# SYSTEM ANALYSIS OF FATIGUE IN PILOTS AND CO-PILOTS EXECUTING SHORT-HAUL FLIGHT OPERATIONS

**BY**

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**THESIS**

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# ABSTRACT

**Background:** This study was conducted as part of Denel's South African Regional Aircraft (SARA) development project. Regional aircraft have a maximum flight time of 60 minutes. Hence, the study focuses on matters pertaining to the short-haul flight context. Pilot fatigue has been recognised as a safety concern in the aviation industry. It impacts on pilot performance across the board, not least in the short-haul context. However, the specific factors that lead to pilot fatigue in short-haul operations have not been well researched. **Research Aim:** To identify and examine the factors which influence pilot/co-pilot fatigue in short-haul aviation contexts. **Method:** Fatigue is multifaceted, and has multiple definitions and descriptions. It is acknowledged as a complex phenomenon, the development of which is dynamically influenced by various factors. Thus, a systems approach based on the work system model by Smith and Carayon-Sainfort (1989) was adopted for this study. A systems analysis was conducted in two parts: 1) a literature analysis, and 2) expert interviews. **Results:** Both the literature analysis and the interviews indicated that pilot fatigue in short-haul flight operations represent composite system outcomes influenced by various factors. The factors identified were structured (systematised) into categories, namely organizational factors, task-related factors, environmental factors, factors linked to technology and tools, and non-work-related factors specific to the individual pilot. An example of a task-related factor would be the performance by pilots of multiple take-offs and landings; organizational factors include work time arrangements and duty scheduling (e.g. unpredictable schedule, early starts/late finishes, number of flight sectors in a shift, extended working hours, numerous consecutive work days, standby duties, flight, duty and rest limitations (regulations and guidelines); and short turnaround periods); environmental factors might include the small pressurised cockpit environment, movement restriction, very low humidity, low air pressure, vibrations, high noise levels, low light intensity light, and inclement weather); there are many examples of how tools and technology utilized by pilots might affect their fatigue levels; and finally, pilot-specific non-work-related factors would include things like the pilot's age, health (lifestyle), family stress, work experience and sleep environment. All of these factors were identified during the literature analysis and have a significant bearing on how fatigue could present in short-haul pilots/co-pilots. Other important fatigue-related factors revealed during the expert interviews included, organizational culture, time management, health implications of fatigue, and management of fatigue. **Conclusions:** Pilot fatigue is a complex and multi-factorial physiological condition. There are many interacting components which contribute to pilot fatigue in short-haul operations. These should be viewed from an integrated perspective and holistic, systems-based approaches should be taken to manage these issues, particularly in the context of short-haul operations. This would optimize pilot performance and well-being and, most importantly, improve the safety of the work environment to enhance overall operation safety. **Limitations:** The study does not quantify the contributions made to pilot fatigue by the various factors explored. Therefore, care needs to be taken when designing and implementing interventions based on this research.

**Keywords:** Aviation, short-haul, pilot/co-pilot, fatigue, workload, system analysis

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# LIST OF ABBREVIATIONS

ALPA-SA - Airline Pilots’ Association of South Africa
CAA - Civil Aviation Authority
CWA - Cognitive Work Analysis
FAA - Federal Aviation Authority (USA)
FAR - Federal Aviation Regulations
FDP - Flight Duty Period
FMEA - Failure Mode and Effects Analysis
FRMS – Fatigue Risk Management Systems
FTA - Fault Tree Analysis
FTL - Flight Time Limitations
JCS - Joint Cognitive System
HF/E - Human Factors and Ergonomics
IATA - International Air Transport Association
ICAO - International Civil Aviation Organization
IEA - International Ergonomics Association
IFALPA - The International Federation of Airline Pilots Association
MEAD - Macro-Ergonomic Analysis and Design
MRO - Maintenance, Repair and Overhaul
NASA - National Aeronautics and Space Administration
NTSB - National Transportation Safety Board
OEM - Original Equipment Manufacturer
OSA - Obstructive Sleep Apnea
PRA - Probabilistic Risk Assessment
SACAA - South African Civil Aviation Authority
SARA - South African Regional Aircraft
SHELL - Software, Hardware, Environment, Liveware and Liveware
SOC - State Owned Company
TLX - Task Load Index (NASA)
WOCL - Window of Circadian Low

# LIST OF DEFINITIONS

| Terms | Definition | References |
|---|---|---|
| Accident | A term used to describe an incident that occurs unexpectedly. | Goode, 2003 |
| Actigraph | A wristwatch-like device containing an accelerometer to detect movement and monitor sleep patterns. | Dinges *et al.*, 1996 |
| Aviation Fatigue | A physiological state of reduced mental and physical performance capacity due to sleep loss, extended wakefulness, circadian disruption or workload (resulting from mental and physical activity) that impairs a crewmember's alertness and ability to safely operate an aircraft or perform safety related duties. | Alcéu, 2015;<br>Ashley, 2013;<br>Tambala, 2017 |
| Circadian rhythm/body clock | Biological rhythm (with a period of 24 hours) that is synchronized with the day-and-night cycle. The circadian rhythm is also referred to as the sleep-wake cycle and determines the human preference for sleeping at night. | Barkai and Leibler, 2000; Dinges *et al.*, 1996 |
| Crewmember | A member of a flight crew assigned by an operator to a particular duty on an aircraft during a flight duty period. | Dinges *et al.*, 1996 |
| Cruise phase | Phase of flight when an aircraft is flying in the sky. | Estival *et al.*, 2016 |
| Descent phase | Phase of flight when an aircraft decreases altitude in preparation for landing. | IVAO, 2016 |
| Discretion period | An extended period of time needed to complete a duty. | Caldwell, 2005;<br>Chang, 2002;<br>Jackson and Earl, 2006 |
| Duty | Any duties that crewmembers are required to perform, including administrative work, training, deadheading, and airport standby reserve or on call duty. | Dinges *et al.*, 1996 |

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| Duty period | The period starting when crewmembers report for duty and ending when they are relieved of all duties after their final flight segment. | Dinges *et al.*, 1996 |
| Environment | The internal and external conditions/surroundings in which human beings (or any other organisms) live and function. | Okema-Opira, 2012 |
| Flight duty period | The period starting when crewmembers report for a duty period (which includes one or more flights) and ending when the last flight segment is completed, and the aircraft comes to rest. | Dinges *et al.*, 1996 |
| Flight time | The time taken from aircraft take-off (during the first flight segment) to the end of the last flight segment when the aircraft comes to rest. | Hiatt *et al.*, 2015 |
| Jet lag | Desynchronization of the circadian body clock and the day/night cycle caused by the crossing of several time zones, substantially removing an individual from their original time zone. | Dijkshoorn, 2008; Dinges *et al.*, 1996; Gropp, 2014 |
| Hardware | The equipment, tools, technology, and machines used within a system (workplace). | Dumitru and Boşcoianu, 2015 |
| Human Factors and Ergonomics | The scientific discipline concerned with investigating interactions among humans and other elements in systems; the profession that applies systems theory, principles, data and methods to design in order to optimise human well-being and overall system performance. | IEA, 2018 |
| Landing | The phase of flight when an aircraft slows down and descends to a runway upon reaching its destination. | IVAO, 2016 |
| Liveware | Term used to denote the human beings within a system as they interact with other system components. | Wiegmann and Shappell, 2003 |

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|---|---|---|
| Long-haul operations | Operations characterised by the crossing of multiple times zones and the covering of long distances. These operations usually take six hours or more. | Caldwell, 2005; Caldwell and Caldwell, 2016; Levo, 2016 |
| Off duty period | A period of uninterrupted time in which crewmembers are free of all duties within a given 24-hour period. | Dinges *et al.*, 1996 |
| Push back and taxiing | Phases of flight during which a pilot reverses an aircraft from its standing position and moves it from one point to another along appropriate taxiways (on the ground). | IVAO, 2016 |
| Schedule | A list of work periods or planned shifts within a defined time period. | Dinges *et al.*, 1996 |
| Sector/segment | A term used to describe a particular flight from take-off at an origin to landing at a destination. | Dinges *et al.*, 1996 |
| Shift work | A pattern or schedule that involves working during hours outside of the standard 08:00 to 17:00 work period. Shift work is also defined as work done during hours when people, according to their circadian body clock cycle, would normally be asleep. | Ashley, 2013; Dijkshoorn, 2008; Dinges *et al.*, 1996; Federal Aviation Administration, 2010 |
| Short-haul operations | Domestic/regional/commercial flights characterised by daytime flying with multiple flight segments, short-turnaround periods, no time zone crossings, and the ability to cover short distances only. These operations generally take between 30 minutes and three hours. | Gander *et al.*, 1998; Levo, 2016; Thomas *et al.*, 2015 |
| Sleep | A vital physiological need; a reversible state of disengagement and unresponsiveness to the environment. | Parsai, 2011; Siengsukon *et al.*, 2013 |
| Software | The regulations, programs, rules, and procedures that operate a system. | Petrilli, 2007 |
| System | A set of interrelating and interdependent parts which form an integrated whole. | Dul *et al.*, 2012 |

| | | |
|---|---|---|
| Take-off | Phase of flight which involves the transition of an aircraft from land (runway) to air. | IVAO, 2016 |
| Task | A term used to describe a discrete piece of work to be undertaken by an individual or group. | Pace, 2002 |
| Window of circadian low (WOCL) | The period between 02:00 and 06:00 in a normal day-wake/night-sleep schedule. | Co *et al.*, 1999;<br>Dinges *et al.*, 1996 |
| Workload | This refers to the amount of work assigned to an individual, as well as the time pressure under which the work is performed, the level of effort exerted during completion of the work, and the psychological and physiological consequences of the work. | Grech *et al.*, 2009 |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background to Study

Fatigue is considered to be a key problem in many industries worldwide, impacting on the overall performance levels, efficiency and productivity of workforces (Caldwell *et al.*, 2009; Reis *et al.*, 2013). In the aviation industry the issue pilot fatigue has long been a concern and is considered a risk factor with regards to flight safety and pilot performance (Reis *et al.*, 2013). This concern grows as the demand for air transport continues to increase (Caldwell and Caldwell, 2016).

Aviation or crewmember fatigue is described as a state of reduced physical and mental capability initiated by insufficient sleep, excessive workload, and unpredictable working hours (Reis *et al.*, 2013; Yuliawati *et al.*, 2015). Such fatigue has been identified as a causal factor in accidents, aviation errors and other incidents which ultimately stand to endanger the lives of passengers as well as crewmembers (Caldwell *et al.*, 2009; Thomas *et al.*, 2015; Yuliawati *et al.*, 2015). Various changes in the global economy, along with societal factors and technological advancements have led to pilots' facing a unique set of fatigue-related risks, largely associated with high workloads and the sheer magnitude of their work-related responsibilities (Caldwell, 2005).

With respect to pilot fatigue, much of the existing literature focuses on the context of long-haul flight operations (Caldwell *et al.*, 2009; Lin *et al.*, 2011; Rosekind *et al.*, 2000; van Drongelen *et al.*, 2013). Long sectors, travelling across several time zones, circadian disruptions and sleep loss have been identified as the main factors impacting on crewmember fatigue during long-haul operations (van Drongelen *et al.*, 2013). Conversely, pilot fatigue during short-haul flights is not well understood, despite an acknowledgement of the considerable fatigue risks in this context (Powell *et al.*, 2007; Vejvoda *et al.*, 2014).

## 1.2 Problem Statement and Research Aim

Short-haul operations require high utilization of both crew and aircraft. Tight work schedules and high workload for short-haul crewmembers specify numerous responsibilities and duties (Chang, 2002; Gander *et al.*, 1998; Powell *et al.*, 2007; Reis *et al.*, 2013; Yuliawati *et al.*, 2015). Pilots working under such conditions for sustained periods might become fatigued (Gander *et al.*, 1998). However, it is not clear which factors contribute to the development of such fatigue. Little is known from a South African short-haul operational perspective. This study aims to examine the factors contributing to the development of pilot/co-pilot fatigue during short-haul flight operations.

## 1.3 Context of Study

This study was conducted as part of Denel's SARA development project, described below. Because there are safety concerns associated with short-haul operations, fatigue being one of them, Denel's project developers mandated an investigation into aviation-related fatigue as part of the SARA project, which led to this study.

Denel Aeronautics, commonly referred to simply as "Denel", is a South African state-owned commercially driven company (SOC) based at the Ekurhuleni Aerotropolis in Gauteng (Denel, 2018). The company has been operating successfully for fifty years (Denel, 2018). Denel offers holistic aerospace solutions, aviation services, and aviation products (Denel, 2015). In addition, it offers continued airworthiness and system integration solutions, advanced maintenance, repair, and overhaul (MRO) services, and refurbishment of mechanical and avionic components of both fixed and rotary wing aircraft (Denel, 2015). Denel is the original equipment manufacturer (OEM) of the Rooivalk attack helicopter, the Cheetah fighter aircraft, and the Oryx medium transport helicopter (Mogoba, 2018).

In recent years, the global market for short-haul air travel has grown rapidly (Mogoba, 2018). In 2012, Denel began to anticipate meeting increased air travel requirements in the future. To this end, the South African Regional Aircraft (SARA) project was initiated (Mogoba, 2018). The SARA would be a twin turbo propeller-driven short-haul aircraft carrying twenty-four passengers (Mogoba, 2018). It would have rough field capabilities and fly at an altitude of up to 25 000ft to avoid turbulence and adverse weather (Mogoba, 2018). The SARA would be cost-effective and fuel-efficient (Mogoba, 2018).

The short-haul duty cycle with respect to the SARA would comprise a range of flights between four to five sectors per day. The average flight time per sector would range between 45 to 105 minutes; with most sectors taking 45 to 75 minutes each. The

SARA's daily route would include both small regional airfields and larger airports. The SARA environment would generally be characterised by daytime flying within the same time zone. Each duty cycle would begin and end at the same airport or airfield, resulting in crew layovers at a home base. In certain limited cases, short-haul cycles would be flown outbound one day, and inbound the next, necessitating a one-night sleep over for crewmembers.

### 1.4 Significance of the Research

Given the current lack of research in the area of short-haul operations, this study represents an initial step in analysing the factors contributing to short-haul pilot fatigue. The study is undertaken from a systems perspective using a work system analysis approach. The study aims to provide a composite and macroscopic view of the activities and factors at play within the aviation environment affecting the workload and fatigue experienced by pilots/co-pilots executing short-haul operations. Apart from bridging a significant gap in aviation literature, it is anticipated that the study will also provide valuable information for regional commercial airlines, enabling managers to maximize the safety and efficiency of their systems.

By examining factors within the short-haul aviation system that could pose a threat to aviation safety, the study aims to identify potential mismatches between human capabilities and various system components that might lead to excessive workload and fatigue for the human components of the system. It is anticipated that the knowledge produced will, in some measure, enhance awareness and enable the implementation of preventive measures with respect to pilot/co-pilot fatigue. It is hoped that certain findings from this study may even prove to be transferable to other high-risk domains outside the aviation industry.

### 1.5 Thesis Structure

The thesis has five main sections:

1) **Background Literature (Chapter 2):** Outlines important background literature relevant to this study. This section reviews the concept of system ergonomics as it applies to human factors and ergonomics and to aviation and provides a foundation for the rest of the study.
2) **Method (Chapter 3):** Describes the method, research concepts and procedures adopted during the study.

3) **Results (Chapter 4):** Presents the results of the study.
4) **Discussion (Chapter 5):** Presents a discussion of the results, acknowledges the limitations of the study, and makes recommendations for future research.
5) **Conclusion (Chapter 6):** Concludes the study and highlights its practical relevance.

# CHAPTER 2

# BACKGROUND LITERATURE

## 2.1 Overview of Chapter

This chapter presents an overview of systems ergonomics theory and provides a necessary foundation for the investigation of pilot fatigue. It also provides a brief overview of human factors and ergonomics (HF/E), the discipline to which this research study belongs (Section 2.2) and considers the importance of HF/E in the aviation context (Section 2.3). Furthermore, this chapter reviews the concepts of fatigue and workload and contemplates something of their complexity (Section 2.4). Finally, Section 2.5 introduces the theory of system analysis, which forms the basis for the methods used in this study.

## 2.2 Systems Ergonomics

Human factors and ergonomics (HF/E) is a discipline concerned with human-artefact interactions (Karwowski, 2005). In the past, authors have claimed that the two terms have distinct meanings. Human factors, it has been argued, is mainly concerned with the social and psychological aspects of a given work situation, whereas ergonomics is more concerned with the physical aspects of that situation (Dempsey *et al.*, 2006). Blewett (2015) states that HF/E was historically associated with the arrangement of workstations, and the designing of chairs to suit an individual's lower back. However, the scope of the discipline has expanded over time (Blewett, 2015). According to Hawkins (2017), the terms are often thought to be synonymous because HF/E focuses on people in their work and living environments, and how they interact with equipment, machines, procedures and other people in these settings.

The International Ergonomics Association (IEA) defines HF/E as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance" (IEA, 2018).

Today, HF/E is viewed primarily as a systems-orientated "science of work" (So and Lam, 2014; Wilson, 2012), commonly called "systems human factors and ergonomics" (So and Lam, 2014). Systems HF/E focuses on the human components of systems, and applies knowledge about human limitations, behaviour and capabilities to the design of systems, environments, tasks or jobs, machines and tools, and other system components (Salvendy, 2012). From an organizational perspective, systems HF/E investigates human behaviour in different contexts, and ensures that job demands do not exceed worker capabilities (Jafri and Moeed, 2016). Thus, systems HF/E ensures that humans are not exposed to work stresses that stand to affect company productivity and safety (Jafri and Moeed, 2016). According to Dul *et al.* (2012), systems HF/E has three distinct characteristics: it takes a systems approach, it is design-driven, and its goal is the optimization of human performance and well-being.

HF/E examines systems broadly and considers interactions within and between multiple levels (Jantsch, 1947). The main objective behind such a systems-based approach is to enhance the safety, wellbeing and performance of people within a workplace by improving the overall design of the systems that they interact with (Pickup *et al.*, 2018). HF/E further incorporates systems thinking by approaching phenomena or problems holistically rather than in a partitioned fashion (Mele *et al.*, 2010). A system, from the perspective of HF/E, comprises software (S), hardware (H), environment (E) and liveware (L) (Dumitru and Boşcoianu, 2015; Wiegmann and Shappell, 2003), and is conceptualized using the SHELL model (see Figure 1). The SHELL model is classified as a conceptual model of human factors that explains the scope of HF/E and helps to improve understanding of the relationship between the human component of the work system (i.e. the human subsystem) and the resources and environment of the system (Hawkins, 2017). The SHELL model adopts a systems perspective to assess how a variety of factors within a system impact human performance (Wiegmann and Shappell, 2003).

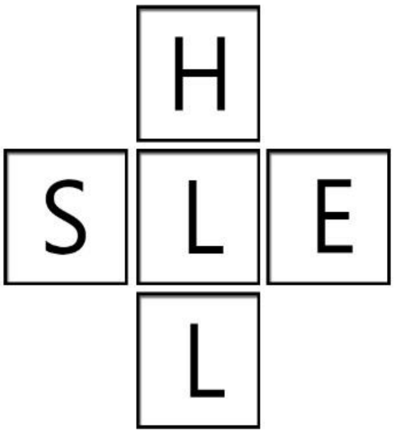


**Figure 1:** SHELL Model conceptualizing interrelationships between human and non-human system factors (taken from Hawkins, 2017, p.20).

Liveware (L) centred in the middle of the image in Figure 1, is defined in two ways, i.e. the human aspects of a work system, and the ways in which humans interact with other system components (Hawkins, 2017; Wiegmann and Shappell, 2003). Software (S) often denotes procedures and other aspects of work design (Wiegmann and Shappell, 2003). Hardware (H) is commonly referred to as the human-machine interface where it refers to the physical elements related to equipment, tools and technology used in work (Dumitru and Boşcoianu, 2015). Environment (E) refers to the environmental conditions within a workplace (Wiegmann and Shappell, 2003). In an optimal work system, all of the non-human system components should be adapted to fit the needs of the human component (Dumitru and Boşcoianu, 2015; Hawkins, 2017). The second "L" at the bottom of the image in Figure 1 also referred to as human-human interface, describes how the human interacts with other people in their workplace (the interaction between people) (Hawkins, 2017).

HF/E is design driven, aiming to achieve a balance between system capabilities and limitations through judicious system design (Dul *et al.*, 2012). In a well-designed system all tools, technology, tasks and environments should be compatible with human cognitive and physical needs, as well as human limitations and abilities (Ahlin *et al.*, 2015). Furthermore, HF/E focuses on matching human capabilities and task design within systems in order to promote safety, efficiency, comfort and reliability, which in turn leads to increased productivity, worker well-being and enhanced worker performance (IEA, 2018). A mismatch between human capabilities and system demands could result in fatigue, error, injuries and accidents within a work system, thus decreasing worker well-being and system productivity (IEA, 2018). Overall, the main priority of systems ergonomics from an operational perspective is to better integrate human workers into their work systems rather than forcing workers to fit their jobs (Selamat, 2016).

Wilson (2014) describes systems HF/E as having six fundamental “notions”, namely system focus, context, interactions, holism, emergence and embedding.

*1. System focus:* The first notion describes systems HF/E as being system focused, with emphases on both understanding the interactions between people and all other elements within a system, as well as system design. This description is similar to that presented by Dul *et al.* (2012). A system is a set of interrelated parts or entities with a joint purpose (Wilson, 2014). In a work system, the human is considered the “worker” and the environment the “work environment” (Dul *et al.*, 2012). In a product/service system, the human is considered the “product user” or the “service recipient”, with the environment being the setting in which products are used or services are received (Dul *et al.*, 2012). A system could also be described as an organisation, work site, community, group, society or building (Wilson, 2014). All systems contain subsystems which influence one another simultaneously (Wilson, 2014). For the purposes of this study, systems HF/E principles will be applied to the context of work systems.

*2. Context:* The second important feature with regards to systems HF/E is context (Wilson, 2014). Context is considered important as human behaviour and performance are influenced by the background, setting, and framework where work is performed (Wilson, 2014). In the modern world context is commonly regarded as being either a complex system or socio-technical system characterized by many system boundaries/ components (Wilson, 2014). The notion of context is important for systems analysis as it indicates where and how components operate within a given system.

*3. Interactions and relationships:* Wilson (2014) explains that interactions and relationships among elements/components in a system are important, and constitute the third important notion in systems HF/E. The nature of a system is that it consists of interacting parts (Wilson, 2014). The aim of HF/E is to optimize the interactions between humans and their environments in work systems (Dul *et al.*, 2012). Humans can interact with their environments in different ways. They can interact with their physical environment (i.e. concrete objects) (Dul *et al.*, 2012), with their organisational environment (i.e. how activities are organised and controlled), and with their social environment (i.e. other people, sociocultural context) (Dul *et al.*, 2012). All three of these environment types are encountered in work systems found within the transport (e.g. aviation, road, railway), healthcare (e.g. hospitals, clinics) and energy (e.g. solar, petroleum) industries, as well as in manufacturing environments and many other contexts (IEA, 2018, Pickup *et al.*, 2018).

*4. Holism:* The fourth important notion with respect to systems HF/E is holism (Wilson, 2014). A holistic perspective is essential in the scientific study of complex systems (Wilson, 2014). In many scientific fields, the adoption of a holistic approach necessitates the implementation of multidisciplinary study methods. Holism recognizes the multifaceted behaviour of complex systems and describes feedback within these systems as a crucial element for understanding their behaviour and addressing any problems that may arise within them (Wilson, 2014). In human factors research, holism implies a focus on identifying the physical, cognitive, and social characteristics of people within a system in order to enhance their interactions with the technology, information, environments, organization and other people within their work environment (IEA, 2018). This should enable the design of optimal jobs, products, environments, tasks and work systems (IEA, 2018). Dul *et al.* (2012) and Sanders and McCormick (1993) further assert that, in taking a holistic approach, the evaluation and optimization of human performance should include an assessment of the essential and necessary interconnectedness between human physiological, biomechanical, cognitive and anatomical factors on the one hand and organisational, environmental, task and technological aspects on the other.

*5. Emergence:* The fifth fundamental notion with respect to systems HF/E is emergence (Wilson, 2014). HF/E recognizes that a system can change and that it can modify its state and the interactions within it (Wilson, 2014). When a system does not adapt to changes, its components can fail or fall apart (Dumitru and Boşcoianu, 2015). When a system malfunctions in response to change, the results can include declines in human behaviour, performance and well-being. These declines, in turn, stand to jeopardize a system's overall safety, effectiveness and productivity. A healthy system will seek balance (homeostasis) through interacting with the environment (Leighninger Jr, 1978).

*6. Embedding:* The sixth and final fundamental notion of systems HF/E is embedding (Wilson, 2014), which is described as the integration of HF/E with the overall system. It describes how ergonomists would execute their work and who they interact with (Wilson, 2014). This is to ensure that ergonomics fits within the organisational system and is embedded within HF/E practice (Wilson, 2014). This would involve assimilating all key stakeholders and subject matter experts so that everyone is on the same page (Wilson, 2014).

Overall, the abovementioned fundamental HF/E notions could be beneficial in the evaluation of existing work system models. The application of sound systems HF/E principles within workplaces across different industries could lead to safer work environments. Indeed, unnecessary illness and injury could be prevented if tasks were designed to be compatible with the capabilities and limitations of humans within work systems. Such compatibility could alleviate much mental and physical stress for workers, ensuring their comfort and ultimately improving overall system operation (Karwowski, 2005; Moriarty, 2014; Selamat, 2016).

## 2.3 Aviation Ergonomics

### 2.3.1 Introduction

Systems HF/E has been extensively applied in the field of aviation research and has proven effective in this context (Perezgonzalez, 2009). The aviation industry (classified as a distributed interactive system) is complex, comprising many kinds of work and human factors, and characterised by an intricate combination of technical, human, organizational and environmental aspects (Harris and Stanton, 2010; Wilson, 2014). It is considered a service industry which plays a major part in business and leisure travel (the latter of which is commonly referred to as the heart of travel and tourism) (Wittmer and Bieger, 2011). The aviation industry is acknowledged as an important source of employment and is recognized for its enablement of social exchange and international trade (Wittmer and Bieger, 2011). The aviation industry is characterised by constant change as technology advances, new business models are established, and markets are increasingly liberalized (Wittmer and Bieger, 2011). Thus, even from this brief description, one gets a sense of the complex and dynamic nature of the air transportation context (Wittmer and Bieger, 2011). This complexity continuously poses challenges to the structural and institutional components of aviation, and continuously alters competition dynamics within the industry (Wittmer and Bieger, 2011). The three main groups of stakeholders in the aviation context are airlines, airports and aircraft manufacturers (Wittmer and Bieger, 2011). Airlines provide the transport service, airports provide ground infrastructure to handle aircraft movements, and the manufacturing industry provides products as well as maintenance, repair and aircraft assembly services (Wittmer and Bieger, 2011).

HF/E is an important factor in the aviation industry because of its primary role in promoting safety, efficiency and well-being of workers in aviation systems across the board, including those within passenger airlines, cargo airlines, and military aviation operations (Stanton *et al.*, 2017). HF/E has also become essential beyond directly aircraft-related contexts, having proven its relevance with respect to air traffic control, management (business administration that runs the aviation industry) , maintenance of aircraft or aircraft parts, regulatory bodies and policy making (Stanton *et al.*, 2017). The threefold aim of HF/E in the aviation industry is to maximise aviation safety, enhance system efficiency, and reduce the risk of human error (Wiegmann and Shappell, 2003; Wiener and Nagel, 1988). This is largely achieved by optimizing the fit between people and the systems in which they work (Dumitru and Boşcoianu, 2015). In the aviation industry, one of the main ways in which this is realized is through the design of aircraft that are aligned with human needs and capabilities. An example of this kind of alignment is ensuring that the displays, technology and tools within a cockpit are made clear to pilots in a bid to avoid confusion and error risk (Hawkins, 2017). Cockpits are also, with input from HF/E practitioners, designed to make the processing of information as easy and quick as possible for pilots (Hawkins, 2017).

In reality, it is often the case that a trade-off between system safety and system performance emerges. In certain scenarios these ideals can be somewhat mutually exclusive and need to be carefully weighed up and balanced. Such deliberations fall squarely within the remit of HF/E. When an HF/E practitioner evaluates human safety factors, all aspects that influence humans and the way they behave in safety-critical situations need to be investigated (Vogt *et al.*, 2010). In the aviation industry, such aspects would include organizational factors such as shift work, scheduling demands and legislations, environmental factors in the cockpit, and technologies employed (Vogt *et al.*, 2010).

One example of the kind of trade-off discussed above is that of pilot pressure vs. system productivity. Pilots are under constant pressure to fly a certain number of flights per day in order to enhance productivity (Caldwell and Caldwell, 2016). This pressure, exacerbated by the nature of the job and company rules, challenges the fine balance between human capabilities and system demands. In this regard, law enforcers consistently struggle to balance the demands placed on pilots with their human capabilities (Karanikas *et al.*, 2018). It is often the case that humans are forced to take on excessive workloads in order for companies to achieve their goals (Dijkshoorn, 2008). In general, human capabilities and their work demands are not well examined and weighed up to ensure system compliance with safety standards and laws (Karanikas *et al.*, 2018). It is the contention of HF/E that such a weighing up would ultimately increase system efficiency and prevent unnecessary incidents and accidents in the workplace (Vogt *et al.*, 2010).

### 2.3.2 History of human factors in aviation

*1940s to 1970s:* Safety is one of the highest priorities in aviation due to the unique and vast set of accident and incident types which can beset this industry (Chialastri, 2012). The discipline known as human factors began in the 1940s during World War II with a focus on the human-machine interface (Hendrick, 2002; Knutsen, 2017). Thereafter, the period between the 1940s and the 1970s was dubbed the “technological era” (Okema-Opira, 2012). During this time aviation was emerging as a mass transportation industry even though the technology supporting aviation operations was not well developed. This led to many safety-related threats (Avers and Johnson, 2011). Technical deficits were behind the majority of aviation accidents and incidents and safety concerns during this period (Okema-Opira, 2012). Some examples of technical glitches in those years include the unavailability of adequate navigational equipment, failed hardware, engine failures, systems failures and badly designed cockpit displays (Avers and Johnson, 2011). From a HF point of view, bad cockpit design was the problem most commonly reported by crewmembers, indicating that the technology at that time was not compatible with human capabilities (Avers and Johnson, 2011; Wiegmann and Shappell, 2001). Thus HF/E research sought to optimize the interactions between people and machines (e.g. displays and controls) in aviation systems (Wiegmann and Shappell, 2001). Researchers focused on flight deck design in order to develop equipment that was user-friendly and aligned with human capabilities (Spitzer and Spitzer, 2000). According to Petrilli (2007, p.4), HF/E was traditionally defined as “the technology concerned to optimise the relationship of people and their activities by systematic application of human sciences integrated within the framework of systems engineering”. Human factors practitioners were traditionally concerned with fitting machines to human limitations (i.e. human engineering) (Wiener and Nagel, 1988). Their approach was predominantly technology-centred with human beings expected to adapt to new technologies and solve problems using common sense (Petrilli, 2007). Today, this engineering approach toward human factors is seen as outdated (Petrilli, 2007).

*1970s*: From the 1970s onwards, technology advanced significantly in many areas, both airborne and ground-based, within the aviation industry (Okema-Opira, 2012). This period marked the beginning of the so-called human era where accident culpability shifted away from technology towards human beings (Okema-Opira, 2012). Thus, the focus of HF/E moved toward analysing how human dynamics might influence flight performance and overall safety levels (Okema-Opira, 2012; Petrilli, 2007). Human error, defined as errors associated with mental or physical activities of individuals that fail to achieve their intended outcome (Wiegmann *et al.*, 2005), was now recognised as the main threat to safety in the aviation world (Hobbs, 2004). According to Chialastri (2011), after the 1970s human error was considered to cause more aviation accidents and incidents than mechanical factors (e.g. poor cockpit design) or environmental factors (e.g. meteorological conditions). A problem during this era was that research tended to focus on individuals only, with very little attention being paid to the operational contexts in which these individuals accomplished their tasks or how these contexts may have led to human error and decreased overall human performance (Okema-Opira, 2012).

