another issue was limited availability of military personnel due to the recent pandemic when the researcher had to wait almost a year to proceed with the Study 2 of this thesis. Based on the researcher's experience, military aviation is a very closed community, not very willing to participate in external research studies due to a big amount of confidential data they cannot disclose.

Finally, the vital gap is a lack of agreement about the definition of fatigue; in other words, there is currently no unified definition of fatigue. The second vital gap is how fatigue is currently monitored and reported in military aviation, including the lack of reporting culture. Numerous fatigue measurement tools are available which are not validated and reliable for assessing the actual level of fatigue, especially in military aviation where most measurement procedures have to be performed in a laboratory due to the military operational environment. Additionally, more studies should be done to investigate fatigue in other military aviation squadrons such as Eurofighter, Communication Flight, Training, Airborne Air Control, Airborne Command and Control, Attack, Bomb, Electric Combat, Flight Test, Helicopter, and others. As already mentioned, each squadron has a different environment, management arrangements, requirements, fatigue, and sleep arrangements, therefore, a different approach is needed to investigate fatigue and develop customised SEMs and Fatigue Report Forms.

8.7 Contributions

The work done for this thesis offers significant key contributions, which are listed and further explored below. All findings are very important for further implication in different settings in relation to fatigue management.

8.7.1 Increased understanding of prevalent fatigue stressors and countermeasures at the selected air base

Throughout the first two studies of this thesis the researcher identified prevalent fatigue stressors and countermeasures at the selected air base and increased awareness of those to Flight Safety Officer of the concerned base who further informed the upper management and took those identified stressors and countermeasures to be taken into account when developing possible military-specific fatigue training and military-specific Fatigue Risk Management Systems as a stand-alone system or as a part of Safety Management System (Wu et al., 2016). The important contribution was finding that unpredicted operations, family issues, poor sleep environment, night-time duties, workload and off-duty leisure activities all present sleep disruptors and unpredicted operations and family do not appear to have significantly greater affect than any of the

other potential sleep disruptors, indicating all should be taken into consideration equally in any further steps the military may take. It became apparent that none of the identified countermeasures is prevalent for fatigue countermeasures and all (i.e., swapping roles with colleagues, coordinated inflight nap, physical exercise, caffeine intake, engaging in conversation with others) should be considered as equal possible countermeasures when fighting fatigue among crew members (Phillips, 2016).

8.7.2 Identification of a military aviation-specific fatigue model

The development of a military-specific fatigue model enabled identification of relationships between three constructs namely *Fatigue*, *Sleep* and *Countermeasures* and the results showed that sleep is a significant predictor of Fatigue, with a standardised regression coefficient of 0.747; $p < 0.001$ which indicates a significant positive relationship between *Sleep* and *Fatigue*. Furthermore, the covariance between Sleep and Countermeasures is 0.535, which is statistically significant ($p < 0.001$) and again implies a significant positive relationship between *Sleep* and *Countermeasures*. The validity of the model was tested by *Convergent Validity* and *Discriminant Validity* along with the evaluation of *Construct Reliability*. In conclusion, all three constructs in the model displayed good internal consistency, reinforcing the validity of the structural equation model (See Figure 8-1). It means that each latent variable is well represented by its observed variables, and this gives confidence in the interpretation of the relationships between these constructs in the structural model which is replicated further below:

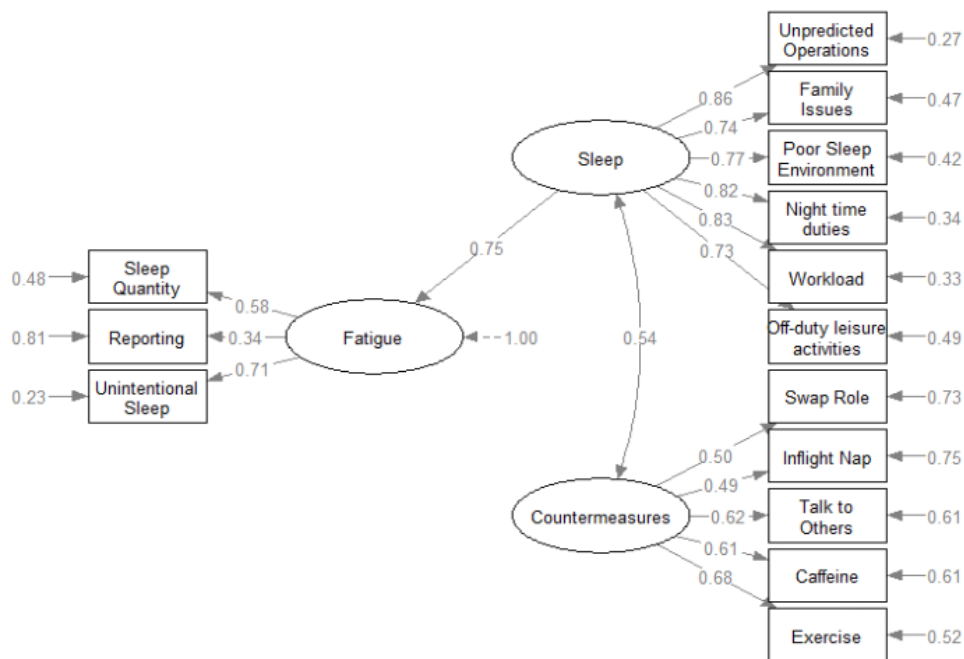


Figure 8-1. Replicated Structural Equation Model

8.7.3 Development of a military aviation-specific Fatigue Report Form

A military-specific Fatigue Report Form was proposed to the selected air base for possible integration into their current operations and improve the overall safety through identification of fatigue issues crew members are experiencing. This research study gave an important insight into the current operational and organisational arrangements by examining the prevalent fatigue stressors and countermeasures. As a result of this, different themes and sub-themes were identified and suggested possible hypotheses based on which a military-specific fatigue model was identified and further contributed to the development of a specific military Fatigue Report Form for the selected air base using heuristic evaluation checklist methodology.

The results of all three studies of this thesis have a great impact on military aviation fatigue management and not solely military aviation but also other settings such as healthcare, commercial transportation, manufacturing, construction industry and others that are exposed to fatigue. For example, the findings of this thesis could be also used by other stakeholders combating fatigue in their operational activities, among which are other European Air Forces that plan to develop and implement FRMS as a

stand-alone system or as part of an SMS (Wu et al., 2016). However, all findings have an impact on fatigue management and an impact on future research studies in the field of fatigue management.

Finally, along with the proposed Fatigue Report Form, the concerned Air Force could identify potential fatigue factors such as recent sleep timing, continuous hours awake, cumulative sleep debt, time on task/workload and predicting fatigue also by using SAFTE-FAST biomathematical model which has been already used by some Air Forces, for example United States Air Force (Mallis et al., 2004).

8.8 Future Studies

Many concepts still require clarification and more research, regardless of the findings of this thesis. All the factors at play (i.e., fatigue, sleep, and fatigue countermeasures) and the connections between them, as well as the unfavourable consequences of fatigue in military operations. Taking into account this thesis limitations, particularly with regard to the limited participation of the selected air base, it is therefore suggested to:

- Do more research studies in the field of fatigue and sleep in military aviation considering a larger sample size.
- Identify factors influencing fatigue also in other military aviation squadrons, as each of them has different and particular operational environment, therefore different factors influencing fatigue and sleep may be applied and need to be considered along with a different Fatigue Report Forms developed.
- Do more research in other settings such as medicine, commercial transportation, manufacturing, and others.

In this thesis, the combined research methodology, including a larger data set, could be significantly more reliable and valid.

Also, it is noteworthy to add that certain research methodologies (i.e., semi-structured interviews and a survey questionnaire) have already been employed by military studies

in literature, whose findings were validated by subjective evaluations gathered in the studies of this thesis.