*1980s:* This era thus signalled the beginning of a more systematic approach to HF/E research. Instead of reductionist approaches to investigating safety threats, human error and performance capabilities, a broader approach was adopted to probe the effects of organisational, human and technical factors on aviation system performance (Okema-Opira, 2012). Each improvement took effect and led to an increased demand for aviation services. This, in turn, led to the expansion of workforces, necessitating additional training time to produce capable pilots (Wiener and Nagel, 1988). This training has ultimately facilitated the way in which pilots and other crewmembers interact with their work environments and aircraft systems (Wiener and Nagel, 1988). All of these factors have impacted human factors (Wiener and Nagel, 1988). This shift affected not only the profession (i.e. pilots and crewmembers), but also the scope of ergonomics itself. For example, it was now acknowledged that human error may be caused by any combination of a multitude of factors including design flaws, poor training, operating manuals, incorrect procedures, organisational culture, rosters, regulations, practices, norms and values, and others (Dumitru and Boşcoianu, 2015).

*1990s:* By this time, it was realized that individuals operate within a defined operational context which has the potential to influence their performance and to shape events and outcomes (Okema-Opira, 2012). The research period that followed was known as the organisational era (Okema-Opira, 2012). As the years progressed, technological advancements led to operational adjustments which ultimately led to organisational change (Caldwell, 2005).

*2000s and beyond*: In recent years, HF/E has become particularly concerned with errors associated with human performance. These would include errors associated with high workload demands and fatigue which have been recognised as playing major roles in the safety of flight (Petriili, 2007). Lintern (2011) asserts that whilst a human-machine interface containing advanced technological artefacts presents various advantages, it has also led to increased operational demands which have been influenced by the organisational changes and aspects at work. Developments in aviation technology have not kept pace with the current understanding of human capabilities and limitations (Lintern, 2011). Consequently, technologically and operational inspired solutions have tended to impose high cognitive demands on humans. This has led to decreased performance levels, increased workload, and more overall stress and fatigue, thus posing a threat to safety and efficiency in aviation work environments (Lintern, 2011). The increased use of computerized and automated systems in many industries has led to a situation whereby the completion of work-related tasks requires less physical (perceptual-motor-skills) effort and more mental (cognitive) effort (Dalal and Kasper,1994). This shift is most evident in complex application domains such as aviation and healthcare (Baxter, 2011). In response, new research areas have developed. One such area is Joint Cognitive Systems (JCS) research, which focuses on understanding how humans cope with complexity that has emerged due to the implementation of advanced technology and other social-technical changes (Hollnagel, 2005). JCS, also known Cognitive Systems Engineering (CSE), is a multidisciplinary framework that is often applied in HF/E research (Bergström, 2012; Henriqson, 2010). This approach was first proposed in the 1970s but was only established in the fields of HF/E and cognitive science by the early 1980s (Baxter, 2011; Hollnagel, 2005). CSE’s focus is on understanding how different technological artefacts are used and how they played a role in human activities (both work and leisure related) (Baxter, 2011), i.e. how humans and technological artefacts interact and work with one another (Baxter, 2011).

The JCS framework is commonly applied when analysing human-machine interactions in complex technical systems such as those found in the aviation context (Henriqson, 2010). It is a concept that has proven effective in the investigation of interactions between humans and technologies and how these interactions contribute to success or failure in different work systems (Henriqson, 2010). According to Bergström (2012), JCS was established as an alternative theory to the information-processing paradigm which initially represented a micro perspective and focused on analysing information processes in the human mind. Now, however, JCS is applied in the analysis of macro-cognitive processes where the analysis arises from the joint interactions that occur in specific contexts in which humans work (Bergström, 2012).

Hutchins (1995) describes JCS as representing fundamental cognitive structures and processes where cognition is distributed. This approach examines distributed cognition systems influenced by various interactions between individuals and the various external resources with which they work. According to Lintern (2011), cognitive systems are influenced by internal mental activity as well as external interactions with both other humans and physical resources. Traditionally, cognition was referred to as an activity taking place within the human mind where humans were viewed as the “cognitive system” (Lintern, 2011). According to Lintern, (2011), cognition (or the cognitive system) could also be characterized as a broader concept that can be applied to a group of humans working together and interacting with technologies. A similar explanation is presented by Henriqson (2010) who states that the concept of JCS takes cognitive research beyond the realms of the individual mind and examines cognition as a broader phenomenon which also includes human-human interactions and the interaction of humans with the suite of resources and materials in their work systems (Henriqson, 2010). According to Henriqson (2010) when humans perform their work in a work system, the relationship between these humans and the technological aspects of that system forms a cognitive system. A cognitive system is thus a work system where humans perform cognitive work through cognitive functions such as problem solving, communication, decision-making and planning (Lintern, 2011). These functions are often supported by processes that involve information exchange, analysis, and perception (Lintern, 2011). This approach is commonly referred to as situated and distributed, whereby the overall performance of a system is driven by both humans and technologies in an operational context (Henriqson, 2010).

In the aviation context, Lintern (2011) describes JCS as a distributed and heterogeneous systems approach which includes a variety of human and machine interactions. The aviation work system is often considered a cognitive system (Lintern, 2011). For example, Hutchins (1995) examined the cognitive processes of pilots in response to demands placed on them in the cockpit. These demands were included those associated with flying tasks, non-flying tasks, and interactions with technological artefacts, respectively.

The judicious design of cognitive tasks that are compatible with technological artefacts, and vice versa, stands to enable innovative solutions that will lead to a reduction in accidents, failures and safety risks in work systems (Flight Safety Foundation, 2010). The problem with human-machine interaction is that there is usually a mismatch between the functional characteristics of intelligent machines and the capabilities of the humans with whom they interact. This results in a mismatch between task demands and controller capacity (Hollnagel, 2005). JCS focuses on the need to maximize the overall performance of the composite system comprising cognitive human understanding, technology, and tasks (Dalal and Kasper, 1994). Artefacts (machines) need to be designed to enable human-machine interactions to function effectively within joint cognitive systems (Dalal and Kasper, 1994).

Recently, research that embraces an understanding of technological, human and organisational factors in combination is still uncommon (Moriarty, 2014). According to Taneja (2002) many attempts to understand the role of human factors in aircraft accidents have been made in isolation with the chief objective of formulating preventative remedial strategies. Thus, human error continues to account for 70-80%

of all aviation accidents (Taneja, 2002). Dumitru and Boşcoianu (2015) have found that decreased human performance has resulted in many aviation incidents. These mishaps have been strongly related to human error caused by fatigue. Pilot fatigue has been recognized as a widespread problem in the aviation industry and has been targeted as a major regulatory priority (Thomas *et al.*, 2015; Petrie and Dawson, 1997). According to Ma *et al.* (2014), fatigue is a major role player in many flying accidents. In studies by Caldwell (2005) and Petrie *et al.* (2004), job-related fatigue was cited as a major issue by 64% and 75% of pilots, respectively.

There has been a strong move to probe the adverse effects of pilot workload and the impact it has on fatigue and aviation safety (Reis *et al.*, 2013). A drawback is that there is very little literature examining and discussing technical, human and organisational factors in combination (Moriarty, 2014). In an attempt to address this paucity, this study will take a multidisciplinary/integrated approach to examining HF/E factors with regards to aviation safety, aiming to understand how humans perform in their work environments and which factors in these environments contribute to excessive workload and fatigue in the aviation context.

## 2.4 What are Fatigue and Workload?

### 2.4.1 Fatigue

Fatigue is a well-known state experienced by all human beings at times. However, whilst it may be a naturally occurring phenomenon, its effects and meaning may differ from person to person and from industry to industry (Fletcher *et al.*, 2015; Walton, 2003). Indeed, it is recognized that fatigue is complex and can be easily misunderstood (Ashley, 2013; Sadeghniiat-Haghighi and Yazdi, 2015). Furthermore, it is associated with many causes that may vary in frequency and intensity among individuals. This makes fatigue challenging to analyse and hard to solve (Ashley, 2013; Sadeghniiat-Haghighi and Yazdi, 2015).

Fatigue is understood and defined in many ways (Tambala, 2017). Fletcher *et al.* (2015) describe fatigue in terms of manifestations involving disruptions (in sensory, muscular or mental processes) causing misinterpretations of sensory inputs, slowed response times, or failure to detect stimuli. Fatigue has also been defined as a reduced physiological capacity to do work or carry out tasks, and as a state of diminished performance, perception, attention, and decision-making ability (Flin *et al.*, 2008;

Walton, 2003). Yet another study defines fatigue as a state of feeling tired, weary, sleepy or mentally and physically exhausted due to underlying factors such as job demands, work organisation, environmental aspects, human biology and life outside of work (Hawkins, 2017; Sadeghniiat-Haghighi and Yazdi, 2015; Walton, 2003). Factors impacting on job-related fatigue include workload, type of work, and duration of shifts (Walton, 2003). Fatigue-related factors that can be classified as explicitly “organizational” include work schedules (e.g. long working days and shift work), work predictability, and the time of day that work is performed (Ashley, 2013; Fisher *et al.*, 2016). On the other hand, “biological” factors (on the part of the affected person) include age, health, amount of sleep, and body clock (Walton, 2003). Lastly, “life outside of work” factors that can affect fatigue include travel to and from work, family and friends, and standard of living (Walton, 2003).

All of the factors mentioned above can result in lack of sleep, circadian disruption, extended time-on-task, extended time awake, physical and mental exertion, high workload, and boredom (Ashley, 2013; Hawkins, 2017; Reis *et al.*, 2013; Tambala, 2017; Yang, 2014). An explanation of the most common related fatigue attributes and causes are discussed below:

*1. Sleep and Circadian Rhythm:* Sleep - a basic human need - is recognized as one of the most important human physiological processes (Co *et al.*, 1999; Deros *et al.*, 2012; Dinges *et al.*, 1996; Parsai, 2011). Sleep is defined as a reversible state of disengagement and unresponsiveness to the environment (Parsai, 2011; Siengsukon *et al.*, 2013). It is vital to overall health and wellbeing, and to the maintenance of alertness, performance and a positive mood (Alcéu, 2015; Dinges *et al.*, 1996). Individuals require seven to eight hours of sleep in every 24-hour period (Co *et al.*, 1999; Dijkshoorn, 2008). Sleep is regulated by two processes in the body, namely circadian rhythms and sleep/wake homeostasis (Parsai, 2011; Tambala, 2017). Circadian rhythms (also referred to as body clock) are described as biological rhythms with periods of 24 hours. They are often synchronized with the day/night cycle (Barkai and Leibler, 2000). Circadian rhythms align the body’s sleep/wake cycle with the external environment and enable individuals to stay awake during the day and sleep at night (Fisher *et al.*, 2016; Tambala, 2017).

Despite a general acknowledgement of the essential nature of sleep, it is compromised by work schedules that involve early mornings, late finishes extended duty periods, irregular work periods, and consecutive duty days (Co *et al.*, 1999; Jackson and Earl, 2006; Gander *et al*., 1998). Furthermore, sleep deficits are often associated with shift work (i.e. work schedules that involve working outside of the standard 08:00-17:00 work period) (Ashley, 2013; Federal Aviation Administration, 2010). The majority of research on fatigue associates it with lack of sleep. Indeed, this association has been prevalent since as far back as 1896 (Ashley, 2013). A study conducted by Patrick and Gilbert in 1896 (cited in Ashley, 2013), found that the onset of fatigue in three volunteers was associated with schedules that required them to stay awake for four days at a time, performing prolonged tasks at regular intervals during that time. The links between sleep deprivation and fatigue (both physical and mental) have been well researched in many contexts, including the aviation industry (Caldwell *et al.*, 2005; Gundel *et al.*, 1995).

*2. Fatigue due to time on task:* The time of day that work is performed has been found to have an impact on sleep loss and ultimately fatigue (Walton, 2003). Shift work that includes night shifts, morning shifts, rotating shifts, irregular shifts or on-call schedules is commonly associated with sleep deficits (Dijkshoorn, 2008). Shift work leads to a phenomenon known as “shift lag”, whereby individuals are awake when they should be asleep and vice versa (Dijkshoorn, 2008; Tambala, 2017). In other words, certain shift work schedules maintain wakefulness in direct opposition to an individual’s physiological programming to be asleep (Caldwell and Caldwell, 2016; Dinges *et al.*, 1996). Shift lag disrupts sleep cycles and may thus reduce the amount of sleep acquired, ultimately causing sleepiness and tiredness (Ashley, 2013; Dijkshoorn, 2008; Fisher *et al.*, 2016; Tambala, 2017). Indeed, any disruption to healthy sleep patterns can induce circadian fatigue (Ashley, 2013).

“Time on task” has also been implicated in the onset of fatigue (Ashley, 2013). This association was first explored by Bartlett in 1943 (cited in Ashley, 2013). It is argued that increased time on task implies more awake time and therefore less sleep (Ashley, 2013). Extended time on task (i.e. extended times spent working) with inadequate rest periods can lead to exhaustion which, in turn, increases fatigue levels (Ashley, 2013).

Both lack of sleep and time on task are clearly associated with diminished overall performance (Ashley, 2013).

*3. Mental and physical exertion:* Fatigue may occur from both physical and mental exertion. Mental exertion is a psychobiological or psychophysiological state provoked by extended periods of demanding cognitive tasks (Silva-Júnior *et al.*, 2016). For example a long day of mental stimulation include activities that involve individuals to stay focused on a task for sustained periods of time (sustained attention); tasks that involve a variety of decision related cognitive tasks; sustained alertness and more (Hawkins, 2017; Sadeghniiat-Haghighi and Yazdi, 2015). While physical exertion is provoked by demanding physical activity that involves the body and muscles used to complete a specific task (Hockey, 2000). Work environments and performance. It can also be defined as when there is a measurable portion of physical resources expended when performing a physical task (Hockey, 2000). Example of physical tasks include strenuous exercise, twisting, pushing, pulling and more (Hockey, 2000). These are all dependant on task demands of specific job (Hockey, 2000).

*4. Acute and chronic fatigue:* Fatigue may occur acutely or chronically (Yang, 2014). Acute (i.e. short-lived) fatigue occurs during and after short periods of demanding physical or mental work (Yang, 2014). Chronic/cumulative fatigue, on the other hand, accrues over a prolonged period (Ashley, 2013). The latter is characterised by extreme fatigue or tiredness that does not go away with rest (Yang, 2014). Fatigue that is present for several days or weeks indicates that an individual has experienced insufficient sleep over a prolonged period (Yang, 2014). Such fatigue is usually associated with shift work, jetlag, and sleep apnea (a sleep disorder whereby an individual's breathing is frequently interrupted during a night's rest) (Yang, 2014). Chronic fatigue can also present in individuals whose job requirements include sustained periods of mental and physical activity with insufficient rest in between (Hawkins, 2017).

### 2.4.2 Workload

Many studies have attributed fatigue to underlying sleep problems and time on task (Alcéu, 2015). However, in many industries, fatigue is the result of a workload that is excessive due to the amount of work assigned and/or the highly demanding nature of the work assigned (Grech *et al.*, 2009; Torres *et al.*, 2016). Mallis *et al.* (2010), assert that fatigue accumulates in response to an excessive workload.

There is no universally agreed-upon definition for the complex and multifaceted construct that is "workload" (Arellano *et al.*, 2015). However, a commonly held understanding of the term is that it refers to the amount of work loaded onto an individual, the time pressure under which an individual completes their work, the degree of effort exerted in the completion of an assigned batch of work, and/or or the psychological and physiological consequences of particular tasks (Grech *et al.*, 2009). Wilson (2002) defines workload as a task component which includes both the number of tasks or amount of work to be done and the number of hours spent at work. The completion of certain work-related tasks might involve a lot of physical (muscle) exertion. This is known as physical workload (Ashley, 2013). The completion of other tasks might involve more mental/cognitive exertion. This is known as mental workload (Diken, 2011). Still other tasks make visual demands on workers. This kind of task commonly involves the acquisition of information through the scanning of displays and instruments, e.g. the use of navigational systems, reading maps etc. (Webb *et al.*, 2010). Finally, verbal and aural demands are imposed by tasks that involve obtaining information through hearing or listening to spoken language, or those that involve communication/speaking (either with people or automated systems) (Webb *et al.*, 2010).

Workload can be a function and attributed to a variety of factors. The main three factors include passive and active fatigue, job demands and perceived workload which are described below:

*1. Passive and active fatigue:* Workload can be described as either underload or overload, i.e. too few or too many demands imposed on an individual, respectively (Alcéu, 2015). Both passive and active fatigue, induced by workload in underload and overload situations, respectively, are common task-related fatigue types (Desmond and Hancock, 2001).

Active fatigue is associated with jobs involving continuous and prolonged activity such as elevated cognitive/physical demands and high workload situations (Alcéu, 2015; Desmond and Hancock, 2001). Under such conditions, individuals may fail to adequately process information, suffer delayed responses during information processing, and experience distraction and diverted attention as the volume of information to be processed often surpasses their capacity to do so (De Gray Birch, 2012).

On the other hand, passive fatigue is often encountered in situations where a low task load (low workload) is present (Alcéu, 2015; Desmond and Hancock, 2001). Passive fatigue may also be encountered in contexts where a workload comprises generally monotonous work requiring little stimulation and effort, and tasks that are simple, easy and repetitive (De Gray Birch, 2012). When individuals are subjected to low task demands it often leads to boredom, sleepiness and performance fluctuations (De Gray Birch, 2012). Jobs that involve prolonged conditions of underload may result in diminished attention, reduced alertness and performance failure due to insufficient effort being invested in the task (Desmond and Hancock, 2001).

*2. Job demands:* Workload is driven by several factors such as the type of job, specific job demands, and task loading (i.e. the number of tasks required to be performed at a specific time) (McLaughlin, 2007; Tritschler and Bond, 2010). The design features of systems and equipment used to accomplish a task can also affect the workload of their users (Tritschler and Bond, 2010). Some systems demand a lot of effort from individuals to accomplish specific tasks, which can induce elevated levels of workload. Other systems demand less effort for the accomplishment of similar tasks (Wickens *et al.*, 1997). Workload can also depend on organizational structure including the procedures, work schedules and job design associated with a particular work system (i.e. company “rules” regarding the way in which tasks should be accomplished) (Lee *et al.*, 2013). For example, workload is directly related to length/duration of work, duration of shifts, rest-break schedules (i.e. work-rest cycles) and various other schedule-related factors (Alcéu, 2015). According to Lee *et al.* (2013) these scheduling factors may have an impact on individuals’ exposure to demands (whether cognitive or physical), which may in turn affect their workload and fatigue levels (Alcéu, 2015; Lee *et al.*, 2013). Workload is also commonly impacted by the circumstances (environmental factors) under which work/tasks are performed (Tritschler and Bond, 2010).

*3. Perceived workload:* Certain researchers have described workload as a human response, or an individual’s perception regarding the degree of difficulty or complexity of a task or task set (Hartman and McKenzie, 1979; Kryger *et al.*, 2017; Torres *et al.*, 2016). Wickens (2002), however, defines workload as the demands placed on an operator’s mental abilities for perception, reasonable decision making, action and sustained attention. In most work systems, human resources are limited. If the resources demanded by a task exceed those of the worker, this could lead to a high perceived workload (Grech *et al.*, 2009). Overall workload is a composite of task demands, skill and experience of the individual, job type, organizational expectations, operating conditions (i.e. internal and/or external environment) and workload perceptions on the part of the individual (Lee, 2010). High workload is directly correlated with fatigue which, from an operations point of view, is often defined as a condition that leads to decreased efficiency and a reduced capacity to work or respond to stimuli (Caldwell *et al.*, 2009).

High workload can induce stress and frustration (Lee *et al.*, 2013; Stokes and Kite, 2017). Stress is defined as an unfavourable response that may be experienced by individuals at certain junctures. Stress is derived from excessive work pressure or demands as well as non-work-related factors such as financial stress, family issues, and other challenging life circumstances (Flin *et al.*, 2008; Stokes and Kite, 2017). Individuals often experience high levels of emotional stress over sustained periods of time, which further intensifies their fatigue levels (Ashley, 2013).

The concepts of workload and fatigue are recognised as safety concerns for individuals engaged in high-risk jobs or industries that involve continuous 24-hour operations (Flin *et al.*, 2008; Loh, 2004). These include doctors, motor vehicle operators, pilots, and many others (Yang, 2014). Safety concerns stem from the fact that fatigue can adversely affect both mental and physical processes (Thomas *et al.*, 2015). It can negatively impact on an individual’s ability to perform a task, specifically with regard to concentration levels, manual dexterity, higher order intellectual processing, memory retrieval, decision making, situational awareness, muscular coordination, adaptability and motivation (Ashley, 2013; Thomas *et al.*, 2015, Yang, 2014). These impacts could intensify the risk of incidents and accidents in all industrial sectors (Flin *et al.*, 2008).

It is clear that fatigue is a complex and much-nuanced phenomenon. For the purposes of this study, it will only be discussed and examined with respect to pilots employed in the aviation industry. Fatigue-related literature emphasises the need for a systems approach to deal with the complexity surrounding the mechanisms and risks of fatigue. The following section provides some background regarding the theories of system analysis.

## 2.5 Theories of Systems Analysis

Systems analysis is a problem-solving method (Karsh and Alper, 2005). It is concerned with identifying a problem or phenomenon by examining a whole system, breaking it down into its different components, and analysing how each component functions and works together with other components to achieve system goals (Karsh and Alper, 2005).

A system can be defined as a set of distinct parts interacting within a boundary to achieve a common goal (Ehlers, 2002; Wilson, 2014). Togo (2009) defines a system as an organized whole comprising various interrelating and interdependent parts. Systems are found everywhere, including the social, biological and physical worlds (Katz and Kahn, 1978). All systems contain subsystems which influence each other simultaneously with each part affecting the actions of the other parts (Meadows, 2008).

There are different types of systems, such as natural systems (ecosystems) and abstract systems (e.g. mathematical equations or computer programs) (Ehlers, 2002; Goede, 2004). Other types include designed systems as well as systems of human activities (Ehlers, 2002).

Systems can be classified as open or closed (Bellinger, 2004; Meadows, 2008). A closed system is self-contained with no external environment at all (Bellinger, 2004). It is not influenced by external events and does not need to interact with its environment to maintain existence (Togo, 2009). Examples of closed systems include atoms and molecules. Open systems, on the other hand, usually interact with their environments to maintain their existence (Togo, 2009). The environments, in turn, are influenced by the actions within these open systems and also by their outputs (Togo, 2009).

Systems analysis as a method is based on systems theory and systems thinking (Laszlo and Krippner, 1998). Systems theory is an interdisciplinary paradigm that can be applied to most systems in nature, in society and in many scientific domains (Mele *et al.*, 2010). Mele *et al.* (2010) define systems theory as a theoretical framework that assists in analysing phenomena by shifting thinking away from the simplistic notion that systems are simply sums of elementary parts and towards a more holistic perspective.

A holistic systems perspective emphasizes the interplay within and between systems and their elements in determining and fulfilling their respective functions (Jantsch, 1947; Meadows, 2008). A holistic approach considers elements such as individuals, organisations, environments, tasks, and technologies (Chisholm, 1967; Jantsch, 1947), and examines problems beyond their hypothetical linear cause and effect links.

As systems theory has developed over the years, researchers from different disciplines have begun applying it in studies about individuals, workers in workplaces, organisations and employees, and work environments (Balabanović and Shoham, 1997; Laszlo and Krippner, 1998). The study of humans and their activities in their work environments is difficult to analyse due to the many diverse variables at play within these contexts (Ehlers, 2002). Few studies relating to humans have successfully and holistically captured the importance of the contexts in which humans operate. This is perhaps not surprising when one considers that during the training of scientists, modules presented are not necessarily integrated with one another or taught in combination (Sanders and McCormick, 1993). Thus, “systems thinking” is not explicitly taught in most places.

Any evaluation of human performance should acknowledge and embrace the essential and necessary interconnectedness between the human being’s physiological, biomechanical, cognitive and anatomical factors on the one hand, and the work environment’s organisational, environmental, task-related and technological factors on the other (Marras and Hancock, 2014; Sanders and McCormick, 1993, Wilson, 2014).

Systems analysis has proven to be the most effective approach from which to analyse the behaviour and performance of humans in their respective environments (Ehlers, 2002). By understanding and exploring a system in terms of its elements (i.e. components) and functions, one can more readily identify why and how the system might malfunction (Balabanović and Shoham, 1997; Laszlo and Krippner, 1998). There are several different methods of systems analysis that can be used. These include Probabilistic Risk Assessment (PRA), Failure Modes and Effects Analysis (FMEA), Cognitive Work Analysis (CWA), Fault Tree Analysis (FTA), Macro-ergonomic Analysis and Design (MEAD), and Work System Analysis.

### 2.5.1 Probabilistic Risk Assessment (PRA)

PRA is a top-down approach to systems analysis. It is used to identify and evaluate the causal factors within a system, as well as the consequences of any adverse effects/outcomes of the system (Wreathall and Nemeth, 2004). These effects and outcomes include human error, equipment failure, and interactions amongst the components of a system (Wreathall and Nemeth, 2004). PRA is used to improve barriers and eliminate system failures (Mohaghegh *et al.*, 2009). It is also often employed as a safety assessment tool in technological industries, the aviation industry, production facilities, manufacturing industries, and offshore drilling facilities (Wreathall and Nemeth, 2004). PRA can help in the achievement of performance goals with respect to safety (Mohaghegh *et al.*, 2009; Wreathall and Nemeth, 2004). In the aviation industry it is used to assess various factors that can lead to failures in aircraft systems (Wreathall and Nemeth, 2004). It is also a useful method by which to identify major and minor elements that could lead to adverse outcomes. Such elements might include procedural mistakes, hardware and software faults, or human actions (Wreathall and Nemeth, 2004). PRA assists in identifying effective solutions to problems within a system (Wreathall and Nemeth, 2004).

### 2.5.2 Failure Mode and Effects Analysis (FMEA)

FMEA is a method used to pinpoint existing problems, errors, and/or failures within a system, design, process or service, and to ascertain their consequences (Liu *et al.*, 2017; Stamatis, 2003; Zhou *et al.*, 2016). A system failure can be described as any problem, error, challenge, or concern relating to a system, service, design, subsystem, or process (Ostrom and Wilhelmsen, 2011; Stamatis, 2003). A failure or error could be associated with human error or fatigue (Stamatis, 2003), e.g. a machine or product failure could be linked to user behaviour (Liu *et al.*, 2017). Failure could also occur due to faulty design, faulty equipment or poor training, e.g. an operational failure in a manufacturing process, in an administration process, or in a business (Liu *et al.*, 2017).

FMEA is usually completed before an adverse event occurs (Stamatis, 2003). It is a method used to identify potential causes and failures of systems (Ostrom and Wilhelmsen, 2011). It analyses the functioning of and relationships between elements in the whole system rather than examining individual system components in isolation (Stamatis, 2003). This approach serves to improve the overall understanding of a system, and to eliminate risks associated with the system, its components, and/or its subsystems through improved design (Stamatis, 2003). This should ultimately lead to better overall systems safety and system integration (Stamatis, 2003). The three most common types of FMEA include system FMEA, design FMEA, and process FMEA (Stamatis, 2003).

Failure mode is associated with system malfunction or system failure (Liu *et al.*, 2017). FMEA is thus concerned with the likely impact of a particular failure on a system (Liu *et al.*, 2017). FMEA is commonly applied in various fields including engineering, chemical industries, medical contexts, the aerospace industry, and mechanical design industries (Liu *et al.*, 2017; Press, 2003; Stamatis, 2003; Zhou *et al.*, 2016). FMEA is an inductive process (Ford *et al.*, 2009). Zhou *et al.* (2016) describe various steps in the FMEA process. The first step involves pinpointing possible failure modes and identifying consequences for each mode. This is done by rating the severity (S) of each failure effect on a one to ten scale (where ten is worst and one is best). Secondly, the potential root causes (e.g. fatigue) for each failure mode are identified. Thirdly, the probability of occurrence (O) for each root cause is rated on a scale of one to ten (where one is not very probable and ten is guaranteed occurrence). Fourthly, the detectability (D) of each failure mode or root cause is rated, also on a scale of one to ten. Finally, a total risk of priority is calculated by multiplying severity (S), occurrence (O) and detectability (D). Solutions and preventative measures can then be formulated to mitigate high risks and prevent critical failures (Liu *et al.*, 2017).

### 2.5.3 Cognitive Work Analysis (CWA)

CWA is an approach employed to examine and understand work in complex sociotechnical systems (Rasmussen *et al.*, 1994). It is used to examine the functional structure of the work domain, focusing particularly on cognitive work (Lopez *et al.*, 2010). It concentrates on analysing constraints that limit human behaviour in a work system (Lopez *et al.*, 2010). CWA comprises several dimensions of analysis, namely work domain analysis, control task analysis, strategy analysis, social organisation and cooperation analysis, and worker competency analysis (Fidel and Pejtersen, 2004). Work domain analysis focuses on constraints associated with the physical, cultural and social aspects of the work environment (Lopez *et al.*, 2010); control task analysis is concerned with constraints relating to work functions and dimensions of work (Rasmussen *et al.*, 1994); social organisation and cooperation analysis focuses on the coordination of work and worker competency analysis centres on constraints associated with human cognitive capabilities and limitations (Fidel and Pejtersen, 2004).

The main aim of CWA is to promote and develop the design of better technology for use in the workplace (Rasmussen *et al.*, 1994).

### 2.5.4 Fault Tree Analysis (FTA)

FTA represents a systematic approach to systems analysis (Ruijters and Stoelinga, 2015). It is an analysis where the event or incident is placed at the root (top event) of a “tree of logic”. Various situations that lead to the effect (the main causes) are added to the tree as a series of logic expressions (Andersen and Fagerhaug, 2006). It is a top-down deductive approach that can be used to evaluate a complex system in order to identify, model and assess interrelationships between lower order events that could lead to undesired and unintended higher order events, accidents or failures within the system (Rausand and Arnljot, 2004; Ruijters and Stoelinga, 2015). It can also be described as a graphical method that analyses how failures that occur within individual system components can lead to overall system failures (Ruijters and Stoelinga, 2015).

FTA is used to identify and examine root causes, faults and failure modes and to quantify their contribution to overall system unreliability (Rausand and Arnljot, 2004). The “top event” is considered to be the undesired event (e.g. an accident), FTA assesses all of the causes leading to this top event (Lee *et al.*, 1985). FTA can be applied both quantitatively and qualitatively (Lee *et al.,* 1985). It is employed in many fields, including safety, engineering, medicine (Rausand and Arnljot, 2004).

The main aims of FTA are to identify the causes of system failure, to identify the effects of human error, to monitor and control these effects in order to improve safety performances within a complex system, and to minimize and optimize resources (Rausand and Arnljot, 2004).

### 2.5.5 Macro-ergonomic Analysis and Design (MEAD)

MEAD is a top-down sociotechnical systems approach (Realyvásquez and Maldonado-Macías, 2018). It focuses on analysing, examining, evaluating and designing work systems (Realyvásquez and Maldonado-Macías, 2018). MEAD focuses on human-work system interactions (Realyvásquez and Maldonado-Macías, 2018). According to Purnomo *et al.* (2017), it is an effective tool in finding and implementing solutions to complex problems. The ultimate objective of MEAD is to enhance and optimize work systems from both a micro- and a macro-ergonomic perspective (Realyvásquez and Maldonado-Macías, 2018) to ensure the overall improvement of safety, employee health, employee quality of life, and system productivity (Realyvásquez and Maldonado-Macías, 2018). According to Purnomo *et al.* (2017), macro-ergonomic analysis can be applied to the human-job, human-software, and/or human-machine interfaces.

MEAD is used to guide systems analyses, and to identify risks and causal factors that can affect a work system (Purnomo *et al.*, 2017).

### 2.5.6 Work System Analysis

Work system analysis is defined as the systematic investigation and description of all relevant aspects of the working environment, including resources and work requirements pertaining to specific jobs (Morgeson and Dierdorff, 2011; Shoaf *et al.*, 1998). Work requirements include all tasks to be performed by a worker and all work activities necessitated by the set of responsibilities assigned to that worker (Morgeson and Dierdorff, 2011; Shoaf *et al.*, 1998). Work system analysis is described as a method by which to examine particular jobs in terms of their job requirements, work activities, physical and mental demands, and organizational aspects (these include the social, psychological and physical work environments and equipment used in the job) (Carayon and Smith, 2000; Karsh and Alper, 2005; Shoaf *et al.*, 1998). Work system analysis can help reduce risk by identifying the factors that could result in hazards within a specific job (Karsh and Alper, 2005).