A deeper comprehension of the effects of each factor and their interactions would be possible with the combination of qualitative and quantitative research methodologies. One such example would be the use of an Actiwatch, which can provide data on quantity, quality, and sleep hygiene.

Furthermore, this could be combined with other available and validated technologies. Future research should look into additional detrimental effects of working long hours, such as how fatigue affects health and how individual factors like personality and circadian type affect it.

Additionally, future work should focus on improving comprehension of the informal arrangements used by crew members for the management of fatigue, sleep, and overall wellbeing. Similarly, other industries should use similar arrangements as coping strategies to prevent the undesirable and detrimental effects of fatigue at work.

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Appendices

Appendix A Ethical approval letters



13 April 2019

Dear Mrs Jurgele ,

Reference: CURES/7960/2019

Title: Fatigue in military aviation

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/7960/2019 has been **approved**. You may now proceed with the research activities you have sought approval for.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team

Figure A-1 An ethical approval letter for Study 1



18 December 2020

Dear Mrs Jurgele ,

Reference: CURES/12528/2020

Title: Fatigue in military aviation

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/12528/2020 has been reviewed. You may now proceed with the research activities you have sought approval for.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team

Figure A-2 An ethical approval letter for Study 2



27 July 2023

Dear Mrs Jurgele ,

Reference: CURES/20025/2023

Project ID: 22957

Title: Fatigue in military aviation

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/20025/2023 has been reviewed. You may now proceed with the research activities you have sought approval for.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team

Figure A-3. An ethical approval letter for Study 3

Appendix B Semi-structured interview questions

Number	Questions
1	<p>Could you describe the nature of your work?</p> <ul style="list-style-type: none"> • For how long have you been doing this job? • What kind of responsibilities do you have as a “pilot/maintenance staff/air traffic controller? • controller”? • What do you find the most demanding about your job?
2	<p>How do you feel about organisational arrangements within the Air Force?</p> <ul style="list-style-type: none"> • What, in your opinion, works well and what does not? • What are the organisational scheduling practices and tools?
3	<p>How is your job scheduled?</p> <ul style="list-style-type: none"> • Are there duty time limits? • What system of work do you follow during and post-deployment?
4	<p>How do you find your job is related to fatigue?</p> <ul style="list-style-type: none"> • How are deployments affected by fatigue? What kind of psychological and physiological preparations are in place before deployments/missions? Are the diet and sleep environment conducive to proper sleep? • Can you refuse to be deployed?
5	<p>What is your attitude towards the perception of fatigue?</p> <ul style="list-style-type: none"> • Do you find it important to report on fatigue issues? • Are you aware of the possible consequences of fatigue? • Are you getting enough sleep?
6	<p>Can you tell me what your opinion is on how fatigue can influence safety within the Air Force?</p>
7	<p>How is fatigue reported?</p> <ul style="list-style-type: none"> • Are you aware of how potential fatigue-risk can be reported? • What is the procedure?

	<ul style="list-style-type: none"> • Does the current safety reporting form allow you to report on fatigue issues? • Are the existing data collection systems and processes designed to capture fatigue-related data?
8	<p>What, in your opinion, may reduce the level of fatigue and fatigue-related issues?</p> <ul style="list-style-type: none"> • How can fatigue hazards be better identified and managed? • What would you change in the current system of reporting fatigue hazards?
9	<p>How do training on fatigue/stress and sleep hygiene help you to sustain your performance level?</p> <ul style="list-style-type: none"> • How often are you trained on fatigue and sleep hygiene? What topics are covered? • Is there any information available on fatigue/stress management? Such as posters, bulletins, forums, website, readings, etc. • Do you think you receive enough information about fatigue and sleep? Are you well informed about fatigue countermeasures and consequences, sleep, and stress management?
10	<p>How in your opinion fatigue impacts your work?</p> <ul style="list-style-type: none"> • What are stressors related to your work? • How do you feel when you are fatigued?
11	<p>What impacts does fatigue have on your life?</p> <ul style="list-style-type: none"> • Health, family, social, and the overall well-being.
12	<p>How do you respond to and mitigate the perceived fatigue/stress?</p> <ul style="list-style-type: none"> • How do you maintain the alertness and performance? • What methods do you use? • How often do you use them? • Are these methods helpful in mitigating fatigue issues?
13	<p>Do you think workload affects your level of fatigue and/or stress?</p>
14	<p>What motivates you at work?</p>
15	<p>What are your values as a military service member?</p>