Work systems are influenced by different elements that operate separately and together to form composite structures (Pace, 2002). The elements of a work system include the worker, the work, and the organizational structure, leadership practices, guidelines, and policies (Pace, 2002). A worker could be either a contracted or a permanent employee within a workplace or organisation (Pace, 2002). The work refers to the set of tasks a worker needs to complete and how these tasks should be performed (Pace, 2002). This is influenced by the organizational structure of a particular work system (Pace, 2002) which includes work schedules, work organization, job design, and management style (Lee *et al.*, 2013). Organizational practices and policies encompass the rules, guidelines, agreements and statements that direct the way in which work and tasks should be accomplished to meet the goals of a work system (Pace, 2002).

Traditionally, a work/job analysis has two main objectives. The first is to identify and describe factors that influence work outcome, and the second is to determine risk, gather relevant data and prioritize targets for work redesign (Shoaf *et al.*, 1998). A work system analysis identifies the factors/elements surrounding an individual through examining the context of their workplace and describes how these elements impact on the work and behaviour of the individual (Carayon, 2009).

This approach moves away from only analysing work systems from a micro-level perspective (Carayon, 2009). This move is endorsed by Hackman (2003) who proposes that one can analyse a phenomenon at the meso-level and then continue to explore how concepts at the macro-level (moving-up) and the micro-level (moving down) help explain its dynamic. The individual is considered to be at the meso-level within the work system, with macro-level concepts including organizational factors, the physical environment work environment, the team, and many more. All of these factors impact the behaviour and attitudes of the worker (Carayon, 2009). At the micro level, on the other hand, are concepts that describe the behaviours of individuals, such as physical, psychological, and physiological processes (Carayon, 2009). Thus, understanding worker performance requires the analysis of micro-level physiological process, one of which is fatigue.

The work system analysis model, adapted from Smith and Carayon-Sainfort (1989), is commonly used in the work system analysis process. The model characterizes a work system into five components: person; tasks; environment; organization; tools; and technology (see Figure 2). It is used to facilitate system design and redesign (Carayon, 2009). The core purposes of the work system analysis model are to enhance the functioning of each individual component and to improve relationships between the different system components to optimize overall safety, worker well-being, performance, and health (Carayon, 2009; Carayon and Smith, 2000).

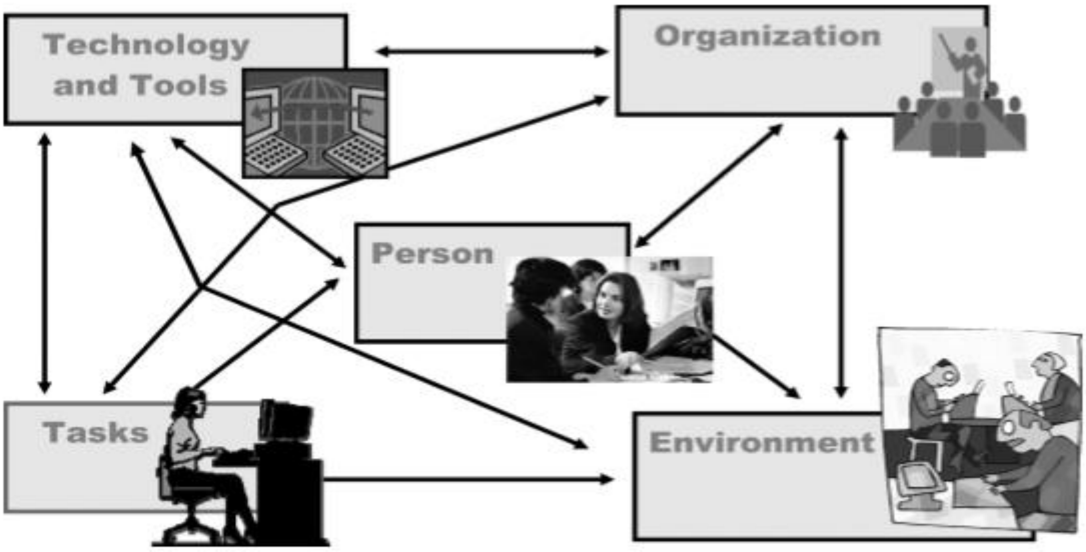


**Figure 2:** Work System Analysis Model (taken from Smith and Carayon-Sainfort, 1989)

The model is widely used in operational settings which include all of the abovementioned factors that can affect workers and outcomes (Carayon, 2009). It places the human worker at the centre of the work system as its most pivotal element. This is because human beings not only operate the system, but also interact with other system components (Hawkins, 2017; Wiegmann and Shappell, 2003).

The work system model describes the tasks performed by the person (individual), including those that require utilising the tools and/or technologies (Carayon, 2009; Carayon and Smith, 2000). It describes the tasks and job activities performed under certain organizational conditions which govern how work should be performed in that system. These include non-physical and intangible aspects like the rules and regulations of an organization, standard operating procedures, work schedules, job design, manuals, customs, computer software, procedural checklists, norms, values, and practices (Carayon and Smith, 2000; Dumitru and Boşcoianu, 2015; Petrilli, 2007). The tasks are also performed in particular environments – both internal and external (Carayon, 2009; Carayon and Smith, 2000; Okema-Opira, 2012). Internal environment refers to noise levels, vibrations, ambient light, air quality and temperature of a work context, whilst external environment refers to the physical environment outside of the immediate workplace (Okema-Opira, 2012).

The many relationships within and between work systems can pose challenges to human factors research because they occur at varying levels of complexity (Petrilli, 2007). All system components play their roles simultaneously and interdependently and should be adapted in accordance with human capabilities (Dumitru and Boşcoianu, 2015). This would ensure safety, system effectiveness and optimized human performance. If work system interactions do not perfectly match the capabilities of the system's human components, it may compromise human performance and lead to high workload demands, fatigue and human error (Carayon, 2009; Dumitru and Boşcoianu, 2015). The work system model has been extensively researched with regard to patient safety in the context of health care organisations, and it is believed that it can safely be applied to other high-risk operations such as those found in the aviation industry (Carayon, 2009).

# CHAPTER 3

# METHOD (SYSTEM ANALYSIS)

## 3.1 Overview and Aim of the Chapter

This chapter outlines the methodological processes used to achieve the research aim, including overviews of the research concept, the proposed methods, and the procedures by which these methods were implemented.

## 3.2 Research Concept and Methodological Framing

This research project aims to examine factors contributing to pilot/co-pilot fatigue in the context of short-haul operational flights (defined in Chapter 1). As a precursor to understanding the variety and complexity of these factors, it will be necessary to thoroughly characterise the work system of pilots undertaking short-haul operations. To achieve this, an analysis based on the work system model of Smith and Carayon-Sainfort (1989) was chosen from the various analysis options outlined in Chapter 2. This particular approach was selected as it provides the most comprehensive systematic investigation of the work systems of individuals. The resulting model was used as a framework for analysis and structuring of the factors leading to fatigue in the short-haul operational context.

As established in Chapter 2, fatigue is a complex issue which is influenced by many different and often independent factors. The aviation industry is a complex system in which a great diversity of work and human factors is present. Pilot fatigue is therefore a multifaceted phenomenon that is likely to be driven by an intricate interplay of factors in the workplace and beyond (Petrilli, 2007). Previous research on fatigue in the aviation industry has identified the need for a macroergonomics / systems approach to better understand and address the factors involved, which according to Dumitru and Boşcoianu (2015) include (but are not limited to) patterns of work, activities, tasks, and duties, the work environment, and the resources and artefacts needed to perform the work. Work system analysis helps to identify and quantify risk areas and other factors contributing to pilot/co-pilot fatigue in short-haul operations, as well as modelling the interactions between different elements in the system. In this study, the work system analysis was conducted in two phases: 1) Literature Analysis and 2) Expert Interviews. An explanation of each phase is provided in Table 1.

**Table 1:** Two phases of the work system analysis.

| PHASES | EXPLANATION | SECTIONS |
|---|---|---|
| **1: Literature Analysis** | The literature analysis was based on existing literature dealing mainly with international data. It has been used to distil the current state of knowledge about the work system of short-haul pilot/co-pilots and the various factors contributing to pilot/co-pilot fatigue in this operational context. | Section 3.3 |
| **2: Expert Interviews** | Experts on South African aviation and on pilot fatigue were interviewed to supplement the findings of the literature analysis. Most importantly, these interviews provided reliable local insight into the South African aviation industry in general, and the issues of pilot/co-pilot fatigue in particular. | Section 3.4 |

### 3.3 Literature Analysis

The literature analysis was conducted in a systematic way as a tool to build a model of pilot/co-pilot fatigue in the context of short-haul operations. It does not conform to the standard criteria of a systematic review, which would include critical comparison and discussion of methodologies used in studies on a certain topic. It will not synthesize the findings and assess the overall quality of the body of evidence, as would the classical approach (Garg *et al.*, 2008). It will also not appraise the reliability and validity of the studies included in the literature analysis (ten Ham-Baloyi and Jordan, 2016). This analysis therefore consisted of a narrative/descriptive review of the relevant literature, which is considered to be a comprehensive and unbiased method of achieving an overview of relevant information on a specific topic (Garg *et al.*, 2008). The method also helps to place collected information into perspective within the framework of the topic at hand (Green *et al.*, 2006). The information gained from this exercise was analysed in accordance with the work system model of Smith and Carayon-Sainfort (1989).

#### 3.3.1 The search and selection strategy

Sources for use in the literature analysis were selected by searching several databases and using relevant internet search engines and research-focussed social networking sites to locate and retrieve scientific journal articles, books, legislation and reports pertaining to the topic. Databases/tools used included Google Scholar, ResearchGate, Rhodes University Library, Science Direct, PubMed, Jstor, Academia and SCOPUS. The searches were conducted between February 2017 and September

2018, with no publication date restrictions imposed. In the case of the Science Direct and SCOPUS databases the ‘advanced search’ option was selected. The remaining databases were searched in their entirety for relevant open access journal articles. The search strategy included a combination of keywords and phrases listed in Table 2. The search applied ‘Boolean Operators’ (AND and OR) to form different combinations of the search phrases in which the keywords were used interchangeably.

**Table 2:** The combination of keywords and phrases used to search each database.

| | | | | | | |
|---|---|---|---|---|---|---|
| Fatigue | | Aviation Industry | | Pilots | | Individual factors |
| OR | AND | OR | AND | OR | AND | OR |
| Workload | | Short-haul operations | | Co-pilots | | Non-work-related factors |
| | | | | OR | | OR |
| | | | | Aircrew | | Technology and tools |
| | | | | | | OR |
| | | | | | | Environmental factors |
| | | | | | | OR |
| | | | | | | Tasks related factors |
| | | | | | | OR |
| | | | | | | Organisational factors |
| | | | | | | OR |
| | | | | | | Work system components |

After removal of duplicates, potential articles were assessed using a two-phase screening process before being downloaded, and then were assessed in greater detail for eligibility before finally being selected or rejected. The first phase of screening checked the relevance of the article title to the topic under review. The second phase involved screening of the abstract, and for articles that passed these first two screening stages the full text was read and used as the basis for final selection or exclusion. Table 3 shows the inclusion/exclusion criteria used to choose the final selection of sources for the literature analysis. For the inclusion criteria, one of the concepts needed to be present for selection.

**Table 3:** Inclusion and exclusion guidelines used during the screening process.

| Inclusion criteria | Exclusion criteria |
|---|---|
| ➢ Peer-reviewed publications, books, reports, website articles and conference papers<br>➢ Short-haul operations (regional/commercial)<br>➢ Workload<br>➢ Fatigue<br>➢ Pilots<br>➢ Short-haul pilots/co-pilots<br>➢ Human factors in short-haul<br>➢ Work system components | ➢ Any papers that did not focus on aviation (the search process returned a number of papers which focused on workload and/or fatigue in other modes of transportation, in particular driving. These were excluded)<br>➢ Any papers that focused on long-haul or ultra-long-haul operation |

Keyword searches of the online databases returned 13729 matching journal articles, of which 3529 were selected on the basis of their title. This number was reduced to 200 after abstract screening, and 123 of these were downloaded. After assessment of the full text in conjunction with the inclusion/exclusion criteria, 98 articles were selected for the literature analysis. Figure 3 summarises and quantifies the screening process.

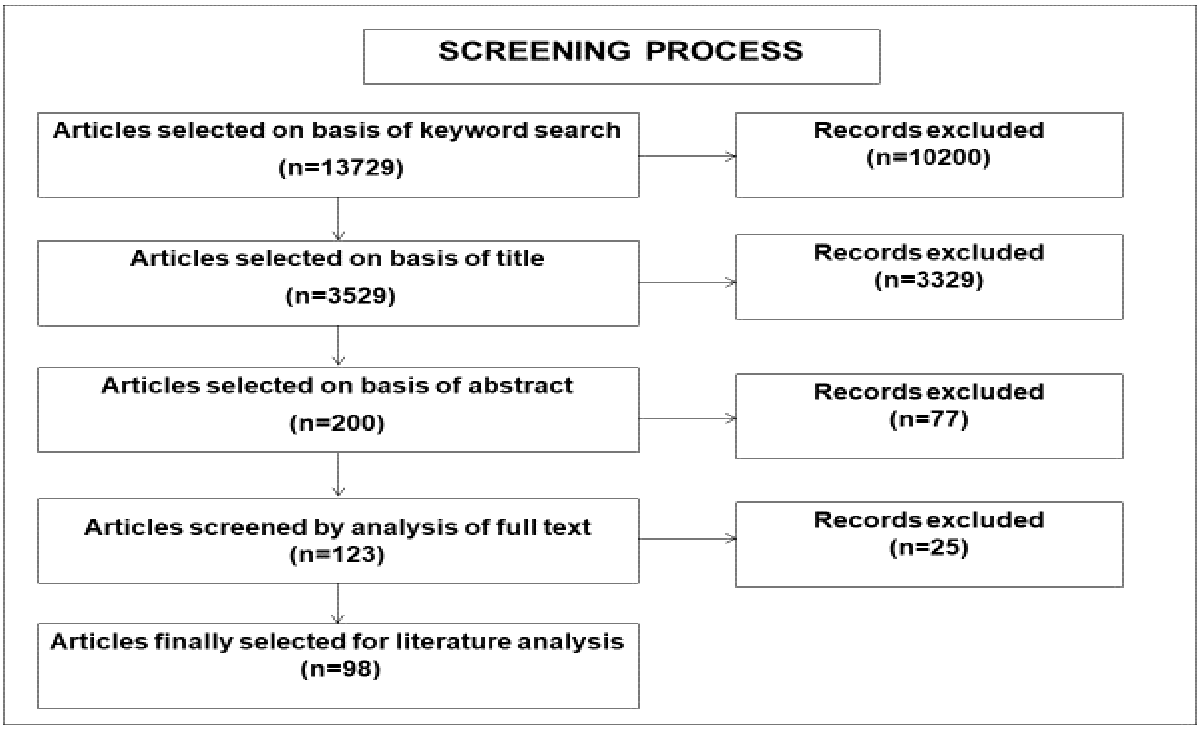


**Figure 3:** Summary of the screening process for selection of journal articles for the literature analysis.

### 3.3.2 Procedure of literature analysis

The literature analysis involved examining the ecology of the work of short-haul pilot/co-pilots based on the work system model of Smith and Carayon-Sainfort (1989), then later exploring the issues of pilot work and fatigue in light of the relationships in the developed model. Table 4 explains the process in detail.

**Table 4:** The four steps followed during the process of literature analysis.

| **Steps** | **Explanation** |
|---|---|
| **1:** An analysis of the work of pilots/co-pilots in short-haul operations | This step involved analysing the work of pilots and the context in which they work, based on existing literature retrieved from the screening process. This was done by exploring the functional and physical structure of the pilot work system, and the relationships between functions and dependent entities in such systems. The work system model adapted from Smith and Carayon-Sainfort (1989) was utilised as the framework for analysing the ecology of pilot work. The model partitions a system into five components, namely the person, physical environment, organisation, task, and tools and technology. |
| **2:** Identification of the factors contributing to pilot/co-pilot fatigue in short-haul operations | Based on the model developed in the previous step, an analysis of all the interactions between the person and the work system components was performed. These interactions were interrogated for their relevance to pilot fatigue to identify the factors contributing to these phenomena. Thus, a preliminary work system map/diagram was assembled. |
| **3:** Abstraction hierarchy approach | This step involved removal of factors from the work system map that were not considered to be major contributors to workload and fatigue experienced by pilots. This was done to reduce the work system map to the set of key characteristics and relationships that are the most important determinants of workload and fatigue. |
| **4:** Quantification of the main findings identified in step 3 | The main factors contributing to workload and fatigue identified in Step 3 (above) were analysed in detail. A graphic representation of these factors was thus developed for the short-haul context, which was structured according to the work system model components. A detailed theoretical description and explanation of the main findings awaits the Results chapter. |

## 3.4 Expert Interviews

### 3.4.1 Research approach

Expert interviews were used to supplement the findings of the literature investigation, particularly by providing insight into short-haul pilot/co-pilot fatigue in the South African context. Interviews served to reveal and clarify participants' thoughts and opinions regarding the South African aviation context, and particularly their perspectives on what the major factors are that contribute to aircrew (pilot/co-pilot) fatigue. Any factors emerging from this process that are not reflected in the existing literature were then added to the developing model. Expert interviews are considered to be the most common and widely used sources of data in present-day qualitative research (Harrell and Bradley, 2009; Rabiee, 2004). According to Kaplowitz and Hoehn (2001), interviewing in research can provide a flexible, valuable and participatory method of obtaining detailed information on a topic based on participants' experiences and perceptions.

### 3.4.2 Sampling

Sampling is defined as a method used to select individuals for inclusion in a study (Taherdoost, 2016). The participants selected to be interviewed included experts who specialize in the field of aviation and fatigue and who thus have theoretical knowledge and practical experience of the topic at hand – pilots from aviation institutions, fatigue specialists, and academics in appropriate fields of aviation research. For studies on single target groups and homogeneous populations it may be unnecessary to sample more than ten to twelve experts. Larger sample sizes are unlikely to change conclusions significantly and may instead lead to data saturation (Boddy, 2016). Participants were recruited through personal communication with people (face to face recruitment), via email, and by snowball sampling. Snowball sampling involves existing interviewees recommending other participants who they would consider to be suited to the study (Babbie, 2007).

Potential participants were screened after the completion of an online pre-screening self-assessment questionnaire (Appendix A1) compiled in Google Forms. This questionnaire was designed to determine the eligibility of participants based on the inclusion criteria outlined in Table 5 (those who did not match the criteria were not interviewed). A link was emailed to participants to allow them to complete the questionnaire online.

**Table 5:** Inclusion criteria for selection of experts for interview.

| SAMPLE SELECTION | REASONS |
|---|---|
| Pilots/Co-pilots (with short-haul experience in Southern Africa) | Pilots and co-pilots were selected because of the value of their practical, lived experience of actually flying in short-haul operations. They can interpret the meaning of key events in the context of practical aviation, discuss their work-related challenges, and provide nuanced insight into their jobs. |
| Fatigue Specialists (FRMS - crew fatigue specialists or academics) | FRMS - crew fatigue specialists were selected because of their expert scientific knowledge of fatigue-related safety risks in aviation. Examples of their varied professional repertoire include exploring the role of fatigue in incidents, providing training programmes for crew and schedulers, etc. Overall, they have extensive knowledge about fatigue in the aviation context and can provide expert insight into factors that they consider to be problematic for short-haul operations.<br>As Wilson (2002) noted, aviation is a high workload and stress-inducing occupation and pilot fatigue can be attributed to many underlying factors such as sleep loss or extended wakefulness, circadian disruption, workload, etc. Academics (scientific specialists) who focus on aviation research were selected for interview as they can provide detailed explanations and interpretations of their opinions, experiences and perceptions regarding fatigue, workload, sleep and circadian physiology in the aviation context. These interpretations are also distinguishing elements of interview research (Kuna, 2006). |

### 3.4.3 Procedure of Expert Interviews

Interviews were conducted one-on-one and were guided by a set of questions prepared beforehand (Appendix A2). Questions were generally open-ended, therefore the interviews could be classified as “semi-structured”. The researcher was given the freedom to ask follow-up questions and to ask for clarification where necessary. In preparation for the real interviews, mock-up interviews were conducted to fine-tune the interview protocols, detect flaws in the questions, perfect questioning style, and in general to ensure that the researcher gained experience and confidence in conducting interviews. Sessions were designed to last approximately 30 to 45 minutes, under the assumption that experts would be more likely to participate in a shorter interview process.

Interviews were scheduled according to the availability of the interviewees, and the questions that were asked and the order in which they were asked remained the same for each interview session. The experts were interviewed either face to face at their respective workplaces, or via telephone or Zoom video communication when meetings in person were not possible. Zoom is a video communication software that provides audio-visual conferencing and collaboration capabilities. The software can be downloaded and used on any digital device and is an attractive alternative to the Skype application. Participants interviewed via Zoom were e-mailed a set of instructions prior to the interview session (Appendix A3) detailing how to connect to the software. All interviews were recorded in full, in writing and through digital recording of the audio stream (using the audio recording feature in Zoom, and independently on the researcher's mobile phone). Permission to record was granted by each expert at the start of the interview session.

### 3.4.4 Expert Interview Data Analysis

The interview data were analysed using a thematic analysis approach inspired by the methods of Braun and Clarke (2006). These authors describe thematic analysis as a method for identifying, analysing, and reporting the themes (patterns) within a dataset. This process is also often described as "encoding qualitative information" (Boyatzis, 1998). The method is flexible enough to be applied in various theoretical frameworks and domains answering a diversity of research questions (Braun and Clarke, 2006). This particular approach has emerged from previous approaches to qualitative data analysis such as grounded theory, discourse analysis and narrative analysis (Braun and Clarke, 2006). It is able to report experiences, perceptions, meanings, and the realities experienced by participants (Braun and Clarke, 2006; Judger, 2016), and has been widely found to provide rich and detailed data (Braun and Clarke, 2006). The method is well suited to participatory research contexts, it is relatively straightforward and simple to learn, and it is accessible to researchers with little or no prior experience of interview research (Braun and Clarke, 2006).

The data analysis was preceded by a thorough familiarisation with the contents of the interviews. Audio recordings were transcribed and written into text using Microsoft Word 2016 (Judger, 2016; Morgan *et al.*, 2013). The recordings were listened to several times to maximise the factual and linguistic accuracy of transcriptions (Braun and Clarke, 2006; Judger, 2016). In the first step of the analysis itself, the transcribed drafts were read several times to identify the key emergent factors, trends and patterns. Secondly the transcribed data were reduced to themes through a process of coding (Braun and Clarke, 2006). The QSR International’s NVivo 12 qualitative data analysis software, version 12.1.90 (NVIVO, n.d.), was utilised to facilitate this categorization. Coding involves identification of descriptive constructs and other features of the data that researchers deem to be particularly interesting and relevant to the aims of the study (Braun and Clarke, 2006). A numerical coding system is then applied to these identified elements of the data, according to their alignment with the research questions and aims (Braun and Clarke, 2006). Thirdly, the coded data were classified into potential themes. A theme is defined as a consistent pattern emerging from a dataset, that is relevant to the research questions and aims (Boyatzis, 1998; Judger, 2016). The transcribed interviews were screened for data relevant to each potential theme, and the themes were reviewed and refined by checking that the data content of each theme was consistent with the coded extracts and the entire data set (Braun and Clarke, 2006). This process was repeated until the emergent themes could be clearly defined and named (Braun and Clarke, 2006). Finally, reports were produced in which the main themes and findings were presented in a narrative format including direct citations of individual participants (Braun and Clarke, 2006).

### 3.4.5 Ethical Considerations

Ethical clearance for expert interviews was obtained from the Rhodes University Human Kinetics and Ergonomics ethics committee prior to participant recruitment and execution of the study (Appendix B1). The ethics application provided the following details: (1) a description of the concept, procedure and methodology of the research; (2) the information that would be provided to participants (instructions, informed consent, participation rights, etc.); (3) information about the potential benefits of participation in research studies such as this; (4) the subject characteristics and requirements of the study; (5) ways in which privacy of participants will be protected, how participation anonymity will be maintained, and a statement of the right to participation withdrawal. These latter guidelines and practices are followed to protect the institution and the researchers from potential legal implications that could arise from methods and behaviours carried out during the research. They are further elaborated below.

#### A) Permission from Experts

Experts were recruited via email. Contact details of potential participants were obtained from staff of the Department of Human Kinetics and Ergonomics (Rhodes

University, South Africa) and staff of Denel Aviation (including Denel SARA project managers and mentors). Firstly, permission letters were sent via email to the Director of Human Resources at Rhodes University and to the Denel Aviation regulating body to seek permission to contact experts. Only once permission had been granted (Appendix B2 and B3) were the selected experts sent recruitment letters (Appendix B4) via email. Recruitment letters included an overview of the purpose and procedures of the study, and the data that will be collected.

#### B) Informed Consent

Prior to commencement of the expert interviews, consent was obtained from the expert participants (Appendix B5). The consent form included a brief introduction to the researcher and supervisor and an outline of the purpose of the study and procedure of the interview session. The letter also confirmed that the employment details and affiliations of participants would not be mentioned in the study unless permission to do so was expressly granted.

#### C) Anonymity and Confidentiality

Information that was obtained through interviews remained strictly confidential. Anonymity was maintained by assigning an identification code to each participant so that their name was not linked to their interview data. Additionally, as mentioned before, employment details and affiliations of participants were not mentioned anywhere in the study. Permission was sought before interviews were recorded, and all audio recordings were stored on a password-protected computer and remained strictly confidential. All information collected during this study was stored indefinitely for use in future publications, conferences and seminars, but participants remained coded to guarantee anonymity.

### 3.5 Chapter Summary

Overall, this chapter describes the application of a work system analysis approach based on the work system model of Smith and Carayon-Sainfort (1989), to examine the work system of pilots/co-pilots in short-haul operations. The work system analysis approach was executed in two phases: literature analysis and expert interviews. The model was used as a framework to identify, analyse and structure the key factors contributing to pilot/co-pilot fatigue in the short-haul operational context. The results emerging from the literature analysis and expert interviews were structured according to the five components introduced by the model - organisation, task, technology and tools, environment, and individual/non-work related. The following chapter provides a detailed description of the study findings.

# CHAPTER 4

# RESULTS

## 4.1 Overview

The first part of this chapter describes and discusses the results obtained from the literature analysis and reports findings regarding the main factors contributing to pilot/co-pilot fatigue in short-haul operations.

The second part of the chapter presents the results that were obtained through the analysis of the expert interviews. These results reflect the opinions of experts in the South African short-haul operational milieu with respect to fatigue (of pilots/co-pilots) in the aviation context and what these experts perceive to be its primary causes.

## 4.2. Literature Analysis Results

During the first phase of the work system analysis (i.e. analysis of existing literature), 98 sources were selected (see Chapter 3 for a description of the literature screening process), of which 43 were peer-reviewed articles, 15 were Masters or Doctoral dissertations, 11 were articles retrieved from websites, 13 were books, 11 were report documents, and 5 were conference papers. These sources were categorized in terms of their content as follows:

- 27 sources pertained to the understanding of workload, stress and fatigue in commercial operations (including aviation);
- 39 sources focused on work scheduling, sleep and circadian rhythm and pilot fatigue in short-haul aviation operations;
- 8 sources focused on flight time, duty and rest limitations in short-haul operations and its influence on pilot workload and fatigue;
- 12 sources related to the link between pilot fatigue and either environmental, individual, or technological factors;
- 6 articles pertained to task-related aspects of pilot fatigue;
- 6 papers related to performance levels, accidents, human factors and work systems in aviation.

Some of the sources, though placed within a certain category, were also related to others. However, each of the sources was deliberately placed in the category which captured the majority of its content. The actual content of the sources is described below.

### 4.2.1 Fatigue in Aviation

Pilot fatigue has been a problem from the early years of aviation (Avers and Johnson, 2011). An historical example, is that of Charles Augustus Lindbergh, the well-known American aviator who was the first to fly solo across the Atlantic. The quote below makes it clear that he experienced fatigue during the flight:

> "*My mind clicks on and off. I try letting one eyelid close at a time when I prop the other open with my will. But the effort is too much. Sleep is winning. My whole body argues dully that nothing, nothing life can attain is quite so desirable as sleep. My mind is losing resolution and control".* (Lindbergh (1954), cited by Avers and Johnson, 2011, p. 87).

However, apart from Lindbergh's experience and testimony of fatigue as a work-related problem, most early aviators were also regularly challenged by failed hardware, engine and other system failures, and the relative unavailability of ground- and air-based navigational equipment (Avers and Johnson, 2011). These factors were usually cited as the leading causes of aviation incidents and accidents (Avers and Johnson, 2011). Human factors such as fatigue were not considered to be priority aviation safety issues (Avers and Johnson, 2011).

Over time, however, the issue of fatigue has been further exacerbated in the aviation context by changes in the global economy, societal factors, and technology (Caldwell and Caldwell, 2016). Currently, one of the most pervasive manifestations of fatigue in aviation is the impairment of pilots' alertness and performance, which has been cited as the leading cause of aviation accidents and incidents in this era (Alcéu, 2015; Avers and Johnson, 2011; Levo, 2016). Notwithstanding this, pilot fatigue remains an unreported problem in many aviation operations (Reis *et al.*, 2013).

Competition between aviation and airline companies has become intense and the demand for air travel has increased over time, which has led to companies expanding into 24-hour operations (Alcéu, 2015; Dinges *et al.*, 1996). To support 24-hour demands, airline management has forced crewmembers into accepting a culture of increased daily tasks and duties, reduced rest and sleep periods, extended working hours, more extreme duty schedules, increased job demands, more responsibilities and greater workloads (Alcéu, 2015; Chang, 2002; Dinges *et al.*, 1996; Gander *et al.*, 1998; Levo, 2016; Powell *et al.*, 2007; Reis *et al.*, 2013; Yang, 2014; Yuliawati *et al.*, 2015). In short, pilots are often driven beyond their capabilities. These demands are predominantly driven and associated with the profit, growth and ecological goals of companies (Dijkshoorn, 2008).

Fatigue in the aviation context has been defined by the International Civil Aviation Organisation (ICAO), the International Federation of Airline Pilots Association (IFALPA), and the International Air Transport Association (IATA) as “a physiological state of reduced mental and physical performance capacity resulting from sleep loss or extended wakefulness, circadian disruption or workload resulting from mental and physical activity that impairs a crewmember’s alertness and ability to safely operate an aircraft or perform safety related duties” (Alcéu, 2015, p.14; Tambala, 2017, p.1). This well-constructed definition has been accepted by many operators worldwide (Alcéu, 2015; Ashley, 2013). Fatigue in the aviation context accumulates because of the increasing effort required by employees to perform tasks effectively and avoid errors (National Research Council, 2011). It is associated with decreased overall performance due to increased work intensity and work duration, decreased quality and quantity of sleep, and the sub-optimal times of the day when pilots work (National Research Council, 2011).

### 4.2.2 Pilot fatigue and workload

#### A) Pilot fatigue and its causes

Pilot fatigue has been identified as an insidious threat throughout the aviation industry (Caldwell and Caldwell, 2016). However, it is not recognised being unacceptable because pilots, even though they might feel exhausted, still manage to take-off and land without incident time after time (Caldwell and Caldwell, 2016). This lack of recognition is very troubling and should be taken seriously. In much literature, pilot fatigue has been identified as a factor contributing to accidents, aviation errors and incidents, ultimately endangering the lives of both passengers and crewmembers (Caldwell *et al.*, 2009; Thomas *et al.*, 2015; Yuliawati *et al.*, 2015).

In general, the nature of work has changed over time from requiring mostly physical effort to requiring more cognitive effort such as constant attention, sustained vigilance, complex decision-making, advanced perceptual-motor control skills and communication, all with little margin for error (De Gray Birch, 2012; Wilson, 2002). This trend is certainly prevalent within the aviation world and definitely applies to pilots.

Pilots suffer from fatigue for many reasons that are unique to their type of work (Caldwell, 2005). The job of a pilot is often seen as a high-workload, stress-inducing occupation (Wilson, 2002). This is largely because pilots bear responsibility for sticking to their daily schedules, and for ensuring that their companies remain profitable, that their passengers are safe and satisfied, and that their cargo arrives on time (Caldwell and Caldwell, 2016). In addition, from a transport industry perspective, pilot fatigue levels are continuously negatively impacted by industrial and cultural changes. These include measures implemented to increase employee productivity and value, increase financial profits and manage mental pressure, increase competition, and employees are expected to be more flexible for their employers (Yang, 2014).

The often-severe mental fatigue experienced by pilots is mainly due to sleep-related and task-related factors (Ashley, 2013; De Gray Birch, 2012; Rosekind *et al.*, 2000; van Drongelen *et al.*, 2013). Sleep-related fatigue is commonly induced by endogenous factors (De Gray Birch, 2012) which include disruption to body clock/circadian rhythm, zeitgeber shifts, and sleep debt (Ashley, 2013; Rosekind *et al.*, 2000; van Drongelen *et al.*, 2013). Task-related fatigue, on the other hand, is induced by exogenous factors such as workload associated with the tasks, duties and responsibilities of the pilot (De Gray Birch, 2012). Both sleep-related and task-related factors are driven by work schedules, work organization, job design and management style (Lee *et al.*, 2013).

### B) Pilot workload related to automation

Flying an aircraft is a multifaceted skill which imposes demands on a pilot’s mental workload (i.e. cognitive processes) (Wilson, 2002). Pilot workload refers to the list of tasks assigned to a pilot in a specified flight operation, along with the effort required by the pilot to perform those tasks and the demands placed on the pilot with respect to those tasks (Hart and McKenzie, 1979). The task-related demands placed on pilots and other crewmembers are determined by the requirements of any given work system (Sandry-Garza *et al.*, 1987).The problems of crewmember workload and fatigue have increased as elements of aircraft design (e.g. cockpit technology and automation systems) have improved (Salas and Maurino, 2010).

Although automation has been shown to alleviate certain types of fatigue experienced in the cockpit (i.e. types associated with manually intensive tasks), it has also resulted in additional more cognitively demanding tasks (Loh, 2004; Sandry-Garza *et al.*, 1987; Wilson, 2002). Automation refers to the replacement of tasks previously performed by operators with automated system components (Brown, 2016). Chialastri (2012) defines aircraft automation as the use of controlled systems and information technology to reduce the amount of human work and the number of manual tasks performed in the cockpit. Automation is also defined as a system that removes the human operator from the control loop and permits unattended operation of the system (Salas and Maurino, 2010).

Automation has helped in addressing the increasing demand for safer critical systems (Bainbridge, 1983). Advanced automation changes the nature of human factor considerations on the flight deck. The flight crew needs to remain effectively ‘in the loop’ as part of the automated system, making the pilot-computer interface essential in keeping pilots informed about system operation, and in keeping computers informed about the conditions and the behavior of the flight crew (Gradwell and Rainford, 2016). In cases of unanticipated failure of an automated system or unanticipated external conditions, human operators can override the automation and operate the system manually (Bainbridge, 1983). Thus, the human operator's task has become more of a supervisory task than a manual control task. This leads to several problems, and many issues and potential pitfalls (dubbed as the "ironies of automation") have been raised with regards to automated systems (Bainbridge, 1983).

Operators used to exhibit high-level manual control skills which could effectively be carried out automatically, requiring few cognitive resources. However, once aircraft control was automated, these skills were not used anymore (Baxter *et al*., 2012). According to Brainbridge (1983) and Onnash *et al*. (2014), manual control skills deteriorate if they are not used often. This may result in a decreased capacity for pilots to manually handle their aircraft systems. It may also lead to delays in pilots’ responses with respect to manual control tasks, as well as to longer decision-making times and an overall decrease in pilot efficiency with respect to manual tasks (Brainbridge, 1983; Onnash *et al*., 2014).

Flying an aircraft does not only involve motor skills, but is also highly dependent upon cognitive processing which is a crucial skill involved in nearly every aspect of piloting (Arthur *et al*., 1998). When automation is introduced, a pilot's ability to build up and employ their system knowledge might be impaired. This is because long-term knowledge is dependent upon frequent use (i.e. learning through practice and experience which strategies to apply to new situations) (Baxter *et al.,* 2012). Arthur *et al.* (1998) argue that cognitive skills deteriorate over time without proper practice, especially skills that were learnt early in training and then not used for extended periods. This is dangerous because when pilots are forced to override systems in instances of automation failure or other unusual circumstances, they may lack the skills to do so (Baxter *et al*., 2012; Brainbridge, 1983). In tasks that comprise only supervisory responsibilities, humans do not have the opportunity to build up knowledge about the behaviour of their systems. They could thus become detached from the underlying processes which they are meant to control (Baxter *et al*., 2012; Brainbridge, 1983). Furthermore, operators of complex systems keep knowledge regarding short-term system characteristics and system states in their working memories with this knowledge being updated over time as the situation changes (Baxter *et al*., 2012; Brainbridge, 1983). This knowledge takes time to build up and is used to make predictions about future control actions. However, in situations where operators manually take over from an automated system, they will only be able to make decisions and take action based on a minimal amount of information (Baxter *et al*., 2012; Brainbridge, 1983).Thus, it seems clear that automation can lead to a decline in operators' vigilance and system monitoring skills (Baxter *et al*., 2012; Brainbridge, 1983).

It seems humans are not built for the task of monitoring systems (Baxter *et al*., 2012; Brainbridge, 1983;). It is impossible for a human being to maintain effective visual attention towards an information interface, where very little happens, for 30 minutes or more. This led to the introduction of automated alarms to ensure that operators monitor systems for correct functioning (Baxter *et al*., 2012; Brainbridge, 1983). However, this creates other problems. Firstly, automated systems that run for long periods without incident may induce automation complacency which is the tendency for an operator to trust a system even in situations where human intervention is necessary (Brown, 2016). Secondly, automated systems outperform their human operators in terms of performance capabilities making it difficult for pilots to distinguish between appropriate system behaviour and abnormal conditions. Furthermore, automated systems tend to perform tasks better than human beings, as they can assimilate more information than human operators can (Baxter *et al*., 2012; Brainbridge, 1983). Overall, automated systems result in operators taking on a purely monitoring role whilst the system is controlled automatically. This increases the risk that pilots will ultimately lack system understanding (Baxter *et al*., 2012; Bainbridge, 1983).

However, other authors have stated that cockpit tasks have been reduced to system management, monitoring, supervision and assessment tasks requiring critical decision-making skills and high levels of alertness (Gradwell and Rainford, 2016; Harris *et al.*, 2001; Sandry-Garza *et al.*, 1987). This increases workload in the areas of understanding and monitoring, as well as programming during important phases of flight (Gradwell and Rainford, 2016). In addition, when an automated system fails, its operator must make split-second decisions on how to proceed, leading to peak workload levels (Mulder *et al*., 2017).

Other cockpit tasks impose visual, verbal, and/or auditory demands on pilots (Sandry-Garza *et al.*, 1987). Thus, mental fatigue on the part of pilots is considered an important aviation safety risk (Reis *et al.*, 2013). Mental fatigue is described as feeling exhausted or worn-out even without physical exertion (Ashley, 2013). Pilots often experience heightened levels of mental fatigue during the take-off and landing phases, which reduce during the cruise phase (Ashley, 2013; Lee, 2010; Reis *et al.*, 2016; Yuliawati *et al.*, 2015). Elevated fatigue levels are most commonly experienced by student pilots because of their lack of experience. They need to deal with a lot of fresh information as well as new and uncomfortable environments, which may lead to them feeling mentally overwhelmed (Ashley, 2013). The Federal Aviation Administration (FAA) defines pilot fatigue as a physiological state of reduced capacity to perform cognitive tasks, with increased performance variability as a function of time-on-task (FAA, 2010). Mental workload and fatigue have become areas of serious concern with respect to pilots (Alcéu, 2015; Wilson, 2002). High workload has a direct correlation with fatigue and may impact negatively on pilot performance and safety (Alcéu, 2015; Wilson, 2002).

### C) Types of Operations

It has been found that the type of aviation operation undertaken has a significant bearing on both the workload and fatigue experienced by pilots (Thomas *et al.*, 2015). There are two aviation operation types, namely long-haul and short-haul (Thomas *et* *al.*, 2015). Long-haul flight operations, also referred to as international flights, usually traverse multiple times zones (Levo, 2016; Caldwell, 2005). Long-haul pilots are responsible for a range of departure and arrival schedules, and need to have the ability to travel long distances (of six hours and above) on a daily basis (Caldwell and Caldwell, 2016).

Researchers have paid considerable attention to pilot fatigue associated with long-haul operations (Gropp, 2014). In the majority of studies published on this topic, pilot fatigue has been attributed to underlying circadian effects and sleep disruptions due to jetlag (Caldwell, 2005; Thomas *et al.*, 2015). Other factors contributing to fatigue include night scheduling, extended overnight flights, and consecutive night shifts (Caldwell, 2005; Caldwell *et al.*, 2009).

In comparison, fatigue in short-haul contexts has received little research attention despite the fact that short-haul pilots face considerable fatigue risks (Loh, 2004; Powell *et al.*, 2007; Vejvoda *et al.*, 2014). In current short-haul operations contexts, pilots are required to fulfil their duties and responsibilities effectively within tight work schedules (Chang, 2002; Gander *et al.*, 1998; Powell *et al.*, 2007; Reis *et al.*, 2013; Yuliawati *et al.*, 2015). Short-haul operations have various attributes that set them apart from long-haul operations (Loh, 2004). For instance, contrary to the long-haul context, short-haul operations (also referred to as domestic or regional flights) generally occur within discrete time zones, where layovers are usually carried out at consistent home bases (Levo, 2016; Thomas *et al.*, 2015). The short-haul environment is generally characterized by daytime flying, multiple flight segments, and no time zone crossing (Gander *et al.*, 1998). In other words, short-haul pilots do not require the 24-hour operational capabilities that long-haul pilots do as (Levo, 2016; Thomas *et al.*, 2015) as their tasks are not executed continuously throughout the night (Gander *et al.*, 1998; Levo, 2016). Short-haul work schedules could thus be assumed to cause minimal disruption to the circadian rhythms of crewmembers as they are allowed to sleep during the night hours and are not required to adapt to new time zones (Gander *et al.*, 1998). This assumption has resulted in a research gap regarding fatigue in short-haul operations (Gander *et al.*, 1998). However, short-haul (domestic) pilots commonly identify sleep deprivation and high workload as the main contributing factors to their fatigue (FAA, 2010). The following section highlights some of the main factors that contribute to pilot fatigue in the context of short-haul operations.

### 4.2.3 Factors Contributing to Pilot Fatigue in Short-haul Flights

During this study it was identified that the workloads placed on pilots in short-haul operations are influenced by numerous factors pertaining to the various system components (i.e. individual, organization, tasks, tools and technology, and environment) in the work system model developed by Smith and Carayon-Sainfort, (1989, p. 30). All of the components thus contribute to shape the way in which workload and fatigue may present in short-haul flight operators. Thus, the key findings for this component of this study were characterized according to five components of the work system model by Smith and Carayon-Sainfort (1989).

The demands and loads placed on pilots are influenced by the tasks they are required to perform under particular organizational constraints. These tasks include pre-flight, in-flight, and post-flight duties (Lacabanne *et al.*, 2012) comprising, amongst others, continuous briefings of the aircraft system, performing pre-flight checks, continuous, navigation of the aircraft and monitoring of cockpit instruments during take-offs, flights and landings (Lee, 2010). Short-haul pilots bear other additional responsibilities such as maintaining on-going communication with engineers, cabin crew, controllers, and dispatchers (Wickens, 2002).

All of these tasks, performed under particular organizational conditions (e.g. scheduling), can further influence workloads and induce fatigue. The aspects of scheduling which have a bearing on pilot fatigue include starting time, finishing time, number of sectors, number of consecutive workdays, standby duty, flight duty period, duty hours, regularity of work hours, and crew size (Co *et al.*, 1999; Gander *et al*., 1998; Jackson and Earl, 2006).

Workloads are further influenced by the technology and tools (e.g. automated systems, infrastructure) used to perform the required tasks under the organizational constraints of a particular company (Co *et al*., 1999; Dumitru and Boşcoianu, 2015; Vejvoda *et al.*, 2014).

The environmental conditions under which pilots perform their tasks can also influence their workloads, e.g. the small, pressurized cockpit environment, restriction of movement, very low humidity, low air pressure, vibrations, high noise levels, and low light intensity (Dijkshoorn, 2008; Dumitru and Boşcoianu, 2015).

Lastly, individual aspects such as age; stress levels (both personal and work-related); lifestyle (e.g. diet, physical activity, sleep), and work experience are also considered to influence the workload and thus pilot fatigue. All of these factors affect the human operator both in isolation and in combination (Ashley, 2013; Dijkshoorn, 2008; Lee, 2010; Mikkelsen, 1998). If the cognitive demands of a job exceed the capabilities of the pilot it can lead to fatigue, which can ultimately lead to errors with catastrophic outcomes (Wilson, 2002).

A) Task-related aspects

Effective human performance is critical for aviation safety (Salas and Maurino, 2010). The roles and responsibilities of pilots/co-pilots are influenced by implicit and explicit patterns of activities and procedures prescribed by an organization’s particular work practices (Salas and Maurino, 2010). The nature of aviation work has shifted over time from being predominantly physical effort to predominantly cognitive (De Gray Birch, 2012; Wilson, 2002). Typical tasks performed by short-haul pilots include carrying out pre-flight, in-flight, and post-flight duties. These tasks require mental resources such as attention, concentration, alertness, and decision making to ensure flight safety and efficient flight execution (Dijkshoorn, 2008). Pilot workload depends upon the overall level of demand for such resources by the tasks assigned (Dijkshoorn, 2008).

Pre-flight duties include pre-flight checks and briefings of the aircraft systems (Lee, 2010). These briefings involve acquiring information about the route, passengers, weather, and flight plans before departure and examining departure procedures and take-off data calculations (Estival *et al.*, 2016). Other briefings would include calculating the speed required to become airborne by examining airport altitudes, outside temperatures, plane weight, wind speeds, and wind directions and calculating fuel requirements (Estival *et al.*, 2016). A pilot commences duty with comprehensive pre-flight checklists/ inspections of all aircraft systems including the fuel, engine, hydraulics, and electronics components (Estival *et al.*, 2016; Lee, 2010). These inspections are to check for abnormalities such as tire wear, oil leaks, or damaged control surfaces (Lee, 2010). The pilot would then enter relevant flight-related data into the flight management computer in the cockpit and check that fuel is loaded before departure (Estival *et al.*, 2016). Only then would the pilot commence with necessary prestart and system checks (prior to passengers boarding) to ensure the fastest, safest and smoothest flight (Estival *et al.*, 2016).

For short-haul pilots, high workload and fatigue arise mainly during execution of in-flight tasks. This is attributed to the high psychological and psychosocial demands experienced during this phase of flight (Lacabanne *et al.*, 2012; Lee, 2010). Short-haul pilots perform many important and complex tasks in the cockpit (Lee, 2010). These can place several demands on their cognitive abilities (Wilson, 2002). These demands can, in turn, generate a heightened perception of mental workload and induce high-stress levels as these pilots bear the responsibility of safely operating their aircraft (Lacabanne *et al.*, 2012; Lee, 2010). In addition, factors such as environmental conditions (e.g. severe weather) and mechanical failure are considered threats when flying (Lee, 2010). These safety threats along with imposed time constraints further heighten pilots' cognitive loads (Lee, 2010).

Pilots perform four meta-tasks in flight, namely aviation, navigation, communication and management of resources (Lacabanne *et al.*, 2012). Aviation refers to controlling the aircraft's flight path; navigation refers to steering the aircraft from its origin to its destination; communication refers to continuous correspondence with air traffic controllers with respect to data, requests, instructions and information; and management of resources refers to the pilot's responsibility to oversee temperature, fuel levels, oil levels, and system displays (Estival *et al.*, 2016; Lacabanne *et al.*, 2012). The first two meta-tasks hold higher priority than the last two (Lacabanne *et al.*, 2012).

There are a number of distinct phases of a flight, each of which presents different workloads and stress levels for the pilot (Lee, 2010; Wilson, 2002). These phases are: push back; taxi; take-off; domestic/oceanic cruise; descent; final approach; and landing (see Figure 4) (Estival *et al.*, 2016; Midkiff *et al.*, 2004;).

Push back and taxiing are phases of flight in which the pilot reverses an aircraft from its standing position (terminal), and drives it along demarcated taxiways towards the runway for take-off (Midkiff *et al.*, 2004; IVAO, 2016). Take-off is the phase in which the plane transitions from moving on the ground to becoming airborne (IVAO, 2016). Once the ground has been left, the engines are run at full power while the pilot sets the flaps, pulls back gently on the yokes (steering instruments) and allows the aircraft to accelerate rapidly until the speed for take-off is achieved (Estival *et al.*, 2016; Sadraey, 2017). Thereafter, the pilot ensures a proper pitch to maintain the appropriate rate of climb (Sadraey, 2017) and increases the lift of the wings, and the plane continues to climb until it reaches the correct altitude for the cruise phase (Sadraey, 2017). The cruise phase is the stage in which the aircraft is flying towards its destination. It is also the phase during which the aircraft consumes the most fuel (Estival *et al.*, 2016). Cruising ends when the aircraft reaches its destination (IVAO, 2016) and the pilot commences the descent phase in preparation for the landing phase (IVAO, 2016). During the descent phase, the aircraft gradually decreases altitude as it is directed toward the ground (IVAO, 2016). The pilot will descend at a constant speed whilst controlling the angle of descent using engine power and pitch angle (Sadraey, 2017). The landing phase is the one in which the aircraft returns to the ground at its destination (IVAO, 2016). To land, the rate of descent and the airspeed are reduced to ensure that the aircraft descends to the runway slowly, and that a gentle touch down is achieved (Estival *et al.*, 2016, IVAO, 2016). As the plane descends, the pilot will set the flaps to the correct configuration and release the aircraft's wheels (Lee, 2010; Sadraey, 2017).

**Figure 4:** Phases of Flight (taken from REStARTS, 2017)

On average, short-haul pilots undertake twice as many daily take-offs and landings as long-haul pilots (Chang, 2002; Gander *et al.*, 2014; Reis *et al.*, 2016). These two phases are considered the most workload-intensive stages of flight and those most susceptible to severe accidents (Ashley, 2013; Lee, 2010; Reis *et al.*, 2016; Yuliawati *et al.*, 2015). Figure 5 depicts the levels of stress and workload experienced by pilots during the various different phases of flight (Experimental Aircraft Info, 2006). It emphasizes that stress levels and workload, which have been shown to increase fatigue levels, are at their highest during take-off and landing (Experimental Aircraft Info, 2006). It also emphasizes that pilot capabilities decrease with increased workload, which could threaten the safety of a flight (Experimental Aircraft Info, 2006).

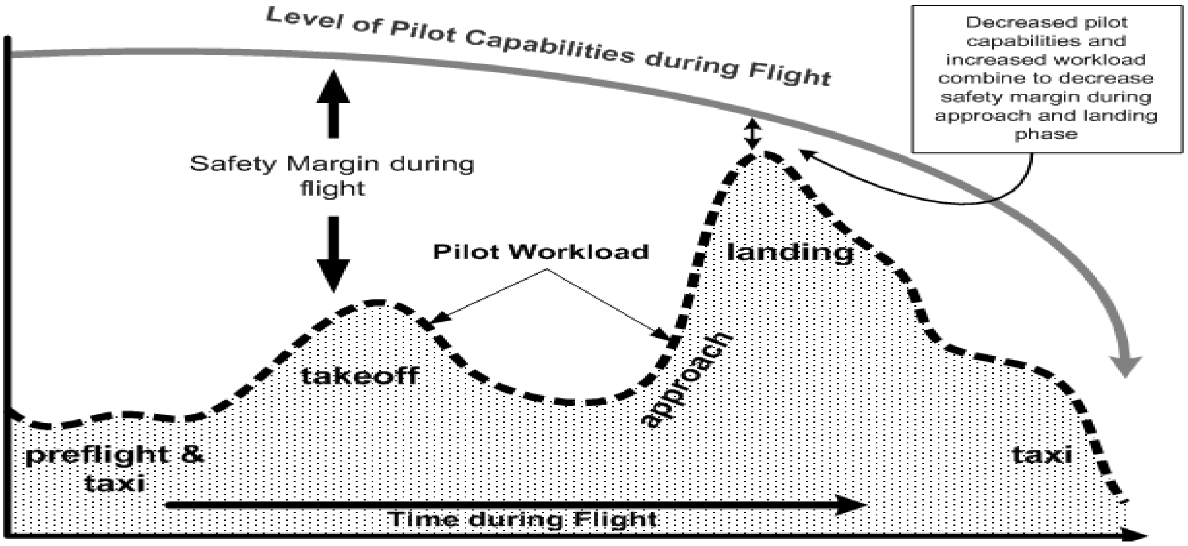


**Figure 5:** Workload and stress during different phases of flight (taken from Experimental Aircraft Info, 2006)

This makes sense as the take-off and landing phases require pilots to perform a considerable number of tasks (Estival *et al.*, 2016; Roach *et al.*, 2012). Both of these phases demand sustained high concentration and intense conversation between the pilot and the air traffic controller (Yuliawati *et al.*, 2015). Such heightened levels of activity can lead to mental fatigue (Ashley, 2013). Mental activity reduces dramatically during the cruise phase of the flight (Ashley, 2013). However, according to Lee (2010) pilots are typically busier during the descent and landing phases than during take-off. Nearly 50% of all flying accidents occur during the descent and landing phases (Lee, 2010). During these stages, a pilot is required to set the flaps and landing gear, maintain airspeed and track the gliding path for a gentle touch down (Lee, 2010). After landing, a pilot is required to write a report recording any technical difficulties or other problems that may have arisen during flight (Estival *et al.*, 2016). Over time and with frequent repetition due to pilots flying multiple segments, having to perform all of these duties can result in increasing fatigue for crewmembers as they progress through their scheduled trips (Wiener and Nagel, 1988).

B) Organisational aspects

*B1) Early Starts/ Late finishes*

There is a great deal of concern in the aviation community that the relative severity of pilots’ schedules along with time-of-day effects may exacerbate workload and the risk of fatigue, and lead to increased safety risks (Goode, 2003). Scheduling demands are very often associated with and strongly driven by company goals established with a view to maximum profit and growth (Dijkshoorn, 2008). Short-haul pilots are subjected to work schedules that involve early starts and late finishes.

A typical duty day for a short-haul pilot would start as early as 06:00 and end at about 23:00 (Chang, 2002). Some schedules begin even earlier than 06:00 (Roach *et al.*, 2012). Each duty cycle begins and ends at the same airport or airfield (Chang, 2002). These early-morning/late-finish shifts are usually sustained for two to three consecutive days or more (Caldwell and Caldwell, 2016). Such early starts result in crewmembers having to wake up in the window of circadian low (Alcéu, 2015). The body has a circadian rhythm (body clock) that regulates various 24-hour patterns of body functions (Co *et al.*, 1999; Dinges *et al.*, 1996). One of the functions of the circadian rhythm is the maintenance of sleep and wakefulness patterns corresponding to the environmental day/night or light/dark cycle (Dinges *et al.*, 1996). The window of circadian low (WOCL) is defined as the hours between 02:00 and 06:00 in an individual's normal day-wake/night-sleep cycle (Co *et al.*, 1999; National Research Council, 2011). Caldwell and Caldwell (2016) emphasize that pilot alertness is lowest and circadian-induced fatigue is most prevalent between these hours. Most crewmembers must report for duty one to two hours prior to the commencement of their schedules (Dijkshoorn, 2008; Nesthus *et al.*, 2007). This would accelerate the onset of fatigue because it requires crewmembers to maintain wakefulness in direct opposition to their physiological programming (Caldwell and Caldwell, 2016; Dinges *et al.*, 1996). In other words, morning shifts hasten the onset of pilot fatigue because they cause pilots to wake-up during a time when sleep pressure is high and alertness levels are low (Caldwell and Caldwell, 2016). It is assumed that when a duty starts before a certain time, especially in the case of early shifts starting as early as 06:00, a certain amount of sleep has been missed (Caldwell and Caldwell, 2016; Roach *et al.*, 2012). These shortened sleep episodes reduce the amount of sleep obtained by crewmembers to a level below their requirements (Deros *et al.*, 2012; Jackson and Earl, 2006; Gander *et al.*, 1998; Techera *et al.*, 2016). Similar findings have been presented by Powell *et al.* (2007) who found that successive early wake-ups and late finishes can disrupt normal sleep routines, resulting in loss of sleep and less restful sleep over the work period (see Table 6). Bourgeois-Bougrine *et al.* (2003b), in their study on short-haul and long-haul flights, found that during short-haul flights, pilot fatigue (41%) was predominantly caused by successive early wake-ups (see Table 6). The majority of short-haul pilots (76%) reported acute fatigue (scored as high and very high on a 5-point Likert scale) linked to sleep loss and sleep deprivation as a result of their work schedules (which included successive early starts and late finishes after night flights); 53.8% of pilots identified workload as a cause of their fatigue. Fatigue was self-reported by 49% of short-haul flight (SHF) pilots.

Spencer and Robertson (2002), found that sleep duration prior to the start of early duties was reduced by an average of one to two hours. Where duty times commenced between 07:00 and 08:00, pilots obtained an average of 6.90 hours of sleep, and where duties commenced between 05:00 and 06:00, they obtained an average of 5.88 hours of sleep. However, where duties commenced between 10:00 and 11:00 crewmembers obtained an average of 7.83 hours of sleep during the night prior (see Figure 6 and Table 6) (Spencer and Robertson, 2002).

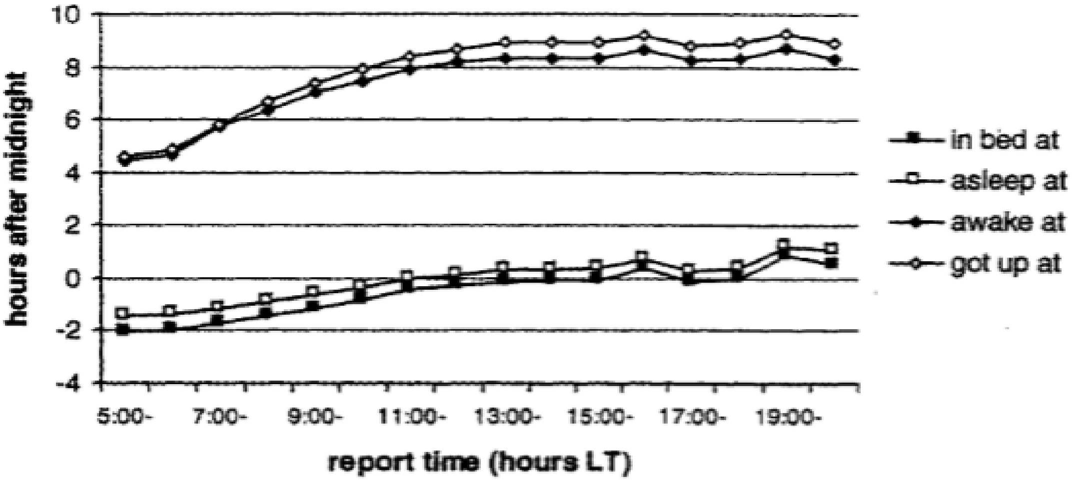


**Figure 6:** Average sleep times prior to the start of duty (taken from Spencer and Robertson, 2002, p. 9)

Spencer and Roberson (2002) demonstrated that where duties commenced before 09:00, there was a higher prevalence of morning fatigue (p<0.01). Crewmembers who commenced duty between 06:00 and 07:00 reported fatigue levels on average 0.22 points higher than those who started later in the day (p<0.05) (see Figure 7).

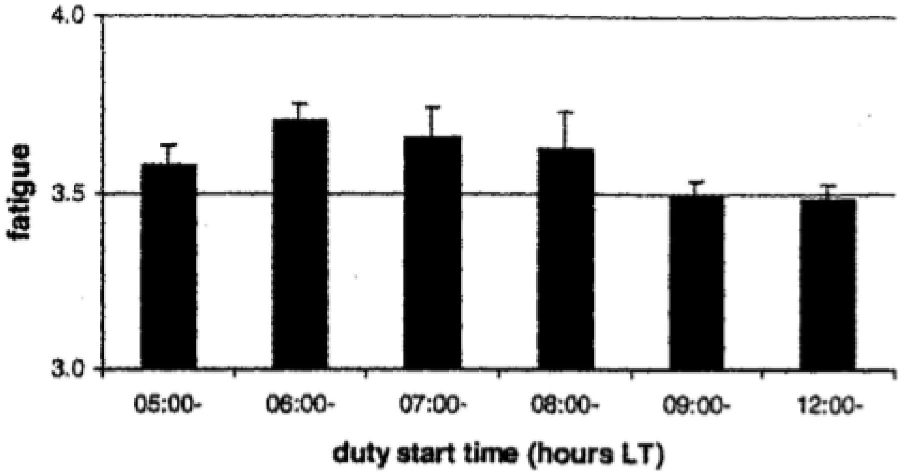


**Figure 7:** The effect of the duty start time on fatigue. Fatigue ratings were based on the Samn-Perelli 7-point fatigue scale 1 = “Fully alert, wide awake”; 2 = “Very; lively, responsive, but not at peak”; 3 = “Okay, somewhat fresh”; 4 = “A little tired, less than fresh”; 5 = “Moderately tired, let down”; 6 = “Extremely tired, very difficult to concentrate”; 7 = “Completely exhausted, unable to function effectively” (taken from Spencer and Robertson, 2002, p. 12)

Roach *et al.* (2012) examined sleep/wake behaviour and fatigue of short-haul pilots with duty cycles beginning between 04:00 and 10:00. Their results (summarized in Table 6) suggest that start times between 04:00 and 05:00 restricted pilots’ sleep time to 5.5 hours and led to them reporting fatigue levels of between 3 (“okay”) and 4 (“a little tired”) on a 7-point fatigue scale (see Figure 8) (Roach *et al.*, 2012). However, where duties commenced later (between 09:00 and 10:00) pilots obtained an average of 6.7 hours of sleep and reported lower fatigue levels between 2 (“very lively”) and 3 (“okay”) on the fatigue scale (Roach *et al.*, 2012).

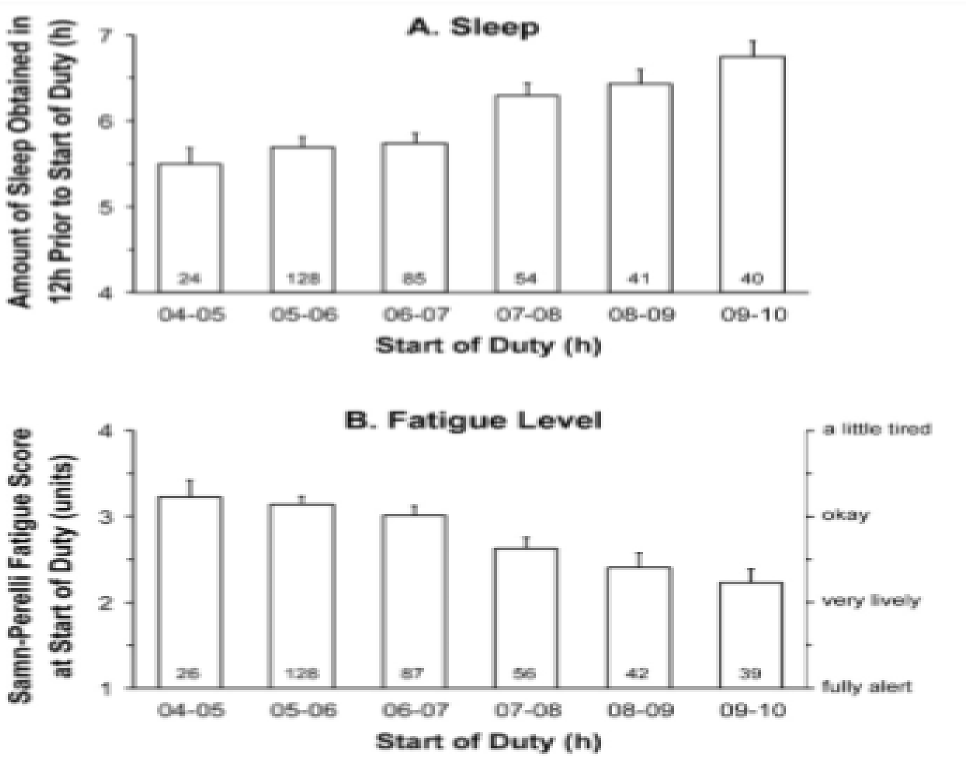
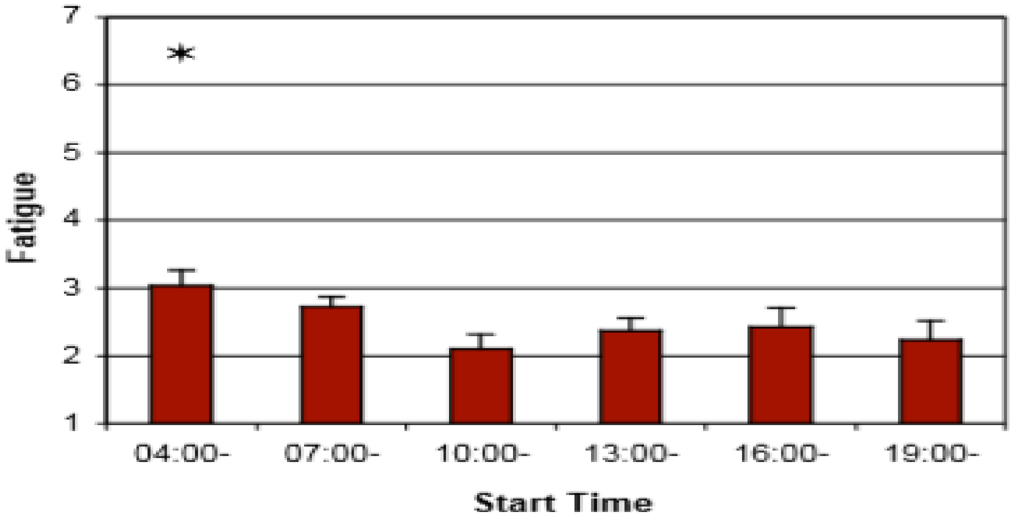


**Fig. 3.** The effects of duty start time on the amount of sleep obtained prior to duty (panel A) and self-rated fatigue at the start of duty (panel B). Data are presented as mean (±standard error). Numbers at base of bars represent *n* (i.e. number of observations).