Appendix C Fatigue Questionnaire

Start of Block: Informed consent

Informed Consent

This consent includes details about the study and the intended use of your data. After carefully reading this consent, please tick the box indicating that you agree to proceed or withdraw. Kindly get in touch with Ms. Spela Jurgele at s.jurgele@cranfield.ac.uk if you have any inquiries about this study.

Procedure

I will ask you 30 questions regarding your work experience, sleep, and fatigue.

Confidentiality

All data is gathered in an anonymous way and will only be presented in aggregate form. No personal information will be gathered or reported, and no data pertaining to you will ever be identified. The information gathered will remain in the Qualtrics database until the researcher decides to remove it. The software platform used to provide the questionnaire on the electronic device you are currently using is called Qualtrics. The information gathered will only be utilised for this study.

Participation

You are free to refuse to take part in any section of this research at any time or to quit completely without consequences. Please close your web browser if you wish to withdraw from the questionnaire at any point; the data won't be uploaded.

I have read the information, I understand it, and give my informed consent to take part in this research.

- ☐ I understand the brief and give informed consent to participate in the questionnaire (1)
- ☐ I do not wish to participate (2)

Skip To: End of Survey If Informed Consent This consent includes details about the study and the intended use of your data... = I do not wish to participate in this research

End of Block: Informed consent

Start of Block: ABOUT YOU AND WORK

Q1 What is your job role?

- ☐ Pilot (1)
- ☐ Loadmaster (2)



Q2 What is your age in years? (enter a number)

Q3 Which aircraft are you currently flying?

- ☐ C-130J (1)
- ☐ C-27 SPARTAN (2)



Q4 How long have you been flying the current aircraft in years? (enter a number)



Q5 Before the COVID-19 pandemic, on average, how many hours did you fly in the aircraft in a month? (enter a number)



Q6 During the COVID-19 pandemic, on average, how many hours do you fly in the aircraft in a month? (enter a number)



Q7 On average, how many hours do you fly in a simulator in a year? (enter a number)



Q8 What is the average number of hours you worked in a month before the COVID-19 pandemic? (enter a number)



Q9 What is the average number of hours you work in a month during the COVID-19 pandemic? (enter a number)



Q10 What is the average number of hours you worked overtime in a month before the COVID-19 pandemic? (enter a number)



Q11 What is the average number of hours you work overtime in a month during the COVID-19 pandemic? (enter a number)



Q12 What is your commute time in minutes (from home to work and back)? (enter a number)



Q13 Before the COVID-19 pandemic, what percentage of your military flying occurred during the following parts of the day? (enter percentages)

During the day (06:00-17:00): _____ (1)

Evening (17:00-23:00): _____ (2)

Night (23:00-06:00): _____ (3)

Total: _____

Q14 During the COVID-19 pandemic, what percentage of your military flying occurs during the following parts of the day? (enter percentages)

During the day (06:00-17:00): _____ (1)

Evening (17:00-23:00): _____ (2)

Night (23:00-06:00): _____ (3)

Total: _____

End of Block: ABOUT YOU AND WORK

Start of Block: ABOUT SLEEP



Q15 On average, how many hours do you sleep per 24 hours? (enter a number)

Q16 In all the time you have been flying, how often have you experienced at least one episode of unintentional sleep while flying in your crew member's position?