**Figure 8:** Average amount of sleep and fatigue prior to the start of duty (taken from Roach *et al.*, 2012, p. 25).

Loh (2004) presented findings similar to those of Spencer and Robertson (2002) and Roach *et al*. (2012) with respect to the link between fatigue levels and duty start times (these are summarized in Table 6) there was a significant main effect ($p < 0.001$). Loh's study noted that early morning start times were associated with higher fatigue levels than later start times. A factorial ANCOVA was used to determine whether start times contributed significantly to fatigue. This statistical analysis indicated that fatigue varied significantly throughout the day in response to start times ($p < 0.05$). Also, according to post-hoc comparisons, fatigue levels were significantly higher where duties started between 04:00 and 07:00 than where they started between 10:00 and 13:00 ($p = 0.04$) (see Figure 9).



✶ Indicates fatigue significantly greater than start times 10:00–13:00

**Figure 9:** The effect of duty start times (DST) on fatigue. Fatigue ratings were based on the Samn-Perelli 7-point fatigue scale 1 = “Fully alert, wide awake”; 2 = “Very; lively, responsive, but not at peak”; 3 = “Okay, somewhat fresh”; 4 = “A little tired, less than fresh”; 5 = “Moderately tired, let down”; 6 = “Extremely tired, very difficult to concentrate”; 7 = “Completely exhausted, unable to function effectively” (taken from Loh, 2004, p. 106).

Overall, early start times have been shown to pose problems to aviation safety. In fact, Alcéu (2015) proposes that the circadian disruption associated with a start time of 06:00 could increase safety risks by up to 50%. To compensate for the reduced number of available sleeping hours due to early wake-ups, one would have to fully adjust their sleep timing in order to obtain their required eight hours (Roach *et al.*, 2012). Indeed, it is suggested that crewmembers should go to bed earlier (Diken, 2011; Roach *et al.*, 2012;). However, some pilots find it difficult to do this for many reasons such as missing out on spending time with friends and family, and difficulty falling asleep due to physiological reasons (Roach *et al.*, 2012). If their hours of wakefulness have not been sufficient to build-up sleep pressure, then pilots will struggle to fall asleep earlier than their usual bedtime (Gander *et al.*, 1998). People are physiologically unable to fall asleep earlier because the body clock has a natural tendency to lengthen days rather than shorten them (Co *et al.*, 1999; Diken, 2011). The longer the period of wakefulness, the stronger the homeostatic pressure/drive to sleep (Gander *et al.*, 1998; Co *et al.*, 1999).

Short-haul crewmembers may also be required to work continuous night shifts, where they are required to work in the evening, seven days per week (Co *et al.*, 1999). Such scheduling has been shown to induce sleep loss and increase fatigue levels as pilots are booked to fly and work during times when they would normally be asleep (Co *et al.*, 1999; Dinges *et al.*, 1996). Despite there, theoretically, being an average of 8.3 hours available for sleep during the day for these pilots, their duty schedules were shown to severely limit the amount of sleep they obtained in reality (Co *et al.*, 1999). In fact, it was found that pilots obtain an average of only 3.3 hours of sleep per day during their night shift periods because they find it difficult to sleep during the day (Co *et al.*, 1999). This difficulty is due to the circadian signal to be awake during the day, which prevents them from obtaining the normal amount of sleep time required by an adult (Co *et al.*, 1999). In reality, what often happens is that pilots find it difficult to sleep during the day, and hence remain awake for the entire day, resulting in extended periods of continuous wakefulness before their night shifts (FAA, 2010; Salas and Maurino, 2010). Ultimately, disrupted sleep patterns will lead to elevated fatigue levels (Federal Aviation Administration, 2010).

Schedules that involve early starts and late finishes not only lead to underlying sleep and circadian effects, but also result in long working hours during a duty day. Indeed, crewmembers required to report early for duty have been shown to experience longer duty days than may be acknowledged (Bourgeois-Bougrine *et al.*, 2003a). This leads to increased workload and high fatigue levels by the end of the duty period (Bourgeois-Bougrine *et al.* 2003a). Similarly, Powell *et al.* (2008), found that scheduling factors such as the length and timing of duty periods impacted significantly on pilots' fatigue levels ($p < 0.001$) (see Table 6). Duties starting and ending in the early hours of the morning (between 03:00 and 06:00) were associated with the highest fatigue levels (Powell *et al.*, 2008). The lowest fatigue levels were recorded where duties started and ended between 16:00 and 19:00 (Powell *et al.*, 2008). Thus, it seems clear that fatigue levels are impacted by the length of a pilot's working day as well as the time of day at which work occurs (Powell *et al.*, 2008). Long duty days and short night layovers reduce the amount of sleep obtained by crewmembers which can hinder their alertness and performance on duty (Gander *et al.*, 1998).

**Table 6:** Summary of studies focusing on the effects of scheduling on sleep, working hours and fatigue.

| AUTHOR | AIM OF STUDY | STUDY DESIGN AND DATA COLLECTION METHODS | SAMPLE | RESULTS |
|---|---|---|---|---|
| Bourgeois-Bougrine *et al.,* 2003b | To clarify what fatigue means to short-haul and long-haul pilots, respectively | Questionnaires distributed to pilots through four airlines. | 3,436 questionnaires distributed; 739 (21.5%) returned | With respect to short-haul pilots:<br>• 41% attributed fatigue to successive early wake-ups;<br>• 76% reported experiencing acute fatigue (scoring high and very high on a 5-point Likert scale) due to successive early starts and night flights;<br>• 53.8% of pilots attributed fatigue (rated as high or very high) to workload;<br>• 49% had reported their own fatigue; they had also reported a reduction in their own concentration levels, attention, and alertness. |
| Co *et al.*, 2010 | To identify operational factors that may affect fatigue during regional airline operations | Retrospective survey comprising 199-questions distributed to 26 different regional flight crews. | 1.424 completed surveys (31%of the total administered) | Where crewmembers were scheduled for continuous overnight duties, they reported an average of 8.3 hours being availeble for sleep. However, they only obtained an average of<br>3.3 hours in reality (i.e. a four-hour sleep deficit). |
| Loh, 2004 | To conduct a systematic investigation into the effects of scheduling factors on the fatigue and sleep patterns of short-haul pilots in Australia; to investigate the sensitivity of a brief performance test designed as a tool for measuring fatigue during flight. | Crewmembers from Ouantas airlines (B767 and B737 pilots) recruited;<br>Information from activity monitors and sleep/duty diaries reported via questionnaires over a 15-day period. | 21 Qantas B767 flight crews operating short-haul routes | With respect to pre-duty fatigue levels:<br>• Early start times (04:00 to 07:00) associated with higher fatigue levels (average of 3, i.e. "okay");<br>• Later start times (10:00 to 13:00) associated with lower fatigue levels (average of 2, i.e. "very lively"). |
| Powell *et al.*, 2007 | To investigate how duty length, number of sectors, time of day, and departure point affect fatigue levels in short-haul operations. | Pilots undertaking short-haul (Boeing 737) operations in New Zealand completed | 1370 completed, suitable questionnaires (67% of those administered) | • Sleep duration reduced with successive early wake-ups (early duty starts) and late finishes;<br>• Fatigue levels of 4.2 to 4.5 (i.e. "a little tired") where duties commenced at 07:00; |

| | | | | |
|---|---|---|---|---|
| | | Samn-Perelli fatigue ratings prior to descent for every scheduled short-haul duty over a 12-week period. | | Fatigue levels of 4.5 (“a little tired”) to 5.0(“moderately tired”) where duties commenced between 16:00 and 22:00. |
| Powell *et al.*, 2008 | To investigate the roles of scheduling factors (i.e. duty period length and timing, and number of consecutive flight sectors) on pre-descent pilot fatigue in two-pilot regional operations. | Pilots flying two-pilot operations of 3-12 hours completed Samn-Perelli fatigue ratings prior to descent for every scheduled duty over a 12-week period | 3023 completed, suitable questionnaires representing both single-sector duties (26%), and double-sector duties (74%) | With respect to duty starting times:<br>• 17% between 05:00 and 06:00;<br>• 24 % between 14:00 and 16:00;<br>• 9% between 20:00 and 22:00<br>With respect to fatigue:<br>• Highest in the early hours of the morning (WOCL);<br>• Lowest in the early evening. |
| Roach *et al.*, 2012 | To examine the impact of early start times on the amount of sleep obtained prior to duty, and on fatigue levels at the start of duty in short-haul airline pilots. | Participants reported data from their own duty and sleep diaries and wrist activity monitors (sleep-wake behaviour) via questionnaires. | 70 short-haul pilots (38 captains, 29 first officers, and three second officers) from major commercial airlines. | • The amount of sleep obtained in the 12 hours prior to duty was low (averaging only 5.5 hours) when duties commenced between 04:00 and 05:00;<br>• Where duties commenced later (between 09:00 and 10:00), more sleep (averaging 6.7 hours) was obtained prior to duty;<br>• Self-reported fatigue at the start of duty was highest where duties commenced between 04:00 and 05:00,and lowest where duties commenced between 09:00 and 10:00. |
| Spencer and Robertson, 2002 | To validate the SAFE (system for aircrew fatigue evaluation) computer program for short-haul operations. | Pilots based at London Heathrow and East Midlands airports completed duty and sleep diaries over 28 days. Fatigue levels were assessed at the end of their flights using the 7-point Samn-Perelli scale. | 157 diaries (from 78 captains and 79 co-pilots) were returned with a 33% response rate. | With respect to average amount of sleep obtained by pilots:<br>• 5.88 hours obtained where duties commenced between 05:00 and 06:00;<br>• 6.90 hours obtained where duties commenced between 07:00 and 08:00 in the morning;<br>• 7.83 hours obtained where duties commenced between 10:00 and 11:00.<br>• Fatigue levels higher (by 0.22) where duties started between 06:00 and 07:00. |

*B2) Number of Flight Segments and Consecutive Workdays*

Short-haul pilots operate two to six flights (sectors) per day on average, working for an average of four to five consecutive days followed by two days off (Vejvoda *et al.*, 2014). Flight time per sector typically ranges from 30-minutes to three hours (Vejvoda *et al.*, 2014). Not much is known about the link between fatigue and the number of segments flown per day. There is no evidence in published studies of short-haul pilots attributing their fatigue levels to the number of sectors flown per day during a duty period. However, in a study by Bourgeois-Bougrine *et al.* (2003a) the highest fatigue levels were associated with schedules that involved four to five consecutive working days containing four to five flight sectors per day. The kind of demands implied by such a schedule are different from those associated with long-haul flights (Rosekind *et al.*, 2000) and can actually lead to more fatigue effects (Powell *et al.*, 2007). According to Marqueze *et al.* (2017), short-haul pilots should have a two-day recovery period after working consecutive days. However, this does not generally happen. It was found that pilots usually only get one day off as the two days are taken to include the twelve hours directly following the end of their previous duty, followed by 24 hours off (Marqueze *et al.*, 2017). This restricted recovery time is an issue, especially where pilots commence their duties in the early morning (Marqueze *et al.*, 2017).

Short-haul pilots identify schedules containing four to five flight sectors per day as very tiring (FAA, 2010). According to Powell *et al.* (2008), multi-sector flights certainly contribute to short-haul pilot fatigue. Their findings show that pilot fatigue levels increased by 0.56 times when pilots flew two consecutive sectors compared to when they flew a single sector (Powell *et al.*, 2008). Similarly, Spencer and Robertson (2000; 2002) found that workload levels were linked to the number of sectors flown. According to Spencer and Robertson (2002), fatigue levels increased over a five-sector flight duty period, however there was no significance ($P < 0.001$) (see Figure 10). Powell *et al.* (2007) found similar results and highlighted the effects of multi-sector duties on fatigue and concluded that each additional sector per day was associated with an increase in the 7-point Samn-Perelli fatigue rating. Fatigue levels increased by an average of 0.38 on the 7-point Samn-Perelli scale with each additional sector (see Figure 11). This is because a pilot's workload is at its highest during take-off and landing. Thus, multiple consecutive flights considerably increase a pilot’s workload (Harris *et al.*, 2001).

**Figure 10:** The effect of the number of consecutive flight sectors on fatigue levels. Fatigue ratings were based on the Samn-Perelli 7-point fatigue scale 1 = “Fully alert, wide awake”; 2 = “Very; lively, responsive, but not at peak”; 3 = “Okay, somewhat fresh”; 4 = “A little tired, less than fresh”; 5 = “Moderately tired, let down”; 6 = “Extremely tired, very difficult to concentrate”; 7 = “Completely exhausted, unable to function effectively” ( taken from Spencer and Robertson, 2002, p. 11)

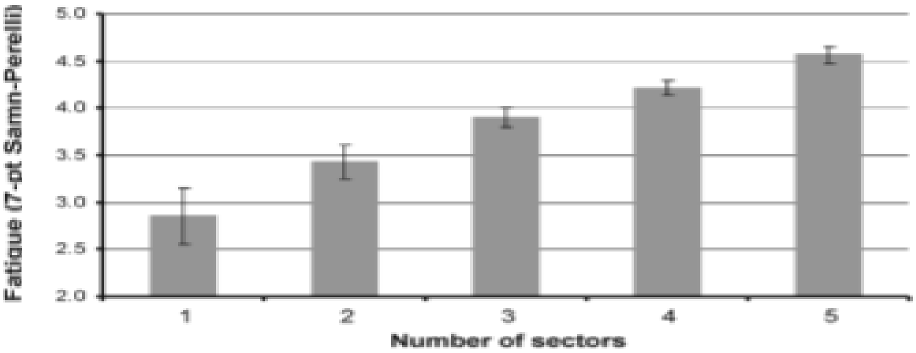


**Figure 11:** The effect of the number of consecutive flight sectors on fatigue levels. Fatigue ratings were based on the Samn-Perelli 7-point fatigue scale 1 = “Fully alert, wide awake”; 2 = “Very; lively, responsive, but not at peak”; 3 = “Okay, somewhat fresh”; 4 = “A little tired, less than fresh”; 5 = “Moderately tired, let down”; 6 = “Extremely tired, very difficult to concentrate”; 7 = “Completely exhausted, unable to function effectively” (taken from Powell *et al.*, 2007, p. 700).

Schedules involving four to six flight sectors per day can result in high workload and can, in turn, affect fatigue levels (Alcéu, 2015). In a study by Co *et al.* (1999), a regional crew considered multiple flight segments as number two on a list of the ten most fatigue-inducing issues with respect to their work. The study also emphasized that multiple take-offs increase the length of the working day (Co *et al.*, 1999). Bourgeois-

Bougrine *et al.* (2003b) report that duty periods more than ten hours long containing four sectors per day, over four consecutive days, made pilots feel fatigued post-flight. According to Bourgeois-Bougrine *et al.* (2003b), fatigue levels increased by 0.48 on the visual analogue scale of fatigue for every additional sector. Similarly, Powell *et al.* (2007) report a 0.38 increase on the 7-point Samn-Perelli fatigue scale with each additional flight sector. Yuliawati *et al.* (2015) report similar findings and go so far as to conclude that the dominant factor influencing pilot fatigue in short-haul operations is the number of flight sectors assigned per duty period. They found that every additional sector significantly increased fatigue level by 0.371 on the fatigue severity scale (FSS) (p=0.000). The FSS is a nine-item instrument used to evaluate the impact of fatigue in individuals (Yuliawati *et al.* 2015). The instrument contains nine statements to explore the severity of fatigue symptoms. Each statement must be read, and participants are required to circle a number from 1 (strongly disagree) to 7 (strongly agree) (Yuliawati *et al.* 2015). The scoring is done by calculating the average response to the questions (Yuliawati *et al.* 2015).

It has been recognized that flying multiple segments can result in cumulative fatiguing effects in pilots, leading to impairment of cognitive functioning which can ultimately result in accidents and incidents (Yuliawati *et al.*, 2015). In addition, Howitt *et al.* (1978) found that fatigue could be caused by behavioural patterns which arise when numerous flights are executed on the same day. These include boredom and lack of concern about maintaining precision on instruments in the cockpit.

Aside from the fatigue-inducing effects of multiple flight sectors themselves, pilots are also challenged by the shorter turnaround periods associated with these consecutive flights. Turnover period refers to the time when an aircraft is on the ground between flights to get passengers off and on the plane (Jackson and Earl, 2006). This period is usually about 15 to 30 minutes in length (Co *et al.*, 1999). Short turnaround times between flights mean more segments in a duty day. From the pilot's perspective this also means more take-offs and landings and other additional time constraints (FAA, 2010; Jackson and Earl, 2006). Consequences of this include increased pilot workloads, increased duty-time per day, longer working hours, and reduced rest periods (Co *et al.*, 1999; Jackson and Earl, 2006; Federal Aviation Administration, 2010).

### *B3) Standby Duty*

Another major issue in short-haul operations is that crewmembers are routinely placed on standby duty (also known as reserve), which is associated with long waking hours, reduced sleep, and increased fatigue (Civil Aviation Authority, 2004; Co *et al.*, 1999). When pilots are on standby duty, they may have to report for duty as per request by the service provider even when they are scheduled to be off duty (Civil Aviation Authority, 2004; Co *et al.*, 1999; ICAO, 2012). This unpredictability in a crewmember's work schedule can lead to sleep loss (Co *et al.*, 1999; Ziebertz *et al.* 2015). Co *et al.* (1999) found that regional crewmembers on standby obtained on average of 5.6 hours of sleep per night, which is more than two hours less than the required amount, due to unpredictability. David-Cooper (2018) pointed out in her study (which examined the effectiveness of flight and duty time regulations for professional pilots in Canada) that pilots often experience fatigue after being on standby duty. This is because pilots often stay awake for long periods of time during the day, sometimes even up to 24 hours after being called to work (David-Cooper, 2018). Co *et al.* (1999) highlighted that, whilst on reserve/standby, duty pilots tended to stay awake for a consecutive 16-hour period, and then again for a further 14 hours after they had been called for duty. Furthermore, pilots often stay awake for long hours even when their standby duty only commences in the afternoon or evening (David-Cooper, 2018). This is because they generally wake up in the morning due to family responsibilities, and then battle to fall asleep again because their body is physiologically programmed (by their natural sleep cycle) to be awake during the morning (David-Cooper, 2018).

### *B4) Flight Duty Period, Long Duty Hours, and Irregular/Extended Working Hours*

Over the last three decades, average working hours have increased globally (Desmond *et al.*, 2012). This has led to concerns about working hours becoming excessive (Desmond *et al.*, 2012). Industry surveys have reported an increase of about 10% in overtime work in the transportation industry alone (Desmond *et al.*, 2012). In most aviation industries, whether in Europe, America or South Africa, there are pressures to increase aircraft utilization, to increase what is expected of employees (in terms of flexibility and working hours, amongst other things), to compete with other airline companies, and to reduce the number of employees (Walton, 2003). Many companies prize flexible rosters, leading to crewmembers having to work irregular schedules that include with more work hours and less rest periods than before (Walton, 2003). This has proven to be an influential factor in short-haul operations (Walton, 2003).

Studies suggest that unpredictable working hours and long duty periods are among the top causes of pilot fatigue (Caldwell, 2005; Caldwell *et al.*, 2009; Yang, 2014). The current Federal Aviation Regulations (FARs) duty/rest recommendations for unaugmented (domestic) operations (FAR 121.47) suggest that short-haul operations involving either multiple flight segments or day and night flying should not entail more than ten to 16 duty hours in any 24-hour period, with each flight duty period being limited to eight to ten hours (Caldwell, 2005; Dinges *et al.*, 1996; FAA, 2010; Honn *et al.*, 2016). The duty period is defined as the time from when a crewmember reports for duty until the time that crewmember is freed of all duties after their final flight segment (Dinges *et al.*, 1996). The flight duty period is the time period from when crewmembers report for a duty period which includes one or more flights, and ends when the last segment is completed and the aircraft comes to rest (Dinges *et al.*, 1996). The flight duty period includes both the necessary pre-flight activities as well as the actual flight time (Dinges *et al.*, 1996; Hiatt *et al.*, 2015). The flight time is defined as the time from when an aircraft takes off during the first flight segment until the end of the last segment when the aircraft comes to rest (Hiatt *et al.*, 2015).

The short-haul operational environment is often characterized by daytime flying periods of 0.5-3 hours, and duty periods of approximately ten to 16 hours per day (Vejvoda *et al.*, 2014). Long duty periods mean increased workloads for pilots (Alcéu, 2015). According to Petrie *et al.* (2004), an estimated 64% of short-haul pilots experience fatigue regularly and have reported being fatigued at least once a week due to their working hours. Caldwell (2005) reveals that 71% of pilots have admitted to dozing off at least once during a flight which indicate that fatigue is present and thus could lead to concerns around safety of flight. The fatigue impact of long hours is further compounded by the fact that there is then less time available for rest and sleep outside of duty periods (Gander *et al.*, 1998). In a survey administered by Co *et al.* (1999), the most frequently cited cause of fatigue, from short-haul crewmembers' point of view, was long duty periods. Regional crewmembers surveyed revealed that their average flight duty period was 11.3 hours, to which they attributed their relatively high fatigue levels (Co *et al.*, 1999). According to Spencer and Robertson (2002), fatigue levels (on the 7-point fatigue scale) increased as duty periods lengthened. The study highlighted that during the first five hours of work, fatigue levels increased linearly by an average of 0.08 per hour; however, after another five hours they began to increase by about 0.14 per hour (see Figure 12). Powell *et al*. (2007) recounted similar findings in their study on the influence of duty duration (h) on overall fatigue levels; they reported an increase in fatigue levels associated with a positive linear function of duty length time (see Figure 13).

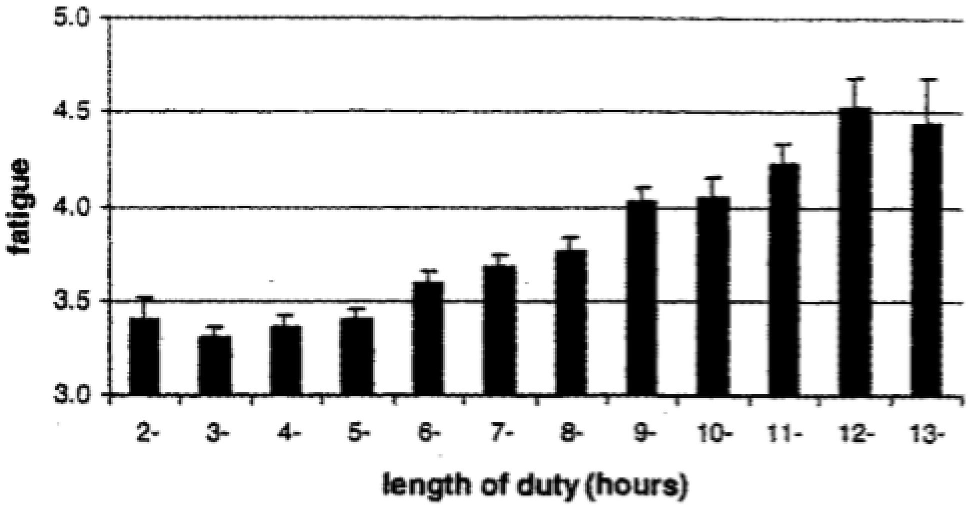


*Figure 3-9 The effect of length of duty on fatigue*

**Figure 12:** The effects of duty duration on fatigue. Fatigue ratings were based on the Samn-Perelli 7-point fatigue scale 1 = “Fully alert, wide awake”; 2 = “Very; lively, responsive, but not at peak”; 3 = “Okay, somewhat fresh”; 4 = “A little tired, less than fresh”; 5 = “Moderately tired, let down”; 6 = “Extremely tired, very difficult to concentrate”; 7 = “Completely exhausted, unable to function effectively” (taken from Spencer and Robertson, 2002, p. 11)

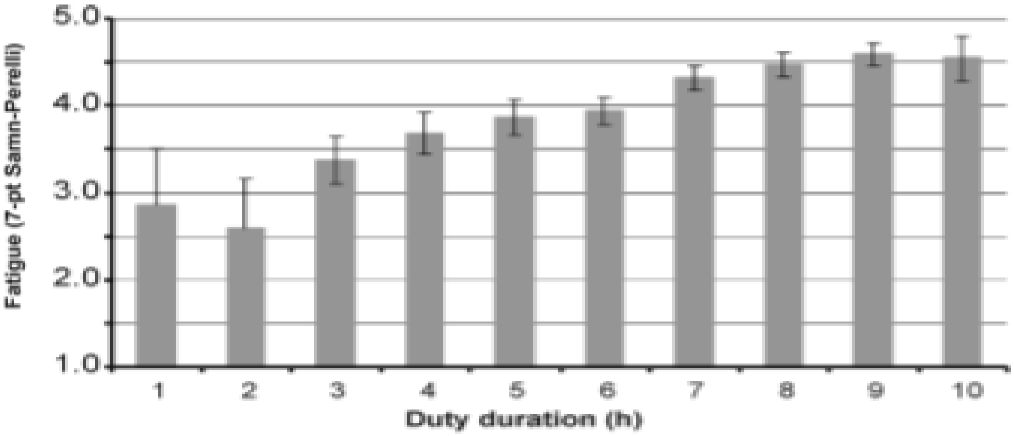


**Figure 13:** The effect of duty duration on fatigue levels. Fatigue ratings were based on the Samn-Perelli 7-point fatigue scale 1 = “Fully alert, wide awake”; 2 = “Very; lively, responsive, but not at peak”; 3 = “Okay, somewhat fresh”; 4 = “A little tired, less than fresh”; 5 = “Moderately tired, let down”; 6 = “Extremely tired, very difficult to concentrate”; 7 = “Completely exhausted, unable to function effectively” (taken from Powell *et al.*, 2007, p. 700)

Short-haul pilots are frequently scheduled to work into their discretion period, which is defined as an extended period of time needed to complete a duty, often due to unforeseen circumstances such as severe weather, unanticipated technical delays, equipment malfunction, aircraft delays due to passenger delays, delays due to loading/unloading of cargo, or medical reasons (Caldwell, 2005; Chang, 2002; Bourgeois-Bougrine *et al.* 2003a; Jackson and Earl, 2006; Powell *et al.*, 2008;). Working into discretion time leads to extended times of wakefulness for pilots, and especially for those with early shifts who can end up working unplanned hours late into the night (Alcéu, 2015). An extended flight duty period is limited to a maximum of twelve hours (Dinges *et al.*, 1996). This limit is based on scientific findings from a variety of sources (Dinges *et al.*, 1996; FAA, 2010; Gander *et al.*, 1998; Levo, 2016). The FARs (FAR 121.41), indicate that any extension of flight duty to twelve hours should be compensated for during off-duty periods, i.e. the subsequent off-duty period should be increased to the degree that the previous flight duty period was increased (FAA, 2010). Twelve hours of flight duty can result in cumulative fatigue effects and impaired performance levels (Dinges *et al.*, 1996; Levo, 2016). However, an extended twelve-hour duty period needn’t imply a twelve-hour flight period. Tasks assigned during discretion time may also include non-flying tasks including office-based work (i.e. pre-flight paperwork, report writing) (Alcéu, 2015). Any extended period of wakefulness or demand for continuous performance or vigilance can induce fatigue (Dinges *et al.*, 1996).

*B5) Regulations*

Various operational effects and scheduling demands are driven or influenced by flight time and duty regulations; each airline follows their own specific regulations which exist (in theory) to mitigate against fatigue and ensure adequate rest before the start of duty. The purpose of the regulations is to protect aviation personnel and to enable them to perform their duties effectively and safely (Civil Aviation Authority, 2004). The regulations comprise a system of prescriptive limits (min/max) which indicate the number of hours pilots can work and the number of sectors they can fly (Steiner *et al*., 2012). However, these regulations have often not kept track with technological advances and the increased demands of 24-hour aviation operations (Co *et al.*, 1999; Steiner *et al*., 2012). According to Caldwell *et al.* (2009), the root of the problem is that prescribed regulations concerning flight time, duty hours and crew rest in the modern aviation world do not accord with the science of fatigue, high workload, sleep and circadian processes. Therefore sleep-related effects and workload issues are particularly problematic in the short-haul context. This was mainly because the regulations currently existing were designed many years ago which have been acknowledged by the National Transport Safety Board (NTSB) (Co *et al.*, 1999; Steiner *et al*., 2012). Historically, the main focus of regulations has been on the length of the duty period, which was thought to be the main determinant of fatigue when the regulations were first implemented in the 1930s (Co *et al.*, 1999; Steiner *et al*., 2012). Caldwell *et al.* (2009) emphasised that since their initial implementation, few modifications have been made to the regulations, and those changes that have been made have not been related to the science of fatigue and sleep. The current European Flight Time Limitations (FTL) do not bring sleep science and the importance of sleep opportunity and quality into consideration, and they also do not acknowledge the contributions made to fatigue by having more flexible, unpredictable shift patterns and workload on a given day (Steiner *et al.*, 2012).Therefore, current definitions associated with these set limits are thus not up to date with the scientific knowledge.

By way of example, consider the definitions of “rest period” (off-duty period), “local night”, and “window of circadian low” (WOCL). According to the Federal Aviation

Regulations (FAR 121.47) and the South African Civil Aviation Authority (SACAA), the minimum rest period (off duty period) is defined as a period of eight to ten hours prior to start of duty the next day (Caldwell *et al.*, 2009; Gander *et al.*, 1998, SACAA, 2013). The off-duty period is defined as a period of uninterrupted time (within any 24-hour period) in which crewmembers are free of all duties (Dinges *et al.*, 1996; Gander *et al*., 1998). Local night is defined as a period of eight hours falling between 22:00 and 06:00 (SACAA, 2013). Crewmembers will often end their duty at the beginning of local night (22:00), and current definitions would allow the start of their next duty to be scheduled as early as 04:00 the following morning, exactly eight hours later and in the middle of the WOCL (which is defined as the period between 02:00 and 06:00, when pilot alertness is lowest and pilots are most susceptible to circadian-induced fatigue) (Caldwell and Caldwell, 2016). Overall this means that pilots would report for duty fatigued, and would be expected to maintain wakefulness in direct opposition to inbuilt physiological rhythms (Caldwell and Caldwell, 2016; Dinges *et al.*, 1996). Further it is important to note that this period will necessarily include a pilot’s commute between home and work, which could easily take an hour in each direction, totalling two hours per day (Caldwell *et al.*, 2009; Co *et al.*, 1999). The rest period will also include mealtimes, time for ablutions, and time to attend to other physiological needs and family commitments (Co *et al.*, 1999). Fitting all of these necessary activities in, together with having to wake up earlier due to early start times, reduce the time available for rest, making it impossible for the pilot to obtain the necessary eight hours of sleep (Alcéu, 2015; Caldwell *et al.*, 2009; Co *et al.*, 1999; Diken, 2011; Techera *et al*., 2016). Reducing sleep time by just one hour per night can increase daytime sleepiness; a reduction by two hours can cause acute sleep loss and induce fatigue which can ultimately lead to diminished alertness and performance levels (Dinges *et al.*, 1996; Gander *et al.*, 1998). It is thus clear how existing regulations fail to safeguard crewmembers against fatigue. According to Wegmann *et al.* (1986), sleep between 02:00 and 06:00 is considered important for the maintenance of alertness and optimal performance during the day. Regulations should be amended to reflect this, which would improve not just the wellbeing of crewmembers but also the safety margins in aviation (Dinges *et al.*, 1996). According to Avers and Johnson (2011), there is a need for flight, duty and rest rule-makers in the aviation industry to develop science-based recommendations.

Further it has been recognized that the prescriptive limits have been set as legal targets not guidelines, but they offer no guarantee against human fatigue (Dijkshoorn, 2008). According to Jackson and Earl (2006), some airlines have actually developed a culture of flying and working as close to the legal maximum number of hours as possible. It has been recognised by Gislason *et al.* (2017) that pilots flying close to the prescribed legal limits for sustained periods are particularly prone to experience fatigue.

### *B6) Crew Size*

Short-haul flights are usually carried out by two pilots and do not have the opportunity for in-flight rest in comparison to long-haul operations (Powell *et al.*, 2007). Additional flight crew is highly recommended as it reduces each pilot's time at the controls and provides each with opportunities for sleep or rest, thus slowing the rate of fatigue level rise from accumulated cockpit workload (Roach *et al.*, 2012). Short-haul pilots do not have extra crewmembers with whom to share the cockpit workload (Roach *et al.*, 2012). They do not have an opportunity to rest or sleep in the cockpit at any stage during a flight (Jackson and Earl, 2006; Roach *et al.*, 2012). Co-pilots assist with flight-related tasks (Diken, 2011). Eriksen and Akerstedt (2006) conducted a fatigue study on pilots who were members of two- and three-pilot crews, respectively. They concluded that reducing crew size by just one member induced a discernible increase in fatigue levels post-flight. This effect was ascribed to increased degrees of sleepiness and workload (Eriksen and Akerstedt, 2006). According to Rogers *et al.* (1995), aircraft with only two seats are associated with elevated pilot workloads and hence elevated fatigue levels.

### C) Environmental Aspects

Work settings for pilots in short-haul operations are typically characterized by small, pressurized cockpit environments (Dijkshoorn, 2008). These are associated with movement restriction, very low humidity, low air pressure, vibrations, high noise levels and low light intensity (Mohler, 1966; Strauss, 2006). Published studies suggest that these aspects of pilots' physical work environments can influence their susceptibility to fatigue (Loh, 2004; Mohler, 1966; Orlady and Orlady, 2002). In fact, environmental characteristics may influence cognitive fatigue directly by increasing pilot workload (Vejvoda *et al.*, 2014). Situations which require pilots to sustain high levels of attentiveness can be made more demanding by the abovementioned cockpit conditions which can induce cognitive fatigue.

There is limited evidence to suggest that environmental factors contribute to fatigue in short-haul operations (Loh, 2004). Amongst the few studies that have shown a correlation is a study by Loh (2004). In that study, crew responses to a questionnaire revealed that high ambient temperatures and noise in the cockpit during regional flight operations were considered by pilots to influence the fatigue levels of the cockpit crew (Loh, 2004).

Pilots in cockpits are subjected to continuous noise throughout their workday (Strauss, 2006). Aircraft noise is generated by its engines, transmission systems, hydraulic and electrical actuators, propellers, cockpit advisory and alert systems, communication equipment, cockpit conditioning systems, and pressurization systems (Dikjshoorn, 2008). Loud noise is associated with the inability to hear others, the need to speak louder, and the need to listen more carefully, all of which can induce high cognitive workloads and induce fatigue Dijkshoorn (2008). Noise has been found to cause fatigue through overstimulation (Landström and Löfstedt, 1987). For example, Dijkshoorn (2008) found that exposure to continuous noise leads to mental fatigue which can reduce performance levels and increase irritability. Thus, noise is not tolerated by the body for long periods of time (Novacek, 2003).

Cockpit lighting can further exacerbate pilot fatigue (Novacek, 2003). Techera *et al.* (2016) found a positive correlation between poor lighting and fatigue. Pilots exposed to either low- or high light intensities find it difficult to focus and concentrate on instruments and controls in the cockpit, which can be mentally draining and lead to fatigue (Novacek, 2003).

A further environmental factor pertaining to pilot fatigue is the fact that pilots work in a confined space and must remain seated in a fixed body position throughout their flight duties (Dijkshoorn, 2008). Flying multiple segments per day with restricted movement can pose several physical demands on the body (Dikjshoorn, 2008). However, the effects of this environmental constraint are far more prevalent in long-haul operations than in short-haul ones (Broo, 2013). Long haul pilots have to endure restrictive cockpit sitting for lengthy periods (Broo, 2013). However, due to the increasingly short turnaround periods in short-haul operations, regional pilots are subjected to more sitting than they used to be (Co *et al.*, 1999; FAA, 2010; Jackson and Earl, 2006).

### D) Technology and Tools

Since the early years of aviation, operational designs and technology have evolved and improved steadily over time and continue to do so (Salas and Maurino, 2010). Perhaps ironically, this advancement has exacerbated overall pilot fatigue by facilitating longer and more frequent flights, and by requiring increased attention from operators to manage more sophisticated equipment (Salas and Maurino, 2010).

Highly automated systems have emerged which have altered the way in which pilots and other crewmembers interact with aircraft systems (Chialastri, 2012). Automation in short-haul operations has relieved pilots of numerous manual control tasks (Harris *et al.*, 2001). Indeed, highly automated systems require minimal human interaction with aviation systems. However, they require more passive vigilance and sustained attention on the part of flight crews (Salas and Maurino, 2010). Although technological advancement has been found to diminish fatigue associated with physically demanding tasks such as flying and simulated activity, it has been argued that, overall, workload and fatigue can actually be intensified with automation (Loh, 2004). According to Harris *et al.* (2001) aircraft automation has increased the number of cognitively demanding supervisory and monitoring tasks assigned to pilots. Fatigue arises due to the number of visual displays and computerized systems that pilots are required to monitor in the cockpit (Harris *et al.*, 2001). Interestingly, automation can also lead to pilots feeling “underloaded” in the cockpit (Matthews and Hancock, 2017). This can lead to the boredom sometimes experienced by pilots. According to IATA (2015), boredom and monotonous tasks have been associated with a special type of fatigue that is induced by a reduction in brain activity. Thus, not only can automated systems induce pilot workload and fatigue, but they can also affect a pilot's performance capabilities (IATA, 2015; Caldwell *et al.*, 2009) by leading to reduced situational awareness in the cockpit, decreased piloting skills over time, a lack of practice with respect to manual flying tasks, and automation complacency (Chialastri, 2012). These performance deficits diminish the abilities of pilots/co-pilots to function in the event of failed automated systems (Chialastri, 2012). This can, of course, pose a threat to overall aviation safety (Chialastri, 2012).

Despite technology evolving throughout the years it has been emphasised that certain short-haul flight operations entail dealing with airports that have limited infrastructure and ill-equipped aircraft compared to those used by major airlines (Co *et al.*, 1999; Vejvoda *et al.*, 2014). Under such conditions, pilots would have to take greater responsibility for operating the aircraft, make a lot more critical decisions, and perform more manual tasks, all with less control over environmental factors on the fight deck (Co *et al.*, 1999). Such a situation could cause increased pilot workload and stress levels, both of which can ultimately lead to amplified fatigue levels (Vejvoda *et al.*, 2014). However, other short-haul operations are characterized by having advanced technology in the form of computer and display instrumentation in the cockpit which has been found to heighten cognitive overload (Salas and Maurino, 2010). Thus, it seems that both highly advanced and relatively rudimentary tools and technology can contribute to pilot workload and thus lead to fatigue in their own ways.

### E) Individual/ Non-Work-Related Factors

A pilot's age has a bearing on their fatigue levels. Ageing brings about a gradual decline in habitual nightly sleep (Miles and Dement, 1980). According to Mikkelsen (1998), age is correlated with increased night awakenings, a higher proportion of restless sleep, and a lower proportion of deep sleep. This is mainly because one's sleep cycle and sleep architecture change as one gets older (Stepnowsky and Ancoli-Israel, 2008). Changes incurred include reduced slow-wave sleep (SWS) (i.e. deep sleep), and increased time spent in lighter NREM (i.e. light sleep in stages one and two) (Caldwell and Caldwell, 2016). Crewmembers over 50 years of age are more susceptible to these effects (Mikkelsen, 1998). Insufficient sleep is invariably linked to increased fatigue (Mikkelsen, 1998; Miles and Dement, 1980). A sleep deficit leads to increased daytime fatigue (Miles and Dement, 1980). As individuals age there is a decline in their slow-wave activity (SWA) (Mander *et al.*, 2017). Slow-wave activity is directly linked to the homeostatic drive to sleep. The longer people stay awake, the greater their drive to sleep, and the higher their SWA during subsequent sleep (Mander *et al.*, 2017). As individuals age, the homeostatic build-up of sleep pressure is slower and weaker during the day than in younger adults. During the night an individual's homeostatic sleep drive is shallower, and there is a decline in relative amounts of SWA in older adults (Mander *et al.*, 2017).

An additional, individual-specific factor that affects sleep is the consumption of caffeine and alcohol (Gander *et al.*, 1998). Caffeine is known to induce daytime sleepiness if consumed prior to bedtime by disrupting the quality and quantity of the sleep that ensues (Gander *et al.*, 1998). The effects of pre-bedtime caffeine consumption include lighter sleep, longer sleep latency, and increased awakenings during the night (Gander *et al.*, 1998). Awakenings can be further increased for other reasons too, such as waking up to attend to family members, trips to the bathroom, random noise events, sub-optimal temperatures in the bedroom, and ruminations (Deros *et al.*, 2012). Alcohol consumption for relaxation after a duty period and prior to sleep could also jeopardize sleep quality (Gander *et al.*, 1998); alcohol can cause dose-dependent sleep changes such as difficulty to fall asleep, and more awakenings during the night (Dijkshoorn, 2008).

Over a number of days, obtaining less sleep than required can cause cumulative sleep debt and changes to important elements of sleep architecture which include deep sleep, fewer awakenings and shorter sleep latency (Dinges *et al.*, 1996; Gander *et al.*, 1998), which ultimately lead to fatigue (Gander *et al.*, 1998). Sleep loss is known to diminish physical coordination, decision-making abilities, alertness, vigilance, mental functioning and mood (Deros *et al.,* 2012).

Another factor that can impact on any individual pilot’s fatigue level is the relative healthiness of their lifestyle. Unhealthy nutritional factors combined with physical inactivity can reduce a person’s ability to deal with fatigue and can cause various health issues (Dijkshoorn, 2008). Having an overall healthy lifestyle is beneficial to human health and helpful in dealing with fatigue-inducing situations such as those encountered by pilots (Dijkshoorn, 2008). Pilots who are physically fit and exercise regularly can adapt well to shift work. Exercise also helps individuals re-establish their circadian rhythm after any disruptions (Ferrer *et al.*, 1995). Other individual-specific conditions that could exacerbate a pilot’s fatigue levels include medical disorders such as sleep apnea, cardiac disease anemia and others (Alcéu, 2015; Dijkshoorn, 2008).

With regards to an individual pilot’s relative work experience, Lee (2010) found that less experienced pilots experienced higher mental workloads than their more experienced counterparts, especially in pressurized scenarios (e.g. technical malfunctions or inclement weather conditions). Experienced pilots can cope well under such situations because they are more skilful. On the other hand, experienced pilots are generally assigned more duty hours and tasks less experienced pilots. Thus, they too are afflicted by high workloads and fatigue levels (Lee, 2010).

A pilot’s sleeping environment at home can either enhance or diminish their ability to sleep properly. According to Co *et al.* (1999), where study participants were asked to rate several factors that disrupted their sleep at home using a five-point scale (1-interferes, 3-no effect; 5-promotes). The four aspects which emerged as being most significant to the respondents were: heat (30%); random noise (21%); background lighting (17%); and high humidity (23%) for (Co *et al.,* 1999).

Stress is another individual-specific factor associated with fatigue. Short-haul piloting can be an extremely stressful job due to high workload, weighty responsibilities, and the need for a consistently high level of performance and safety (Stokes and Kite, 2017). Stress is associated with excessive workloads that lead to pilots becoming emotionally and mentally exhausted at the end of their working days (Lee, 2010). The three main types of stressors include physiological stressors, psychological stressors, and environmental stressors (Petrilli, 2007). In short-haul operational settings, pilots are subjected to environmental stressors such as unpleasant cockpit conditions (mentioned earlier) (Ashley, 2013). Some of the physiological stressors encountered by pilots include fatigue, poor physical condition, illness, anxiety, poor mood, and depression (Ashley, 2013). Psychological stressors experienced by pilots may include financial issues, bereavement, family problems, or poor interpersonal relations with their bosses (Ashley, 2013). High stress levels can impact on a pilot’s performance; they can narrow an individual's attention span and impair their decision-making abilities (Petrilli, 2007). Overall, stress can diminish a pilot’s ability to safely operate an aircraft (Lee, 2010).

### 4.2.4 Effects of Pilot Fatigue

Fatigue reduces a pilot’s ability to carry out normal functions (Alcéu, 2015). Physical and subjective manifestations of fatigue include reductions in vigilance and judgment, slowed reaction times, a general feeling of tiredness, nodding off unintentionally, lethargy (i.e. a lack of energy, feeling exhausted, and/or weariness), sleepiness and a lack of motivation when workload is low (Alcéu, 2015; Caldwell and Caldwell, 2016). On the other hand, mental manifestations of fatigue may include lack of concentration, periods of inattention, slow cognition, poor decisions, bad mood, a tendency to forget information, and difficulties memorising information (Caldwell and Caldwell, 2016).

Subjective fatigue experienced by pilots may decrease the quality of their communication and social interaction with other crewmembers and workgroups (FAA, 2010). This is a serious concern; the exchange of information between aviation crewmembers and workgroups is crucial in the bid to avoid error and to ensure that flight safety is maintained (FAA, 2010).

All of the different types of fatigue, as well as the feedback loops between them, stand to impair a pilot's overall ability to safely operate an aircraft and perform safety related tasks. The consequences of this could be deadly (Loh, 2004). International statistics reveal that pilot fatigue accounts for four to eight percent of all aviation mishaps (Caldwell, 2005; Caldwell and Caldwell, 2016). It has been recognised as a contributing factor to several aviation incidents and accidents worldwide (FAA, 2010).

There is little empirical evidence explicitly linking flight incidents/accidents to pilot fatigue in short-haul operations. According to Goode (2003), this is mainly because no fatigue-related tests have been conducted either before or after any reported accidents. Furthermore, the National Transportation Safety Board (NTSB) has been reluctant to ascribe accidents to pilot fatigue in report documents (Goode, 2003). However, one major aviation accidents (in commercial operations) reported by the NTSB where fatigue was a probable contributor or culprit include the Guantanamo Bay accident of 1993 (Goode, 2003; Rosekind *et al.*, 2002).

It is thought that the Guantanamo Bay accident was consequence of the flight crew having been on duty for 18 consecutive hours of which nine hours were flight time hours (Rosekind *et al.*, 2002). It was ultimately concluded that the pilots were fatigued, and that they were suffering from sleep loss and circadian disruption (Rosekind *et al.*, 2002). Their performance was detrimentally affected during a critical phase of flight (i.e. the approach phase) (Rosekind *et al.*, 2002).

Another fatigue-related accident reported by the NTSB was the collision of Korean Air Flight 801 (Boeing 747-300) into high-lying terrain in 1997 (Rosekind *et al.*, 2002). This crash resulted in 228 deaths, and captain's fatigue was identified as its main cause (Rosekind *et al.*, 2002). Here, fatigue led to the pilot's failure to adequately brief and execute the non-precision approach (Rosekind *et al.*, 2002). Not only was the captain fatigued, but so were the first officers and the flight engineers who, as a result, failed to adequately monitor and cross-check the captain's execution of the approach (Rosekind *et al.*, 2002).

A study of the relationship between pilot schedules and commercial aviation accidents by Goode (2003) reported that 20% of human factor accidents are associated with duty periods of ten or more hours, whilst 5% of these accidents are associated with duty periods of 13 or more hours. Overall, an increased proportion of accidents due to pilot fatigue take place where duty periods are long. Similarly, Yang (2014) found that the proportion of accidents associated with long pilot duty periods is higher than those associated with shorter duty periods.

Ashley (2013), Lee (2010), Reis *et al.* (2016), and Yuiliawati *et al.* (2015) all acknowledge that pilot fatigue can be a contributing factor with respect to flight errors and accidents.

### 4.2.5 Integration and Summary of Literature Findings

Figure 14 is a graphic representation summarizing the main factors impacting on short-haul pilot fatigue as revealed by the literature analysis, as well as the interconnectedness of these factors. The image was constructed in the form of the initial work system model introduced earlier.

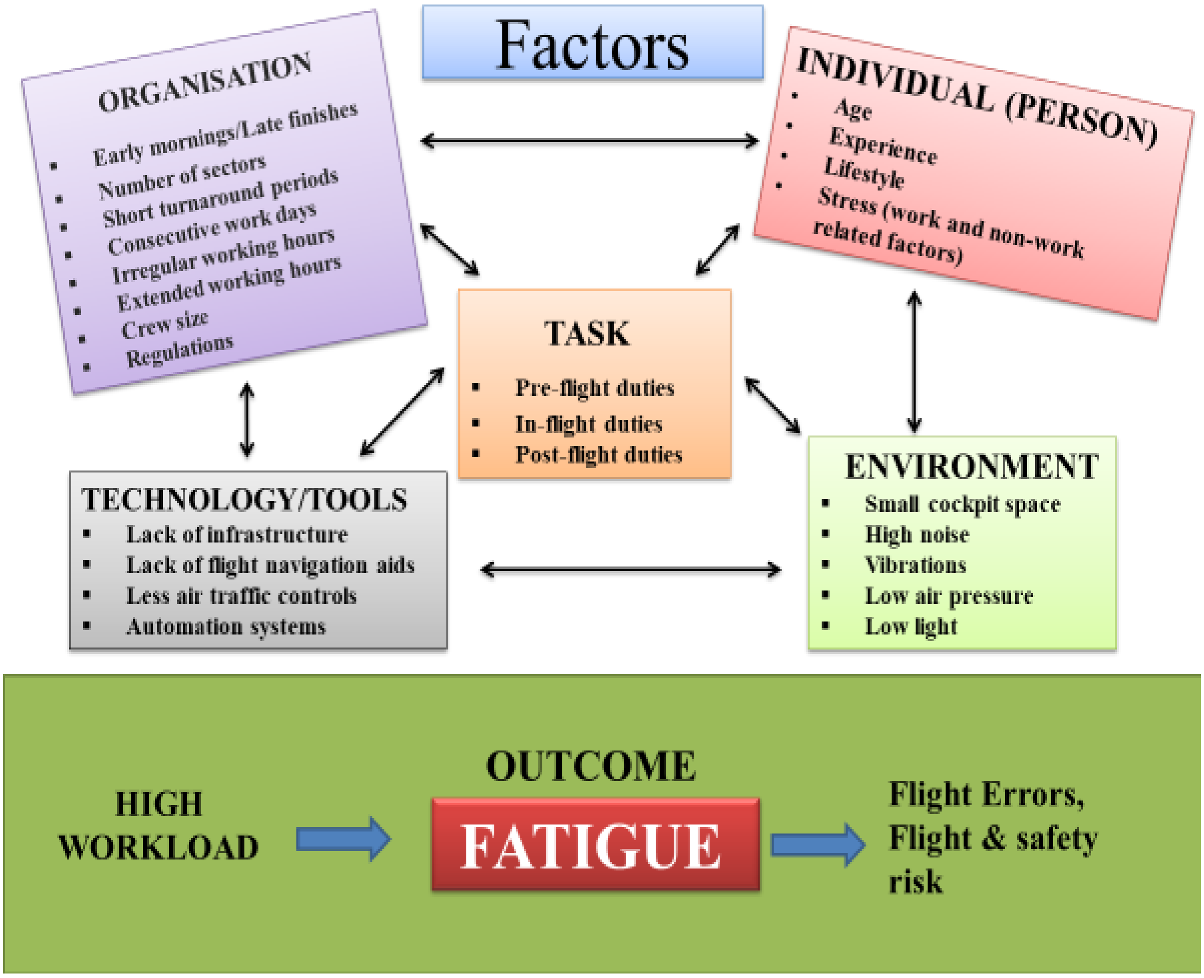


**Figure 14**: Factors contributing to pilot/co-pilot fatigue in short-haul operations.

Pilot fatigue and high workload can both be induced within the short-haul context. They are driven by interactions and interrelationships between the tasks at hand, environmental aspects, technology and tools, organizational factors, and individual (i.e. non-work-related) factors. The relationships and interactions between these factors are dynamic and interchangeable, and they all influence one another.

The tasks/work performed by pilots (including pre-flight, in-flight and post-flight duties) are all influenced by organizational aspects such as work scheduling systems and policies which direct how work should be done within a given company. Within the short-haul context, scheduling affects the amount of work and the number of tasks that pilots need to complete on a day-to-day basis. Schedules that induce pilot fatigue are usually characterized by early starts/late finishes, extended working hours, multiple flight sectors, working consecutive days, few fellow crewmembers, standby and reserve duties, and/or short-turnaround times. These factors, in turn, are influenced by the prevailing flight and duty regulations at any given time. Amongst other things, current regulations govern the number of hours pilots can work, how long their duty periods should be, how much reserve and standby duty they should be assigned, and the number of sectors they should fly in relation to the time their duty commenced.

Demanding schedules increase the number of tasks and activities that pilots need to perform. For example, if a schedule involves multiple flight sectors, the pilot will need to perform several take-offs and landings, as well as aviate, navigate, communicate and manage resources for each respective sector. This can give rise to fatigue as these activities place strenuous demands on the pilot’s cognitive abilities by requiring constant attention, concentration, alertness, and decision-making. Thus, the relationship between scheduling and tasks is interchangeable, with each influencing the other.

All piloting tasks are performed with the aid of certain technology and tools. In the current short-haul aviation industry, a high demand for air travel has led to the advent of 24-hour short-haul operations, escalating the number of daily tasks and duties that pilots need to perform. This has largely been enabled by constant technological advancement. For instance, because short-haul aircraft have developed to a point where they can facilitate longer and more frequent flights, organizational scheduling practices have evolved to enable many additional flights. Thus, at least in the short-haul context, scheduling demands are predominantly influenced by the available technology and tools. As technology has advanced, so automated systems have evolved, leading to fewer physical and more cognitive cockpit tasks. Thus, instead of physically controlling their aircraft, pilots are now expected to perform more supervisory tasks whilst the automated system controls the plane. These supervisory tasks require monitoring, vigilance, and sustained attention. It has been convincingly argued that automation can actually exacerbate pilot workload and in turn lead to increased fatigue levels. For one, due to piloting tasks becoming progressively cognitive in nature (coupled with an increase in flight sectors and working hours) pilots’ mental workload and fatigue have increased. However, automation can also exacerbate pilot fatigue by inducing the boredom (referred to as “underload”) that is often associated with monotonous tasks. Thus, more advanced aircraft systems can induce cognitive overload. On the other hand, where aircraft systems are relatively less advanced, high pilot workload and fatigue levels can arise from the need to make constant, high-stakes decisions in the air. Overall, all three factors (tasks, organization and technology and tools) interact interchangeably, influencing one another in different ways.

In short-haul operations, environmental aspects that can influence fatigue levels include confined space in the cockpit, very low humidity, low air pressure, high noise levels and low light intensity. These are all influenced by the way in which aircraft systems are designed and equipped (with respect to technology and tools). The nature of the cockpit environment can exacerbate workload. Where cockpit automation and design lead to a demand for mainly cognitive responses (e.g. sustained periods of attention or focus) from a pilot, cognitive fatigue can easily arise. This can be further exacerbated where pilot schedules (i.e. organizational factors) involve extended work hours, multiple flight sectors, and a number of consecutive workdays. Thus, high workload and fatigue among short-haul pilots can be viewed as a product of interactions between environmental aspects, technology and tools, tasks, and organizational factors.

High workload and fatigue are products of lack of sleep, reduced recovery, and extended wakefulness. It has already been discussed how these are influenced by organizational/operational factors (e.g. scheduling and the prevailing aviation regulations). However, pilot-specific factors such as age and work experience have been acknowledged as secondary factors influencing fatigue levels. In general, more experienced pilots (who are usually older pilots) bear more responsibility and are assigned more tasks than their less experienced counterparts because they can cope better with challenging environmental conditions and job demands. However, these extra responsibilities and tasks increase the workloads of older pilots making them more susceptible to fatigue. Other individual-specific factors which have a bearing on fatigue levels include, amongst others, a pilot’s health status, family responsibilities, and marital situation. These are all factors that can add stress and induce fatigue which, in turn, can impact a pilot’s performance at work, affect how they perform their tasks, diminish their ability to cope with environmental constraints, and affect the ways in which they interface with automated systems in the cockpit.

## 4.3 Expert Interview Results

### 4.3.1 Sample Characteristics

Based on responses to a pre-screening questionnaire, experts were selected based on their knowledge and experience in the fields of aviation and fatigue. In total, four experts (n=4) agreed to participate in the study. One participant (P1) was an academic specializing in fatigue, sleep, and circadian physiological research; another (P2) was an airline pilot (captain) and senior training captain for domestic/commercial (short-haul) operations in South Africa; the third (P3) was an airline pilot (captain), a senior training captain in South Africa for both domestic/commercial (short-haul) and international flights, and a member of the Airline Pilots' Association of South Africa (ALPA-SA); the fourth participant (P4) was an airline captain for South African short-haul operations and an aviation fatigue specialist in the short-haul context. The experts interviewed were all males who ranged between the ages of 34 years and 58 years, with a mean age of 47.25 years (SD ± 8.93). The participants’ mean employment duration in their current job was 22.75 years (SD ± 10.43). One of the participants was interviewed face to face while the other three were interviewed using the Zoom software (telephone video call). Interviews took place during October and November 2018.

### 4.3.2 Findings of Expert Interviews

Taking into consideration the research aim, a word cloud was formed based on the interview responses, showing the 1000 words used most frequently by the interviewees. (see Figure 15). This word cloud was generated using the NVIVO 12 software (NVIVO, n.d.). It was created to allow for a visual representation of the topics discussed in the interviews.

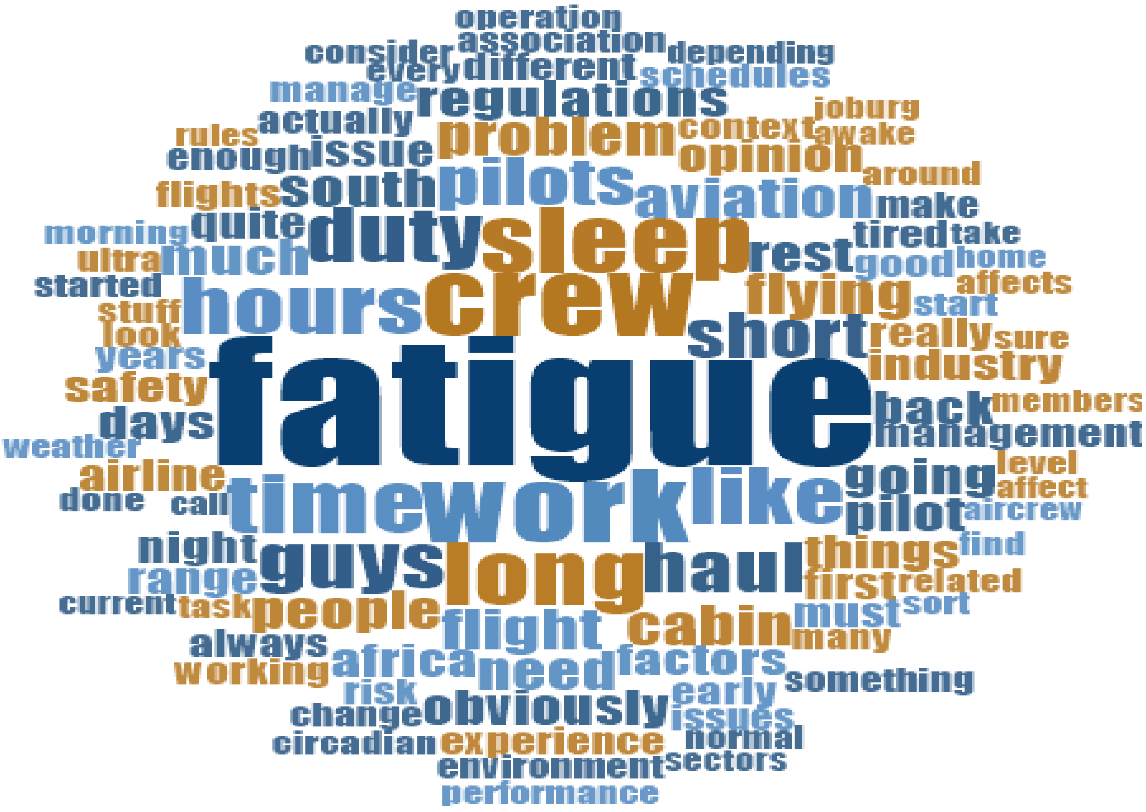


**Figure 15:** Word Cloud of the 1000 words used most frequently by expert interview respondents.

It can be seen from the word cloud that “fatigue” was the dominant topic spoken about during the interviews. Among the other most common words were duty, hours, time, work, long, short-haul, crew, pilots, cabin, sleep, regulations, problem and aviation. These words are also commonly used in the sources chosen for the literature analysis, and therefore are likely to be linked in some way to the major factors in short-haul that lead to high workload and fatigue. The dataset derived from interviews was considered to have reached saturation when successive interviews provided no new analytical information. This point was identified after the last interview, which provided no information that had not already been gleaned from previous interviews. Data saturation brings the interview process to a legitimate closure as it indicates that further interviews are unlikely to add significantly to the dataset. Several categories, themes and sub-themes emerged naturally from the interview data, which were identified based on the thematic analysis approach (Figure 16). Overall, these categories, themes and sub-themes were considered to represent important factors in the aviation experience of the interview respondents. For each theme and sub-theme, representative quotes from the interviews were selected and are presented later in this section. To reduce text volume, not all relevant quotes have been reproduced here. Note that the interviews were conducted orally[1] and have been transcribed according to a thorough process described in the Methods section of this study. For anonymity purposes names of airlines and individuals who were mentioned in the interviews were marked as “xxx”.