- ☐ Never (12)
- ☐ Sometimes (13)
- ☐ Most of the time (15)
- ☐ Always (17)

Q17 How often have the following disrupted or interfered with your sleep over the past days?

Always (1) Most of the time (2) About half the time (3) Sometimes (4) Never (5)

Unpredicted
operations (1)

Family issues (2)

Poor sleep
environment
(e.g. too hot,
cold, noisy,
bright) (3)

Night-time
duties (4)

Workload (5)

Off-duty leisure
activities (e.g.
movies, sport)
(6)

End of Block: ABOUT SLEEP

Start of Block: FATIGUE ARRANGEMENTS

Q18 Please rank the causes of stress you experience at work.

_____ Unpredicted operations (1)

_____ Deployments (2)

_____ Environment (3)

_____ Family (4)

_____ Anxiety (5)

_____ Uncertainty (6)

_____ Workload (7)

_____ Other (8)

Q19 I have experienced at least one performance degrading effect of fatigue while flying at my crew position.

- ☐ Agree (1)
- ☐ Disagree (2)

Q20 Please select any performance degrading effects of fatigue you have experienced in flight.

- ☐ Poor judgement (1)
- ☐ Degraded situational awareness (2)
- ☐ Slowed reaction time (3)
- ☐ Procedural errors (4)
- ☐ Forgetfulness (5)
- ☐ Increased distractibility (6)
- ☐ None (9)
- ☐ Other (please specify) (10)

Q21 For each of the following fatigue countermeasures, please indicate how likely would you:

	Very likely (1)	Moderately likely (2)	Neither likely/unlikely (3)	Moderately unlikely (4)	Very unlikely (5)
Swap the role with colleagues (1)					
Take an inflight nap coordinated with other crew members (2)					
Talk to others (3)					
Caffeine intake (e.g. coffee, energy drinks) (4)					
Exercise (e.g. move around, stretching legs) (5)					

Q22 What tools (if any) are available for communicating fatigue in your organisation?

- ☐ Fatigue report form (1)
 - ☐ Safety reporting form (2)
 - ☐ Fatigue survey (3)
 - ☐ Personal report to flight safety officer (4)
 - ☐ None (5)
 - ☐ Other (please specify) (6)
-

Q23 Have you ever formally reported being fatigued while on duty?

- ☐ Yes (1)
- ☐ No (2)

Skip To: Q24 If Have you ever formally reported being fatigued while on duty? = Yes

Q24 Have you ever received feedback on reporting fatigue?

- ☐ Yes (1)
- ☐ No (2)

Q25 Were you satisfied with the feedback?

- ☐ Yes (1)
- ☐ No (2)
- ☐ Not completely (3)

End of Block: FATIGUE ARRANGEMENTS

Start of Block: TRAINING ON FATIGUE AND SLEEP

Q26 I have received sufficient training on:

Strongly agree (1)	Somewhat agree (2)	Neither agree/ disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
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Fatigue (1)

Fatigue causes (2)

Fatigue
consequences (3)

Fatigue
countermeasures
(4)

Q27 What type(s) of training on fatigue have you received?

- ☐ Crew Resource Management training (1)
 - ☐ Fatigue training provided by a flight surgeon (2)
 - ☐ None (3)
 - ☐ Other (please specify) (4)
-

Q28 I have received sufficient training on sleep hygiene.

- ☐ Strongly agree (1)
- ☐ Somewhat agree (2)
- ☐ Neither agree nor disagree (3)
- ☐ Somewhat disagree (4)
- ☐ Strongly disagree (5)

Q29 What type(s) of training on sleep hygiene have you received?

- ☐ Crew Resource Management training (1)
 - ☐ Sleep training provided by a flight surgeon (2)
 - ☐ None (3)
 - ☐ Other (please specify) (4)
-

End of Block: TRAINING ON FATIGUE AND SLEEP

Start of Block: OTHER COMMENTS

Q30 Is there anything else you would like to say?

End of Block: OTHER COMMENTS