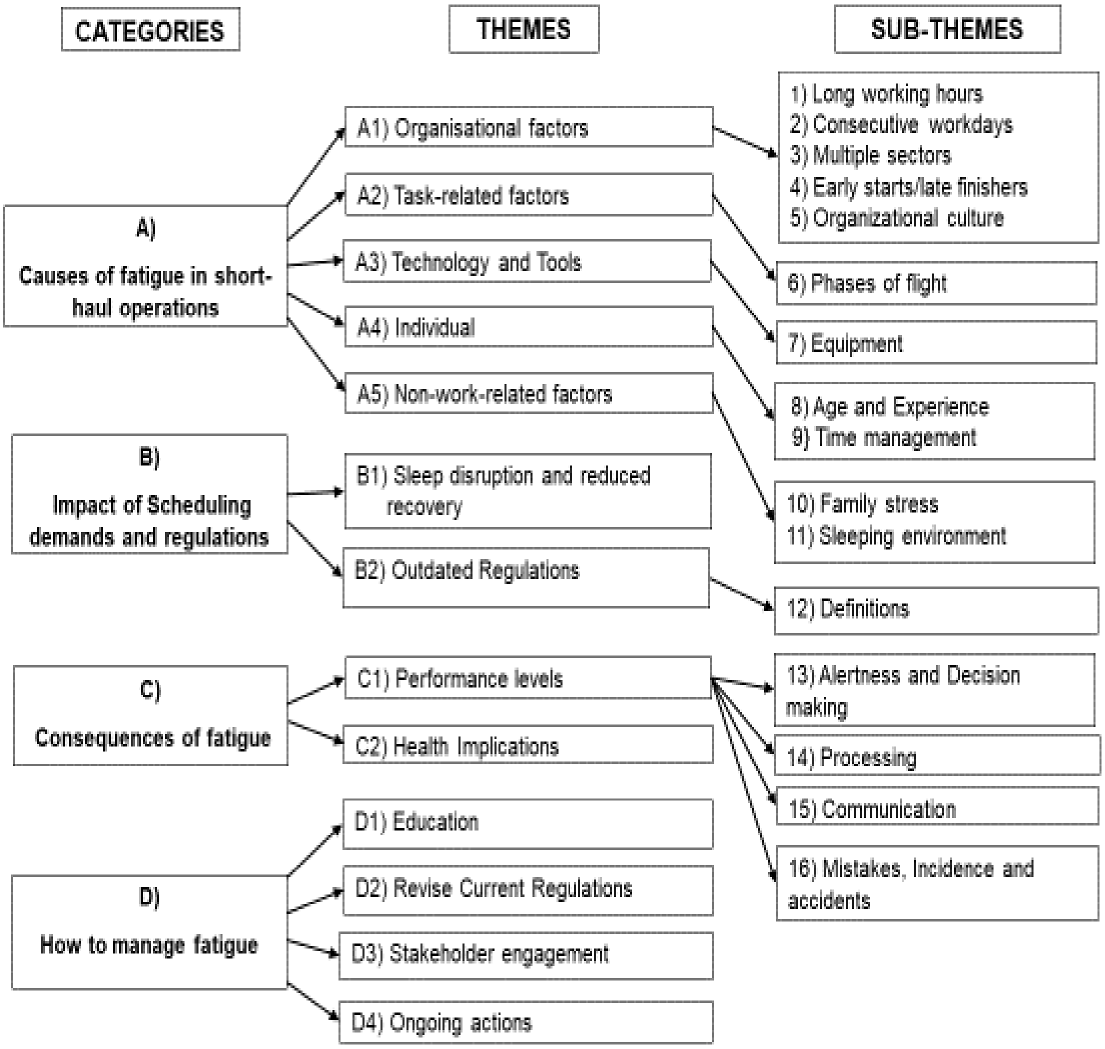


**Figure 16:** Flow chart of the categories, themes and sub-themes that emerged from the expert interviews.

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[1] The interviews were conducted orally, then transcribed. For the sake of readability, the responses have been gently edited with regards to language and grammar.

### A) Causes of fatigue in short-haul operations

The interview data facilitated identification of the factors that respondents considered to be the major causes of fatigue in the short-haul context. Within this category of “major causes”, several key themes emerged such as organizational factors, task-related factors, technology and tools, individual factors, and non-work-related factors.

#### *A1) Organizational Factors*

Interview data indicates that various organizational factors in the aviation context are key causes of crewmember fatigue. It seems that this factor is an ongoing challenge affecting the day to day working lives of pilots in the South African short-haul context. For example, fatigue resulted from several rostering issues, including long working hours, consecutive workdays, multiple sectors, early starts / late finishes, scheduling regulations, and certain aspects of organizational culture. Examples of responses include:

- Sub-theme 1: Long working hours

> *“The main things that contribute to it are the very awkward sometimes very awkward working hours that the pilot's and cabin crew have to perform over multiple days. More often than that there are operation delays for a variety of reasons and these operation delays allow or require that they extend their duty and I think legally they're allowed to extend by one hour per day or per duty period, but not more than twice in one week”. (P1)*

> *"The current regulations in South Africa are excessive you can on any given day if you started a duty and you know in the morning sometimes you can fly, no not fly you can be on duty for 14 hours that does not consider your wake-up time, does not consider commuting time, it considers the time that you actually report for duty and the time that you actually knock off. So what that means is that by and large if you have a full day like that, you probably been awake for two hours before, that you'll likely awake for two hours to three hours after that depending on the extent of the commuting depending on other things that happened. Which means that you are awake for 18 hours in a day now depending on the timing of that flight landing and whether there are operational delays or not means you landing a plane after say three or four sectors having*

*been awake for 16 to 17 hours which is where we know things our alertness is not where it should be". (P1)*

- Sub-theme 2: Consecutive workdays

*"You can cycle crewmembers in short-haul operations forwards and backward and forwards and backward for seven days giving one day off and then cycle him again for seven days and he can do 60 hours of duty in that week. So that is obviously a big issue" (P2).*

*"So, you can fly for seven days so the airline I work for now they roster works 6 days and then they give you two days off. But now with the problem with sit work you can finish on day six let's say at 11 o'clock at night and then you have your two days off but you get up on day one at 3 o'clock so the problem is although you have two days off you only get one night of unrestricted rest and that's a huge problem for us". (P2)*

*"Short-haul is much more tiring for the reason that you work more consecutive duty days. I think the biggest risk is our short-haul domestic flying especially the short-haul night freight flying can be quite challenging". (P4)*

*"In South Africa it seems that they roster five days on two days off depending on the operational demands. (P1)*

- Sub-theme 3: Multiple sectors

*"With short-haul it's a lot of sectors so every sector you do your fatigue will increase with the sectors". (P2)*

*"So certainly like short-range flying up and down those guys are busy there is no doubt I am sure you have been on flights from PE to Cape Town and especially very short sectors like Durban they do four of those a day, four sectors so like Joburg to Durban back to Joburg back to Durban and then Joburg especially for these high-density airplanes like xxx, xxx, and xxx".(P3)*

- Sub-theme 4: Early starts/Late finishes

*"So short-haul operation it's because your roster changes. In one week, I will start off let's say waking up 3 o'clock in the morning and the next night I can sign off at midnight or then legally you only need nine hours off then you can start again". (P2)*

*"The short-range guys repetitive early morning starts, multiple sectors and things like that as you know certainly for short-range guy's it has become a serious problem". (P3)*

*"For a junior pilot, you end of having three weeks of early starts in a row and have to take-off every morning for three weeks in a row, so that would mean you have to wake up about 04h30am and that was tiring by the time you had finished. Most days say we worked during the day and if any charter flight would come up we would do that and then we would do an evening shift we would work to about 7 o'clock and that was tough so it was a lot of up and down short flying normally you didn't fly in bad weather but by the end you would feel very trashed and that would be similar to what the guys are doing now the low-cost carriers". (P3)*

- Sub-theme 5: Organizational culture

Apart from the scheduling aspects raised by interview respondents, the "culture" in the aviation industry could also impact fatigue. This factor has not been identified as a cause of fatigue in the literature. Examples of participant responses include:

*"The prevailing culture in some aspects of the aviation industry is a major factor that contributes to the perpetual challenge of fatigue in the industry". (P1)*

*In my experience there I've listened to the way that people speak and the majority of people who are in management, have their roots in the military, so they have flown in the air force and the prevailing culture around that is don't cry, big boys don't cry and so the culture of being honest about challenges that you face at work or the culture is that you can't complain about the challenges that you have at work and so pilots and cabin crew are reluctant to come forward with issues that they might have in relation to flight and duty periods or they have to do it anonymously because they are fearful of retribution from*

> *management and that organizational culture is not conducive to a safety culture." (P1)*

*A2) Task-Related Factors*

Fatigue is also dependent upon the number and intensity of tasks performed by pilots on the job. The majority of participants reported that their job requires intense flying. The large number of sectors flown in a given duty period necessitates several take-offs and landings per shift. While cruise phase necessitates more cognitive demands. Both factors leading to high workload and correspondingly high levels of stress. Examples of interview responses include:

- Sub-theme 6: Phases of flight

> *"In short-haul like in South Africa, I think that fatigue mechanisms are different but you flying more intensely that is what's happening you know you have a high workload because of high number of sectors because the duty periods or the sectors are short (….). The fact that taking-off and landing a plane is a stressful experience so you have workload issues (….)". (P1)*

> *In cockpit settings as soon as you are taking off then and in-flight you are cruising; it largely becomes observation where they have to be more cognitively alert to what's going on and that interaction might present a different type of tiredness with fatigue". (P1)*

> *"In the short-haul operation, we do a lot of sectors and a lot of flights so there is always high pressure the whole-time take-off and landing, so you've got a lot of high workload in short-haul operations". (P2)*

*A3) Technology and Tools*

The type of equipment in the cockpit is an important factor that relates to fatigue; particularly, whether the instrumentation is old or modern. Various factors linked to aviation equipment can lead to elevated workload and fatigue. Examples of responses on this topic include:

- Sub-theme 7: Equipment

*“The type of equipment you are flying certainly like the more modern jets it becomes much easier to manage”. (P3)*

*“Cockpits are much easier from a workload perspective where the older equipment you have to do a lot more interpreting on what you see and cognitively it could make you tired a bit quicker”. (P4)*

*A4) Individual Factors*

Numerous individual factors were highlighted by interview participants as contributing to pilot fatigue. The main factors identified were personal attributes such as age, experience and time management. Examples of responses include:

- Sub-theme 8: Age and experience

*"Changes with things like age and it changes with I suppose home arrangements and whether you have got kids, family stress, etc”. (P3)*

*“It depends on your experience and age, it’s the same as the pilots when you young I am talking among airline flying so remember most of my perspective is from an airline perspective, is that the younger guys like to go out and do their touring and going out for late night socialising. But of course, when you younger you recover much quicker than with the older guys”. (P4)*

*“The older you get the more difficult it is to fall asleep in my experience”. (P1)*

*"In general, the less experienced you are the quicker you get fatigued because you have to put so much more effort in. The more experienced you get the easier it becomes to manage your work environment and you don't get as tired as quickly”. (P4)*

*“If you had to look at let's say a brand new first officer would get more tired than an experienced first officer who has seen it all before, so he doesn't have to use his brain as much and I tell you with the captains the new captain let's say you guys are in the Eastern Cape and but here up where I am in Durban right now but up in Joburg up in summer the weather becomes terrible I mean this afternoon if you look at the weather in Joburg there are thunderstorms*

> *everywhere so the new captain flying in this environment would fatigue much quicker than the experienced captain". (P4)*
>
> *"The seniors may not be getting enough rest than the juniors because they have a lot more responsibility. It sounds a bit odd because the more experienced you are the better at it, but you may have more responsibility if you take it too much to heart it could affect". (P4)*

- Sub-theme 9: Time management

> *"I think a lot of factors are outside of the workplace and it's from an education and prioritization point of view where I just think individuals are not very good at managing fatigue or managing their time off to make sure that they are better prepared and I understand why, they have kids, families, you got social commitments". (P4)*
>
> *"A big issue with people, they are not utilizing their off time as they could to prepare everything for the next duty". (P1)*

*A5) Non-Work-Related Factors*

Numerous non-work-related factors were highlighted as causes of fatigue, including such concerns as family stress and sleeping environment. Examples of relevant responses include:

- Sub-theme 10: Family stress

> *"Non-work-related, stress on the family and stuff on that, no worse than any kind of profession". (P3)*
>
> *"How you deal with when you're outside of the working environment, I had pilots tell me that they get home and they get agitated with their kids and their wives because they want to rest, but the kids and their wife or partner want their time and so you create that conflict which further adds or you know might add stress to their lives and that is an operational effect of long work hours, long days". (P1)*
>
> *"The fact that the disconnect between somebody's work and home life would add stress. Stress with kids or whether that marital or whatever it is, it all contributes to some hot mess of difficulties". (P1)*

- Sub-theme 11: Sleeping environment

Some short-haul cycles in South Africa require pilots to fly outbound during the day and then inbound the next day. Pilots therefore need to sleep in an unfamiliar environment between the outbound and inbound legs, which may lead to poor quality sleep. In addition, the home environment may not be conducive to good sleep. Sleeping environment is therefore a factor that could potentially lead to fatigue. Examples of relevant responses are as follows:

> *“ You talking about short-haul not talking about long haul but the transmeridian travel certainly I mean in South Africa the only operator that does transmeridian and travel properly is xxx airline, but your xxx and your xxx airline and whatever will fly origin they will fly as far as Nigeria, they will fly far as Mauritius and those are extended flights with quite quick turnaround times and so that's an issue sleeping away from home something that happens quite often in a hotel environment. It is something that the pilot and cabin crew in my mind struggle with because sleeping in an unfamiliar environment”. (P1)*
>
> *“How noisy it is when you sleep a lot of the pilots and crew have small kids and babies”. (P3)*

B) Impact of scheduling demands and regulations

The specific schedules and regulations that govern a pilot’s work rhythms are often not in line with their sleep and rest requirements. Poor scheduling can negatively impact sleep quality and quantity, and it can lead to long working hours and reduced rest periods (often due to early starts and late finishes). Issues such as these can contribute to fatigue in crewmembers. Examples of relevant responses include:

*B1) Sleep Disruption and Reduced Recovery*

> *“ If you're flying awkward schedules early starts mixed with late finishes mixed with operational you no delays whatever and you knocking off at 10 o'clock or 11 o'clock on a Friday evening and then you have to report for duty at 4 o'clock in the Monday morning that really allows you one night of adequate rest and so short-haul is an issue and it needs to be legislated properly (….) inadequate sleep accumulates, sleep debt because of suboptimal hours of work and sleep, extended work hours". (P1)*

> *“Your recovery period is very short with long duty days so that's the law. That is a South African law, not a country law”. (P2)*

> *"Over and above the working time probably interferes with sleep because there's certainly in the South African context the working time is not the same, so they have mixed schedules, so they have early start late finishes then a normal day”. (P1)*

*B2) Outdated Regulations*

All countries have set regulations regarding duty period hours, flight duty limits, flight time limits, rest requirements, etc. These regulations (limits) are represented on tables which are used by regulators to legislate the number of hours pilots can work, the length of duty periods under different circumstances (e.g., whether or not the pilot is climatized), the reserve and standby regulations, the number of sectors a pilot/captain can fly depending on the time the duty commenced, etc. A key issue that emerged from interviews was that many of the regulations governing short-haul operations in South Africa are outdated and unrealistic, and are therefore in urgent need of adjustment. This was a focal point of the interviews. Examples of participant responses include the following:

> “*Current regs are outdated. We were working outside of the existing rules (….) for short-range fatigue is a problem, the current rules were written in a different era". (P3)*

> *“They are shocking I think the current regulations of South Africa are outdated. They can be equivalent or good at duty length, but not good at protecting sleep. The duration of the sleep time that is provided is too short, that is the problem”. (P4)*

> *“We have to continually address whether or not the regulations pertaining to flight duty period are appropriate it's been agreed that they're not they are outdated.* Where *often the challenge comes is a pilot will or any worker will always look for work to be made easier let's fly or work less, let’s fly and work more conducive hours that are not obstructive or don't interfere with home life but your management will look at how can we sweat that asset properly, and the regulations are there to limit the hours of duty and to an extent that considers the circadian rhythm and sleep-related factors but, the regulations*

> *are looked at as targets, not looked at as limits and so your scheduling crew, your scheduling people will say, how can I fly this person so that their legal? they don't say, how can I fly this person so that we maximize safety?". (P1)*

- Sub-theme 12: Definitions

The definitions of scheduling terms such as “local night” and “standby and reserve duty” in the South African aviation context influence the way the scheduling regulations are applied. Flawed or biased definitions can result in long working hours, reduced recovery periods, and negative sleep and circadian physiological effects. These issues were raised often by the interview participants. Examples of responses include:

> *“The definitions of how long people can be on standby for because they consider standby or reserved standby if you are reserved you can be on reserve for 24-hours but what does that mean for the quality of sleep you get and what happens if you get called out for duty. The same with standby if you are there at the airport you know it is a monotonous task it is just you being there and what is the impact on your level of alertness if you've been awake again for a long period of time so a lot of the time the current regulations are not up to date with our current understanding of sleep and circadian physiology and the necessary amount of sleep that people need and also how much rest people need and it largely comes down to the definitions of certain things in the regulations". (P1)*

> *“The main one is your local night how that is defined and what they called the WOCL period. So, the window of circadian low the definition of that influences the duty length of somebody, how long a duty can be. So, if you define the window of the circadian low between two and five in the morning or between two and six in the morning it implies how you can roster somebody. So, it's those definitions that have an impact on how the regulations are applied but I do think that this is an issue currently in South Africa”. (P1)*

> *“The definition of in the law of what is considered a local night because when they have their periods off the definition of a local night as it stands in the legislation is eight hours between the hours of 22:00 and 06:00. So if you do the maths if you clock off at 22:00, eight hours later is 04:00 in the morning which means that you can start your duty at 04:00 which we know is a problem*

> *because the people have to wake up early enough and that is where your sleep dept accumulates, the commuting all of that kind of comes in". (P1)*
>
> *"At home, for short-haul, you must always get twelve hours off, so it includes local night off, are those eight hours for xxx airline is between ten and eight, for the CAA it is any eight hours from nine until seven which I disagree with they have got the wrong definition. If it does something to the local night at EASA you must have 16 hours off before your next duty". (P4)*

Participants have emphasized that differences in the regulations applied by different airlines in South Africa mean that some are more afflicted by the issue of fatigue than others. The airlines most seriously affected are the low-cost carriers. Examples of relevant responses include:

> *"It would depend on let's say for a small example like one airline xxx flight and duty is a well-negotiated flight duty the one let's say at other airlines xxx they fly to the CAA rules which is a lot harder so certainly amongst airlines their pilots are a lot more tired (….) purely by the rules they operate to and not as strong union wise". (P4)*
>
> *"You can see a difference in fatigue between airlines and I can walk into a room and say you and you are the xxx pilots because they look so tired because they work so hard (….) the current regulations are the main endurance to fatigue, the one airline xxx they have got the twelve hours off (….) the other airlines, xxx they only get nine hours and it's just not enough time to rest so it's the countries regulations that are the problem". (P4)*

C) Consequences of fatigue

The issue of pilot fatigue and its impact on safety has been recognized by interview participants as a forefront concern in the aviation industry. The seriousness of the issue stems from the great variety of consequences of fatigue. For example, it affects pilot performance through a reduction in communication effectiveness, reduced alertness, and impaired decision making and processing ability. In addition, fatigue can impair judgement, leading to increased chances of mistakes and consequently a greater likelihood of aviation incidents and accidents. Fatigue also has a impact on health, which in turn will have personal and job-related implications. The reported consequences of fatigue were grouped into themes and subthemes as follows.

*C1) Performance Levels*

Fatigue reduces the ability of a pilot to make effective decisions in the cockpit. It may also reduce alertness levels, impair reasoning and judgment, and slow down information processing. The emergent sub-themes are given below, with examples of relevant interviewee responses:

- Sub-theme 13: Alertness and decision making

*“Alertness is probably going to be reduced, it affects decision making, it affects risk-taking perception, it affects executive decision making, and it affects how you respond in emergencies”. (P1)*

*“In emergency if you fatigued and you not able to think rationally and to make decisions effectively one run the risk of reverting back to something that's inappropriate and inappropriate response to a scenario which could lead to an operational tragedy”. (P1)*

*"It's very stressful landing an airplane with 180 people behind you in bad weather. I guess this issue of when you are fatigued on your last sector and you landing in bad weather how does that interact how does that affect your decision making about whether it's safe or not to land and that's really the key is there isn't a causal link between fatigue and safety it's just how the fatigue with a changed ability to think, to react, to decide affects your judgment about whether to land in a precarious environment to a precarious situation”. (P1)*

- Sub-theme 14: Processing

*“As you know the big thing with fatigue is your processing just becomes so much slower your reasoning is just not good enough”. (P2)*

*“If you are tired your processing is just not there that’s what makes it such a big threat”. (P2)*

- Sub-theme 15: Communication

*“It also effects on how you relate to each other, communication between pilot’s communication between cabin crew”. (P1)*

*“If you are tired you don’t want to communicate so obviously you will do less or give them less information if you are tired, so communication will definitely be affected”. (P2)*

- Sub-theme 16: Mistakes, incidents and accidents

*“So, fatigue definitely affects crew performance and slips, errors, lapses and that sort of stuff and certainly you are more prone to it the more tired you are". (P3)*

*“The big issue with fatigue is you start making more mistakes for every reason and that’s how I see it within myself. So when I start mixing up my call signs, so when I start forgetting the odd checks, when I start missing out on radio call and then I start thinking and tell the guy listen here I think I am getting tired here we need to watch each other. So it’s definitely for me although I feel good I notice there is just a cognitive disjoint between what I normally do to what I am actually doing so that’s how it affects it the most for me personally (….) from a performance perspective is definitely just a slowing down like more forgetting and it’s all unintentional”. (P4)*

*"It's a serious problem because we have had all these accidents over the years people have died because of fatigue and the last one was the flight to Dubai accident in Russia (….) The guys were absolutely working to death long day just the way the roster was designed and at the end of the day what was quite a simple manoeuvre the guys couldn't do it and they obviously caused an accident and all those people died". (P2)*

*“the NTSB which was the US guys the safety bureau they started investigating it first and started citing fatigue as a contributory cause to accidents and more and more as they realised the degraded performance because of pilot error which leads to another one and cognitive misinterpretation of the environment*

> *which leads to an accident or serious incident and so on and because of this they started realizing fatigue was playing a bigger role". (P4)*

*C2) Health implications*

Fatigue can negatively affect the physical and mental health of pilots, which in turn could have disruptive effects on sleep, which then increases levels of fatigue once again. The extensive health implications of fatigue should be explored further as part of an integrated approach to managing fatigue. Examples of participant responses include:

> *"In the long term when you involved in the career of this where you constantly having your sleep shortened and circadian rhythms disrupted there are health applications. It's not only sort of the immediate effect it's also the long-term effects. (P1)*

> *"That's a career in aviation where you have these constant disruptions, trans meridian travel what is it doing to your mental and physical health and what are you using to cope with it. The coping mechanisms that perhaps you know cigarettes that might also now add some challenges to their health which again ultimately affects their ability to work and willingness to work so I think this issue of fatigue is a very good avenue to explore other issues of health and psychological health in aviation or in any context really because it has far-reaching implications for safety but also for the health of the crew". (P1)*

> *"Health status has an impact on sleep, sleep has an impact on the risk of fatigue and so they say you can't have these different these separate pockets and again I might be speaking out of turn all of this must be integrated into the way that they manage safety and it should all kind of fit in". (P1)*

D) How to manage fatigue

Participants shared their ideas about how fatigue can be communicated about and managed at the individual level, the company level, and the governmental level. The implementation of these ideas would constitute a large step towards mitigating fatigue in the South African aviation industry. Various themes emerged from the expert responses such as education about the issue of fatigue, the need to revise current regulations, raising awareness among the various sectors of the aviation industry, and on-going actions to manage fatigue that are already in process.

*D1) Education*

The first step towards fatigue management in the industry would involve educating all of the aviation stakeholders about the issue of fatigue, to establish a consistent foundation of knowledge. Examples of relevant responses include:

> *"The first recommendation is education of all levels of stakeholders so we're all on the same page. The regulator, the civil aviator authority, you have management you have the unions and you have pilots; all those individuals need to be together and then need to understand the problem at hand. The need for vertical integration between all levels of stakeholder". (P1)*

> *"Most airline schedules have no idea about this stuff, but I think it's a question of education, educating those guys as well. I think once that is done then you can probably end up with a win-win, which is what the Europeans have done". (P3)*

*D2) Revise current regulations*

The next step would be to raise the issue of current aviation regulations. All stakeholders in the aviation industry who are engaged in fatigue risk management should begin to critically engage with existing regulations, with a view to revising and updating them. This was often raised by participants, whose responses include:

> *"The second after the education is to interrogate the regulations. I think if we get everyone on the same page integrating the understanding, interrogating the appropriateness of the regulations, rostering properly and rostering using science and making sure that individuals involved in the working environment are aware of the need to use their time appropriately and to report for duty rested. If everybody is educated and understands this and if you get the regulations right and management in the different operations understand the importance of this it hopefully start to change the way that they treat the issue and that they don't look at these limits as targets to sweat the asset and maximize income but to see them as there's the limit I'm going to move away from them slightly and rather take a human centred approach to how the work is scheduled rather than maximize the productivity". (P1)*

> *"If you look at guys like Ryanair and EasyJet in the UK and Ireland they have done, Ryanair is Irish and easyJet is British they have looked at quite a lot of*

> *fatigue they play with early starts, short sectors stuff and certainly Ryanair has five days on and four days off working pattern and I think easyJet is similar and that seems to work for those guys. So, they have modified the rules a bit themselves to deal with that (….) it's not perfect, but I think it better than what we have got at the moment". (P3)*

One of the experts proposed a scheduling solution for fatigue management in short-haul operations:

> *"I would like to see is the way we put flights next to each other needs to be more scientific, because sometimes you can have a very tiring flight, let's say you have 100 flights to fly in a month, 30% will be very tiring 30% will be moderately tiring and 40% will be quite easy. So a trick is to put a hard flight with an easy flight then a medium flight, so that we can manage the continual workload that's what I would like to see the planning I think we can plan a lot of flights and how we can put it together just with a little bit of scientific knowledge on how much time we can sleep, the duty schedules, it will take care of 50% of the issue we have got". (P4)*

*D3) Stakeholder Engagement*

Participants agreed that all relevant stakeholders should engage with one another and work together to mitigate the issue of pilot fatigue, rather than in isolation. The following responses capture this sentiment:

> *"What's important about fatigue is it's a three-way process your government must have its fatigue management law in place, regulations in place and so they got a responsibility to make sure that that's correct and that's in place. Then obviously the company has got the responsibility for them to roster the crewmember whoever does the work in a responsible way, then obviously the third one is the crewmember themselves has also got a responsibility to manage this threat is when all three work together the regulator, the operator, and the crewmember to work as a team so that's an important part". (P2)*

> *"The third is to consider not only commercial aviation but to consider all the others, there are helicopters, there is military there are flight schools, there are firefighters all of those must be involved again it is the stakeholders because they are all affected by the duty regulations". (P1)*

*D4) Current Ongoing Actions*

Certain fatigue mitigation activities are already taking place. These include ongoing discussions around the issue of pilot fatigue, conversations around the current aviation regulations in South Africa, and the development of education programs by fatigue specialists. Some responses reported by the experts along these lines include the following:

> *"I think it's becoming a concern now and that's why they're recognizing the need to change regulations in South Africa but also in other contexts like Australia going through the process Europe has just been through the process America has just been through the process South Africa is going through it". (P1)*

> *"How airlines got to fatigue management was they started, well investigators started understanding how to research whether fatigue played a role in accidents and because it is quite a new sign the NTSB which was the US guys the safety bureau they started investigating it first and started sighting fatigue as a contributory cause to accidents and more and more as they realised the degraded performance because of pilot error which leads to another one and cognitive misinterpretation of the environment which leads to an accident or serious incident and so on and because of this they started realizing fatigue was playing a bigger role. So, they decided to get the regulator to get airlines to actively manage it so to try and identify the hazard. They brought up this fatigue risk management process to try and identify the holes in the process, but they saw it was so important and they developed a fatigue risk system that is separate from the safety system (….). So they said right develop the regulation based on science and operational knowledge which is what the CAA and xxx has got involved with in the meeting in Johannesburg and then they said to the companies education number one, let's start a personal intervention, and try and find some reporting system to identify the hazard so it's actually happening". (P4)*

> *"What we doing we educate, and we have a reporting system and we try and capture it so people can phone me and try and do small things to make a change. So, from a government perspective it's been done internationally it's just our own CAA is battling with it, the companies are trying through education*

> *trying to identify the hazards through fatigue report form and that is what is happening so that is all we can do at the moment". (P4)*

## 4.4 Summary of Outcomes from Expert Interviews

There are several fatigue-related factors that emerged from both the expert interviews and the literature analysis. These include task-related aspects (e.g. tasks related to take-off and landing), organizational factors (e.g. early starts and late finishes, number of flight segments, consecutive workdays, extended working hours, and unpredictable work schedules), technological factors (e.g. equipment in cockpit), and individual/non-work-related factors (e.g. age, work experience, health status, family stress, and sleeping environment).

Interestingly, several fatigue-related factors identified during the expert interviews are not highlighted in the literature at all. These include organizational culture, individual time management skills, knock-on health implications of fatigue, and fatigue management.

Chapter 5 considers and compares the results obtained from the literature analysis with those obtained through the expert interviews.

# CHAPTER 5

# DISCUSSION

Numerous studies have investigated workload and fatigue-related factors in the field of aviation, but few have focused on fatigue-related factors concerning short-haul operations, especially in the South African context. This study was conducted to begin filling this research gap. The study investigated the factors contributing to pilot/co-pilot fatigue during short-haul operations, utilizing a work system analysis method based on both literature analysis and expert interviews. This chapter first presents a discussion of the significance and usefulness of the work system analysis method, then compares the results from the literature analysis and the expert interviews. The literature analysis was based on existing research about fatigue in the context of short-haul aviation operations. It highlights key issues, challenges and contributing factors related to short-haul workload and fatigue emerging from relevant operational studies across the globe. The expert interviews, on the other hand, represent the opinions, views and perceptions of selected local experts, about the issue of fatigue in the South African short-haul milieu.

## 5.1 Overview of the Work System Analysis Method

This study presents a multidisciplinary / integrated approach to investigating the ergonomics and human factors related to safety in the aviation context (specifically focused on pilot/co-pilot fatigue). It aims to understand and characterize the performance of humans in this particular work environment, and to identify which environmental factors contribute to workload and fatigue in the context of short-haul aviation operations. It has been recognized that aviation is a complex system in which a multiplicity of work and human factors co-exists and interact (Harris and Stanton, 2010). Humans play a vital role in this context as the overall operators of the systems that sustain the aviation industry (Wiegmann and Shappell, 2003). Pilots are amongst the most important and valuable human elements in this industry (Hawkins, 2017). However, due to the nature of their work they are also considered the most vulnerable to fatigue, which can adversely affect their performance and can have disproportionately drastic consequences (Hawkins, 2017). Their vulnerability stems from the high demands of their work system, which includes a diverse array of task-related aspects, organizational aspects, technological aspects, environmental aspects within the cockpit (internal) and outside the cockpit (external), as well as individual aspects. All of these can interact with each other at varying levels of complexity, and all of these interactions are in some way correlated with pilot workload and fatigue. The multidimensional nature of such a system can pose challenges to human factors research (Petrilli, 2007). The work system model applied in this study is a unique approach to understanding the development of fatigue and workload in the focal context. This is because it adopts a holistic approach, providing a “road map” of the whole pilot system in which the various causal factors and system components (and their interactions) that contribute to workload and fatigue are modelled together rather than independently. Thus, a framework is provided allowing analysis of various aspects of a work system, the interactions between separate factors, and the possible system outcomes. The study findings indicate that fatigue in the context of short-haul aviation operations is a multi-factorial physiological condition with no single cause, many systemic drivers, and a wide variety of possible manifestations.

## 5.2 Comparison Between Literature Analysis and Expert Interviews

The job of a pilot is demanding and the development of fatigue is inevitable. Both the literature analysis and expert interviews revealed that fatigue is not limited to the feeling of tiredness associated with long periods of wakefulness, that usually governs sleep and other circadian factors. Instead, it is better viewed as a condition leading to changes in performance and subjective perception due to sustained periods of either mental or physical work (Alcéu, 2015; Ashley, 2013; National Research Council, 2011; Tambala, 2017). Fatigue is dependent upon how humans interact with the environment (the context), how the work is structured, the types of tasks and activities undertaken, and the duration of these tasks (Alcéu, 2015; Ashley, 2013; National Research Council, 2011; Tambala, 2017). All such external factors combine with intrinsic natural changes in physical, psychological, and emotional state, which also affect the ability of humans to perform in relation to specific tasks (Alcéu, 2015; Ashley, 2013; National Research Council, 2011; Tambala, 2017). Therefore, in the aviation setting “fatigue” incorporates all of these internal and external factors. It is recognised as a very serious concern in the aviation context because it might present a risk to the safety not only of pilots/co-pilots but also of the goods and passengers that they carry during short-haul operations.

As has been mentioned, it was found that short-haul pilot fatigue result from a number of interacting components. According to the literature analysis, the primary factors contributing to fatigue were task related factors, organizational factors and technological aspects, whilst environmental factors in the cockpit, and individual and non-work-related factors, were identified as secondary causes (Chapter 4, sub-section 4.2.3, pp. 52-79 and Figure 14, p. 82). Both primary and secondary factors are relevant to the development of fatigue and are thus essential components of any model attempting to understand fatigue and its management. The effects of fatigue are discussed in the literature results section of Chapter 4. The expert interviews identified the following as key factors leading to fatigue: task-related aspects (especially take-off and landing); organizational aspects (early starts and late finishes, number of sectors, consecutive workdays, and extended duty hours); technical aspects (equipment used); and individual and non-work-related issues. Additional factors are discussed in Chapter 4, including the impact of scheduling demands and the current South African regulations, as well as the consequences and management of fatigue (Chapter 4, sub-section 4.3.2).

It has been found that short-haul operational pilots experience the kinds of issues related to workload and fatigue that were highlighted in the interviews. Based on the results presented in Chapter 4 (Sections 4.2 and 4.3), the factors common to both the literature analysis and expert interviews include: (1) a combination of organizational factors such as long / extended working hours, working consecutive duty days, flying multiple flight segments, short rest periods, mixed / unpredictable rosters (early starts and late finishes), standby duty; regulations (flight time and duty limitations); (2) task-related factors such as the high number of take-offs and landings during inflight duty; (3) technological factors including the equipment used in the cockpit (old vs modernised cockpit displays); and (4) individual / non-work-related factors (age, experience and family stress). In addition, both the literature and experts have highlighted the impact of pilot fatigue on performance capabilities.

The factors mentioned by experts that did not also emerge from the literature analysis include organizational culture, the health implications of fatigue, time management, and ways to manage fatigue. Conversely, the factors that were derived from the literature analysis but were not mentioned by the experts, include crew size, environmental factors within the cockpit (small pressurised environment, movement restriction, noise, vibration, low ambient air, humidity, low light) and outside the cockpit (bad weather), lifestyle (physical inactivity), and workload and fatigue related to automated systems.

The following discussions are structured according to the categories present in the work system model developed earlier in this thesis (p. 31).

### 5.2.1 Task-Related Factors

Evidence from both the literature analysis and expert interviews indicates that fatigue arises from increasing workload. This in turn stems directly from the high number of take-offs and landings that pilots must perform on a daily basis due to the large number of sectors flown on a typical duty day (exacerbated by unplanned flights), with limited rest periods in between (Ashley, 2013; Chang, 2002; Gander *et al.*, 2014; Reis *et al.*, 2016; Yuliawati *et al.*, 2015). Additional stress is incurred by pilots when their regular activities must be performed under unexpected time pressure (or other forms of pressure), such as when a mechanical failure occurs and when weather conditions are unfavourable (Caldwell, 2005; Chang, 2002; Jackson and Earl, 2006).

Take-off and landing are considered to be the most workload intensive stages of a flight, and the most susceptible to severe accidents. This is due to the large numbers of tasks that pilots must accomplish in a short space of time to successfully execute these stages. Essential requirements include high concentration levels, alertness, focused attention, clear decision making, and effective communication (Ashley, 2013; Yuliawati *et al.*, 2015). Within the context of South African aviation in general, and short-haul operations in particular, the job of a pilot is consistently a high-workload profession and therefore very stressful and demanding. Expert interviews have revealed that on a daily basis short-haul pilots perform many flights in many sectors. Pressure is high throughout, and especially during take-off and landing. Thus, the workload in the short-haul context can be considered to be extremely high (see Section 4.3.2, Theme A2, Sub-theme 6, p. 91).

These high demands are ultimately driven by economic factors; the desire of airline companies to maximise profit and promote growth. Competition among aviation service providers drives the reduction of ticket prices and fosters a culture in which short-haul pilots are pressured to perform more tasks and cover more sectors on a daily basis (Chang, 2002; Gander *et al.*, 1998; Powell *et al.*, 2007; Reis *et al.*, 2013;

Yuliawati *et al.*, 2015). This is a problem because higher level management decisions may not be made with due consideration of the safety risks associated with their economic goals. Intense cognitive demands are placed on pilots during in-flight aviation activities such as navigating the plane, performing continuous communication, and managing resources (Lacabanne *et al.*, 2012). These demands are heightened when flying multiple segments throughout the working day (Lacabanne *et al.*, 2012), leading to higher degrees of mental fatigue (Alcéu, 2015; Ashley, 2013; Lee *et al.*, 2013). The literature states that mental activity is reduced during the cruise phase of flight (Ashley, 2013), potentially giving pilots a break. However, the interviewed experts generally disagreed with this, reporting a high incidence of mental fatigue during cruise phase (in-flight duties) because this phase is largely observational, and pilots must be more cognitively alert. This interaction can present different types of tiredness with fatigue (Section 4.3.2, Theme A2, Sub-theme 6, p. 91).

### 5.2.2 Organizational Factors

Literature analysis and interviews both agree that insufficient sleep and reduced periods of recovery and rest are an existing and continual problem in the short-haul context, and are key causes of fatigue in pilots. Important operational effects causing this sleep and recovery deficit include early report times and late finishes, long and extended working hours, unpredictable working schedules, flying multiple flight legs, and working consecutive duty days (Alcéu, 2015; Co *et al.*, 1999; Gander *et al*., 1998; Jackson and Earl, 2006). These organizational factors were the most frequently reported and discussed issues relating to pilot fatigue in both the literature analysis (global context) and expert interviews (South African context).

#### A) Early Starts and Late Finishes

According to studies in the short-haul context, crew members can report for duty as early as 06:00 and end their duty between 22:00 and 23:00 (Chang, 2002; Roach *et al.*, 2012). Within the South African context this scheduling demand is exacerbated as crewmembers have to wake as early as 03:00 and sign-off at midnight. This does not allow for the mandatory nine-hour rest period before duty commences the next day (Section 4.3.2, Theme A1, Sub-theme 4, p. 90). The repetitive nature of early starts and late finishes (especially when flying multiple segments) is a problem in the short-haul context (Section 4.3.2, Theme A1, Sub-theme 4, p. 90). Sleep and rest periods are disrupted and reduced because according to Alcéu (2015), the regulators regulate crew schedules starting as early as 05:00 to 06:59 and do not acknowledge that crewmembers are required to report for duty one to two hours before the actual start of duty and therefore must wake in their WOCL (the period between 02:00 and 06:00). This very issue is common among short-range junior pilots in South Africa, who have reported up to three consecutive weeks of early starts for which they must wake as early as 04:30. As may be expected, this scheduling demand is reported to be very tiring (Section 4.3.2, Theme A1, Sub-theme 4, p. 90). Roach *et al.* (2012) have pointed out that when aircrew commence their duty before 09:00, for every hour before this time that duty begins, the crew members will likely lose 15 to 30 minutes of sleep. Sleep is further hampered because according to Co *et al.* (1999), the rest period prior to an early start would include family commitments and the time taken for ablutions and meals. Factors such as these should be taken into consideration by aviation management authorities (Alcéu, 2015; Diken, 2011), especially since research has shown that eight hours of uninterrupted sleep on consecutive nights is necessary for proper mental and physical restoration (Techera *et al.*, 2016).

### B) Long and Extended Duty

Long and extended duty days are also factors currently experienced in the short-haul context. The "flight duty period" begins when crewmembers report for a duty that includes one or more flights, and ends when the aircraft comes to rest after completion of the final segment. Based on the Federal Aviation Authority (FAA) and South Africa Civil Aviation regulations, flight duty should not exceed 16 hours within a 24-hour period, it should not exceed 35 hours during the preceding seven days, and each individual flight duty period should be limited to eight to ten hours (Caldwell, 2005; Dinges *et al.*, 1996; Federal Aviation Administration, 2010; Honn *et al.*, 2016; SACAA, 2013). However, according to Vejvoda *et al.* (2014), today's short-haul operations involve pilots flying between 30 minutes and three hours per sector, and working ten to 16 hours a day. This applies equally in South Africa as it does internationally; expert interviews revealed that fatigue results most often from very awkward working hours performed over multiple days (Section 4.3.2, Theme A1, Sub-theme 1, pp. 88-89). Powell *et al.* (2008) showed that time of day and long working hours were key factors contributing to fatigue in their study. Short-haul crewmembers in South Africa are often on duty for 14 hours but can be awake for 16 to 17 hours depending on commuting time to and from the workplace, the time crewmembers wake for duty, and operational delays (Section 4.3.2, Theme A1, Sub-theme 1, pp. 88-89). The literature indicates that crewmembers may often live at least an hour's commute from their workplace, necessitating at least two hours of daily travel time (Caldwell *et al.*, 2009; Co *et al.*, 1999). This would extend the working day, ultimately contributing to pilot fatigue (Smith *et al.*, 2012).

The literature analysis also emphasised that crewmembers often work into their discretion period due mostly to unforeseen factors such as extended waits between flight segments, equipment malfunction, unanticipated technical delays, air traffic delays that are beyond the control of the operator, medical reasons, and unforeseen weather conditions. Factors such as these may increase the regular duty hours by up to two hours (Bourgeois-Bougrine *et al.* 2003a; Caldwell, 2005; Chang, 2002; Powell *et al.*, 2008; Jackson and Earl, 2006), which will have a corresponding effect on fatigue levels (Spencer and Robertson, 2002). Other factors leading to long working hours include early starts and late finishes, which have already been discussed at length. Crewmembers who report earlier for duty will work longer hours on a given duty day and will therefore experience higher levels of fatigue at the end of the flight duty period (Bourgeois-Bougrine *et al.* 2003a).

C) Consecutive Workdays

Another factor highlighted in both the literature analysis and the interview findings as a cause of fatigue in the short-haul context was the number of consecutive workdays. The literature revealed that short-haul crewmembers are scheduled to work on average four to five consecutive workdays (Bourgeois-Bougrine *et al.*, 2003a). The repetitive nature and high stakes of the job results in a demanding workload, which is known to be a cause of fatigue (Yuliawati *et al.*, 2015). In the South African context, crewmembers generally work six to seven consecutive days with one to two days off before the cycle begins again (Section 4.3.2, Theme A1, Sub-theme 2, p. 89). The experts have noted that working consecutive workdays shortens crewmembers' recovery period, especially when combined with late sign-off and early start. In South Africa crewmembers end their duty on day six at 23:00, they have the next day (day seven) off work, then they begin the cycle again the following day (day one), often with an early duty start for which they must waking as early as 03:00 (Section 4.3.2, Theme A1, Sub-theme 2, p. 89). Consequently, they do not obtain the full 48-hour recovery period and therefore remain fatigued as they enter the new cycle. This is similar to the experience of Brazilian pilots, who also do not receive the required two days off work at the end of consecutive workdays (Marqueze *et al.*, 2017). Ideally, crewmembers should get the twelve hours off duty on the day that their flight duty period ends as well as the next 24 hours (Marqueze *et al.*, 2017).

D) Number of Flight Sectors

The number of flight segments scheduled per duty period was another factor that all of the analyses identified as a cause of crewmember fatigue. In today's short-haul operations internationally, the duty schedules encompass four to five sectors per day on average (Vejvoda *et al.*, 2014). A similar picture is evident in South Africa; according to Denel, it is envisioned that the SARA short-haul duty cycle will encompass four to five sectors. The Federal Aviation Administration (2010) has stated that short-haul schedules including four to five sectors of flight per day are among the more fatiguing schedules to fly, leading to performance decrements (Powell *et al.*, 2007). In support of this, Spencer and Robertson (2002) have shown that fatigue levels steadily increase as the number of sectors flown progresses across a five-sector flight duty period. This finding was mirrored by Bourgeois-Bougrine *et al.* (2003a) and Powell *et al.* (2007). Short-turnaround times between flights (15 to 30 minutes) enable multiple segments to be flown in a single duty period, and reduce rest periods between flights (Co *et al.*, 1999; Jackson and Earl, 2006). This is a common problem experienced by South African short-haul pilots; the expert interviews revealed that crewmembers generally perform many sectors, and fatigue accumulates with every sector. This pattern is typical in some airlines in South Africa (Section 4.3.2, Theme A2, Sub-theme 3, p. 89).

Overall, the results suggest that short-haul operations as currently structured (in South Africa and abroad) are problematic due mainly to the issue of pilot/co-pilot fatigue and the impact that this inevitably has on safety. Few studies have probed this issue further, investigating (for example) how many sectors are optimal to minimise fatigue. Of the studies that are more in-depth, Spencer and Robertson (2000) recommended a 45-minute reduction in the time per sector, but they found no increase in fatigue across sectors when only two sectors were flown. In keeping with this, Powell *et al.* (2008) found that fatigue only increases from the second sector onwards.

### E) Standby and Reserve Duty

Standby and reserve duty were raised in the literature analysis and expert interviews as factors promoting fatigue. In South Africa this could be a problem as pilots can potentially be called to a duty of 14 hours after having already been awake for a 16-hour shift. This would be of particular concern if calls were to come when crewmembers should be asleep (Dinges *et al.*, 1996). The South African short-haul legislation states that standby duty is regarded as rest time, and is only legally considered to be working time when pilots are actually called to duty (SACAA, 2013). Note that only the hours worked are compensated for (SACAA, 2013). These policies should be investigated (as should the functional definitions of the terms “standby” and “reserve”), because being on standby is likely to detrimentally affect the relaxation and sleep of aircrew members as stated in the interviews (Section 4.3.2, Category B, Theme B2, Sub-theme 12, p. 96-97). The unpredictability of standby places limitations on how these periods can be structured, and may lead to increased anxiety (Co *et al.*, 1999). Indeed, Ziebertz *et al.* (2015) state that the unpredictability of standby periods will interfere with the ability to relax. Extended periods of wakefulness (or poor sleep) while on standby are likely to result in reduced alertness levels which would influence the crewmember’s performance during their next work period (whether a call from standby, or their next regular shift) (Co *et al.*, 1999; David-Cooper, 2018; Ziebertz *et al.*, 2015). Overall, standby and reserve duty could contribute to crewmember fatigue.

If the opportunity for sleep and rest is continuously disrupted then crewmembers are at risk of accumulating sleep dept (Dijkshoorn, 2008). If sleep debt is incurred by crewmembers over several consecutive days, the chances of flight-related fatigue events is substantially increased (Co *et al.*, 1999; Dinges *et al.*, 1996). Reis *et al.* (2016) stated that the restriction of sleep can induce high levels of fatigue. Aside from the flight-related hazards of fatigue, disrupted sleep can have detrimental effects on the health of affected persons (Williamson *et al.*, 2011). Sleep disruption may lead to cardiovascular disease, obesity, high blood pressure, and diabetes (Hartzler, 2014). According to Techera *et al.* (2016), consistent and adequate sleep is absolutely essential for sustained performance. In other words, pilots need to get enough rest periods to be fit for duty (Yuliawati *et al.*, 2015). Techera, *et al.* (2016) pointed out that the recovery/rest period is a vital phase in which the negative effects of exertion (both mental and physical) are reversed, returning the body to a pre-fatigued state.

Overall, a combination of different working time arrangements cause increased workload, sleep disruption and reduction of rest periods, all of which contribute to fatigue in short-haul crewmembers. This issue is due in large part to poor scheduling designed and implemented by operators and management structures in the aviation industry, and can be alleviated by appropriate changes in legislation.

F) Regulations

Another finding emerging from the interviews and literature analysis was that the current state of flight time and duty limitation regulations contributes to workload and fatigue in short-haul operations. It is questionable whether the current Flight Time Limitations (FTL) and associated regulations are appropriately defined and achieving their stated objectives; the expert opinions gathered in this study would say that they are not. The precise definitions of these regulations influence the way in which they are applied. Experts in the industry consider the shortcomings of the existing definitions to be a serious current issue in South African aviation due to their consequences – sleep disruption and reduced recovery periods, which are the primary causes of pilot/co-pilot fatigue (Section 4.3.2, Category B, Theme B2, pp. 95-97). This finding is consistent with several studies emphasising that the definitions of "rest period" (off-duty period), "local night" and "window of circadian low" (WOCL)" does not protect sleep and rest of crewmembers (Caldwell *et al.*, 2009; Caldwell and Caldwell, 2016; Gander *et al.*, 1998, SACAA, 2013).

A related issue raised by the experts was that regulations have not been adequately followed. Operators routinely schedule up to the regulation limits, treating prescribed limits as targets rather than as indicators of the upper ceiling for duties (Section 4.3.2, Category B, Theme B2, pp. 95-97). This finding is consistent with a study by Steiner *et al.* (2012), who observed that the rules governing flight times, duty times and rest periods in short-haul operations are often set as legal targets rather than being viewed as extremes of practice reserved for exceptional circumstances. A clear problem in current South African aviation is that the regulators often push pilots to work to the maximum limits of duty, flight time etc., simply because it is considered legal and has become the norm (Section 4.3.2, Category B, Theme B2, pp. 95-97).

Notwithstanding the above, it is recognised by experts that the main issue regarding the regulations is simply that they are outdated and therefore fail to safeguard crewmembers as they should (Section 4.3.2, Category B, Theme B2, pp. 95-97). This finding was mirrored by Caldwell *et al.* (2009), which emphasised that the regulations currently been followed in the modern world are still those implemented since the 1930s. According to Avers and Johnson (2011), the regulations need to develop science-based recommendations. This need applies as much to the international context as it does in South Africa. For example, Steiner *et al.* (2012), emphasised that the current European Flight Time Limitations (FTL) also need to include science-based knowledge of sleep science, circadian effects, fatigue and workload. Overall it can be said that current scheduling practices for aviation crewmembers do not match the basic biological and physiological capabilities of pilots and crews. Caldwell (2005) pointed out that the pilots and crewmembers are not designed to operate effectively in the pressured 24/7 schedules demanded by the modern aviation world.

#### G) Culture

In addition to the organizational aspects (scheduling and regulations) and task-related aspects discussed above, the expert interviews revealed that the culture in the aviation industry could also contribute to the perpetual challenge of fatigue. This factor has not been identified as a problem in the literature. Company culture contributes to the risk of fatigue as flight crew often avoid talking openly about the topic (and especially about situations in which fatigue has affected their own performance) for fear of losing their jobs. Expert interviews show that this applies directly to the flight crew in the South African short-haul context; employees are reluctant to speak about the challenges that they experience with fatigue and the challenges associated with flight and duty periods (Section 4.3.2, Theme A1, Sub-theme 5, pp. 90-91).

### 5.2.3 Non-Work Related / Individual Factors

Various personal or individual factors specific to each different employee have been directly linked to sleep and fatigue. The interview and literature results both emphasised that fatigue can vary as a function of personal attributes such as age, experience, and time management, and also personal contextual factors such as family dynamics, having children, and health status (Ashley, 2013; Dijkshoorn, 2008; Lee, 2010; Mikkelsen, 1998; Miles and Dement, 1980). These are considered to be secondary factors linking to fatigue, but they are nonetheless important for understanding the development of fatigue in individuals.

### A) Age

Susceptibility to fatigue appears to increase with age. Expert interviews revealed that older crewmembers experienced greater difficulty falling asleep, leading to increased disruption of sleep quantity and quality. In addition, younger pilots generally recover more quickly from tiredness (due, for example, to late night socializing) than older pilots. In general, older pilots are thus more prone to fatigue than their younger colleagues (Section 4.3.2, Theme A4, Sub-theme 8, pp. 92-93).

Consistent with this, Mikkelsen (1998) and Miles and Dement (1980) have found that as age increases, so does the average number of awakenings per night, leading to restless nights of sleep. Age causes sleep to become more fragmented and lighter, and all such sleep changes can lead to excessive daytime sleepiness which can affect a pilot's performance during the day (Stepnowsky and Ancoli-Israel, 2008). Few studies have investigated the effects of age and its resultant sleep-related effects on fatigue and performance in short-haul pilots, and this would appear to be a priority area for future research.

### B) Experience

Amount of flight experience emerged from both the literature analysis and the expert interviews as a factor related to fatigue. According to the expert opinions, less experienced pilots are likely to develop fatigue more quickly than experienced pilots. This is because the former group will generally need to expend more effort per task than their more experienced colleagues who are more familiar with the tasks and better able to manage their work environment. In addition, experienced pilots will be more comfortable handling stressful situations (such as bad weather conditions) and will therefore expend little extra energy in these situations, whilst less experienced pilots will usually find such circumstances more challenging and fatiguing (Section 4.3.2, Theme A4, Sub-theme 8, pp. 92-93). This is corroborated by the literature. For example, Lee (2010) found that the less experienced pilots reported high mental workload during pressure situations, probably because they are less skilled and must therefore invest more effort to execute the work properly. This could lead to high mental fatigue (Lee, 2010). Based on the data from the expert interviews, the situation in South Africa is more nuanced; levels of fatigue were often reported to be higher in senior pilots than in junior pilots. This is mainly because despite their greater skill, senior pilots have more responsibilities and get less rest on average than do the junior pilots. The literature states that because of their greater knowledge and skill and their greater ability to cope with heavy work demands, the more experienced pilots would often be granted more tasks and higher responsibility and would therefore work longerhours. This in turn can cause high levels of fatigue due to the operational effects inherent to the job (Lee, 2010). Although experience has already been recognised by the experts and certain published studies as a factor contributing to fatigue, little is known of the details of its effects. Future studies are therefore necessary to probe this issue further.

### C) Health

The health status of pilots is another factor that will inevitably affect their sleep quality and levels of fatigue. Dijkshoorn (2008) noted that pilots who are physically active and eat healthily can cope with stressful and potentially fatigue-inducing situations much better than unhealthy pilots. Regular physical activity and good health have been shown to improve both sleep quality and quantity (Ferrer *et al.*, 1995). The experts have argued in their interviews that fatigue can detrimentally affect health status, which in turn leads to negative impacts on sleep. Cyclically, poor sleep quality increases the risk of fatigue, and thus begins a compounding cycle of fatigue (Section 4.3.2, Theme C2, p. 100).

Generally, people (including pilots) who are physically inactive are at risk of experiencing sleeping problems because poor physical condition may compromise the brain mechanisms that stimulate longer periods of slow-wave sleep (Pellegrino and Marqueze, 2019; Rosekind *et al.*, 2002). Such individuals are likely to experience lighter and less restorative sleep and more nocturnal awakenings than physically fit and active people (Rosekind *et al.*, 2002). As has been previously explained, poor sleep usually leads to suboptimal performance the next day. Pilots are encouraged to live a healthy lifestyle as this aids recovery of disrupted circadian rhythms, promotes daytime alertness, reduces stress, relieves anxiety, and can help boost immune functioning (Ferrer *et al.*, 1995). Clearly, good physical condition is an effective strategy to prevent and combat fatigue. Nonetheless, due to the nature of a pilot’s job (consistent and sometimes extreme sleep deprivation, disruption of circadian rhythms, high levels of responsibility, etc.), fatigue of some degree will inevitably be part of a pilot’s professional life. As has been noted by the experts interviewed for this study, fatigue can affect health status in many ways, including both mental and physical health. It therefore has far-reaching implications for professional performance, crew dynamics, and general levels of safety in the aviation industry, and is a key consideration when exploring other physical and psychological health issues in aviation (Section 4.3.2, Theme C2, p. 100). As with several of the other secondary factors linking to fatigue, the issue of crewmember health has not been adequately dealt with in the literature. The relationship between work hours or working conditions and health is poorly understood, as are the implications of fatigue for crewmember health in short-haul operations. Further evaluation of this aspect is needed.

### D) Time management

Time management challenges were recognised by expert interviewees as an important individual factor contributing to fatigue. However, this issue was not recognised by most studies reviewed in the literature analysis. Many experts report difficulties in managing their fatigue, and in managing their time off to ensure that they are well prepared for their next shift. These difficulties have usually been due to family and social commitments and to having young children (Section 4.3.2, Theme A4, Sub-theme 9, p. 93).

One of the few studies that have recognised this issue is Bor *et al.* (2016), asserting that individuals do not use their time “wisely” when they are off duty. However, this is often due to a conflict of professional and personal priorities since pilots have obligations, responsibilities and interests outside of the work context (Bor *et al.*, 2016). These include social interactions (spending time with friends) and family responsibility (spending time with family, taking care of children, and more) (Bor *et al.*, 2016). Conversely, effective time management has been recognised as an individual strategy to manage the risk of fatigue (Avers *et al.*, 2009; Dijkshoorn, 2008). As so few studies have examined the links between time management and fatigue in the aviation industry, the importance of this aspect is difficult to judge. However, based on the data from the expert interviews it should not be overlooked in an integrated approach to the understanding of fatigue.

### E) Family stress and sleeping environment

Non-work-related factors such as family stress and sleeping environment emerged in both the literature analysis and the expert interviews as factors influencing sleep quality and therefore fatigue. Concerning the sleep environment in the short-haul context, pilots are often scheduled to fly outbound during the day and must therefore spend the night in unfamiliar settings such as foreign hotels (e.g., Denel regional aircraft scheduling, like some South African airline outbound flights to Nigeria and Mauritius). According to Caldwell and Caldwell (2016), sleeping in an unfamiliar environment often involves beds that are too hard or soft, bedrooms that have too much light, temperatures that are too cold or hot, roommates who snore, etc. These factors are all known to interfere detrimentally with sleep (Caldwell and Caldwell, 2016). The literature suggests that the home sleeping environment can also have a negative impact on the quality and quantity of sleep. According to Co *et al.* (1999), the most common culprits are excessive heat, random noise, background lighting and high humidity. For example, expert interview responses revealed that many pilots have young children and babies, and resultant random noise during the night was found to disrupt sleep (Section 4.3.2, Theme A5, Sub-theme 11, p. 94). Not much research has been undertaken on the links between sleeping environment and fatigue in the short-haul context, and more such studies will be necessary to better understand this issue.

Other non-work-related aspects such as financial stress, unique family situations, and other life pressures outside the work context are known to also contribute to fatigue (Flin *et al.*, 2008; Stokes and Kite, 2017). Factors such as these emerged from expert interviews as key causes of fatigue, and were reported to have a large impact on work performance. Many experts highlighted the disconnect between work and home life as a major cause of stress. For example, conflict may often develop between pilots who need to rest in their time off, and their children and partner who want to spent time with them. Marital problems were also cited as common causes of stress and fatigue in aviation personnel (Section 4.3.2, Theme A5, Sub-theme 10, p. 93). These lifestyle stressors have a huge impact on performance capabilities, reducing attention levels and impairing decision making (Petrilli, 2007).

### 5.2.4 Environmental Factors and Technology and Tools

Several studies have found that environmental factors in the cockpit can contribute to pilot/co-pilot fatigue. Variables such as noise, vibration, ambient air conditions, humidity, confined space, and lighting all have a bearing on comfort, and many can also be linked to perceived or subjective performance levels (Dikjshoorn, 2008; Landström and Löfstedt, 1987; Novacek, 2003; Strauss, 2006; Techera *et al.* 2016). These are considered to be secondary factors in the development of crewmember fatigue, but are likely to be particularly important in situations requiring close attention and intense concentration (e.g., take-off, landing, poor weather conditions). They should therefore not be overlooked when developing a model of fatigue in the short-haul context. The lack of emphasis in the expert interviews on environmental factors in the cockpit suggests that more research is needed before definite conclusions can be drawn about the influence of this factor on pilot/co-pilot fatigue.

In the context of technology and tools, the operation of flight equipment was raised in the expert interviews as a major cause of fatigue and workload. The main emphasis was the use of older versus modern equipment in the cockpit. Experts reported less stress, lower workload and greater ease of workload management in cockpits equipped with modern aviation tools, compared with those containing older equipment. In the latter case, flying requires higher mental demands which can in turn lead to greater fatigue (Section 4.3.2, Theme A3, Sub-theme 7, pp. 92).

Consistent with this, Co *et al.* (1999) found that not all cockpits in short-haul aircraft are equipped with computerised systems and display instrumentation. Operation of older equipment has been shown to induce high cognitive workloads and heightened stress levels, as pilots must perform many manual tasks and make large numbers of critical decisions while flying (Vejvoda *et al.*, 2014). In contrast, modern equipment alleviates many of the pressures mentioned above. However, increased automation and advanced computer and display instrumentation introduces challenges of its own; short-haul pilots may experience elevated cognitive demands as they must perform more supervisory and monitoring tasks (Harris *et al.*, 2001). The expert interviews did not highlight automation as a contributory factor to workload and fatigue, and these factors need to be further explored in future.

### 5.2.5 Consequences of Pilot Fatigue

In short, fatigue reduces a pilot’s performance levels (Alcéu, 2015; Caldwell *et al.*, 2009; Loh, 2004). According to Alcéu (2015) and Caldwell and Caldwell (2016), fatigue commonly impacts pilot performance in the following ways: reduction in vigilance, poor judgment, low alertness, slowed reaction time, lack of concentration, periods of inattention, slow understanding, poor decisions, forgetfulness, and deteriorations in the quality of communication. Many of these effects were also reported in expert interviews, including impaired decision making, lack of alertness, and reduced processing and communication capabilities (Section 4.3.2, Theme C1, pp. 98-100). Interviews further indicated that fatigue-related decline in pilot performance can result in mistakes (slips, errors and lapses) which can cause incidents of varying severity, including accidents which could lead to human injury or death (Section 4.3.2, Theme C1, Sub-theme 16, pp. 98-100). It is thus clear that pilot fatigue is a critical concern in the South African short-haul context and in the aviation industry in general.Overall, fatigue can impair a pilot’s ability to safely operate an aircraft and perform safety related tasks, the consequences of which can be deadly (Loh, 2004).

### 5.2.6 Summary

Pilot fatigue in short-haul operations result from complex interactions of a diverse variety of factors, many of which have been shown to affect the rest and recovery period of aviation crewmembers, as well as their sleep duration and quality. The primary factors affecting fatigue are directly linked to the nature of the pilot’s job, including tasks and activities, operational demands (organizational aspects at work) such as working time arrangements, duty schedules, regulations etc., and technology and tools. In addition to the primary factors, various secondary factors also influence pilot fatigue. These include environmental factors (internal and external factors at work), as well as individual and non-work-related factors such as age, experience, personal attributes, health status, family situations etc. A comprehensive understanding of fatigue and the development of management strategies to mitigate its causes and effects will require due consideration and effective modelling of the primary and secondary factors discussed in this chapter.

## 5.3 Interventions to Mitigate Fatigue

It is evident from the results of this study that fatigue is caused by a wide diversity of system components in the aviation short-haul industry. Therefore, there is no single solution to the issue of crewmember fatigue. As noted by interview respondents, it needs to be addressed at the individual level, company level and governmental level. This study also demonstrates a clear need for improvements in the way that fatigue is managed at every one of these levels. For example, inadequacies have been highlighted in the current regulations governing flight, duty and rest limitations in the South African aviation context (note that these shortcomings are by no means unique to the South African legislation), and the regulations urgently need to be revised and corrected. Improved guidelines should be provided to raise awareness amongst aircrew of the issue of fatigue, and to improve their understanding of this issue in the short-haul context. They should also receive practical guidance regarding reduction and management of fatigue for the purposes of personal benefit and for the establishment of a safer work system. There is little discussion of this educational aspect in the literature. However, the expert interviewees suggested that awareness be raised amongst all stakeholders in the aviation industry regarding the seriousness of fatigue, its contributing factors, the importance of sleep and circadian physiology, and the importance of adequate rest for crewmembers. All stakeholders could then be involved in developing effective strategies to help mitigate and manage fatigue amongst professionals in the industry (Section 4.3.2, Category D, pp. 100-104). The interview respondents recommend that fatigue be managed according to a three-way process. Firstly, the government should develop an informed fatigue management law and put regulations in place to ensure its implementation. Secondly, the company should create fair, safe and effective schedules governing the workload of aircrew. Lastly, crewmembers are responsible for managing their own fatigue and their rest time effectively (Section 4.3.2, Category D, Sub-theme D4, pp. 103-104).

In keeping with the recommendations of the interviewees, Avers *et al.* (2009) emphasised that industry involvement from all stakeholders (the regulator, operator, and individual crewmember) is critical to successfully manage fatigue in aviation industries. Therefore, the regulator should be responsible for development and management of regulations that take due consideration of fatigue and its determinants. The individual (aircrew) is responsible for informed and effective management of their workload, work environment and rest period. The operator is responsible for the design of fair and effective schedules that suit the limitations and performance of pilots, and is also tasked with management of the workload and working conditions of aircrew (Avers *et al.*, 2009).

According to Caldwell (2005), education programmes and training that explicitly address the issue of fatigue and the science of sleep and circadian physiology are key requirements if the problem of fatigue is to be effectively addressed and dealt with in the operational aviation context. Co *et al.* (1999) emphasised that education plays an important role in managing fatigue, and that such education should be levelled at all industry members, schedulers, flight crew, policymakers, flight managers and cabin crew. Key issues to be addressed include knowledge of fatigue, sleep and circadian physiology, and the effects of fatigue on flight operations (Co *et al.*, 1999). Overall, this strategy would promote safety in aviation operations and improve the performance and alertness of crewmembers in regional airlines (Co *et al.*, 1999). As scheduling practices are considered the main contributor to fatigue and high workload, educational programs around this issue should be implemented for aviation management and regulators. Expert interviewees recommended that regulators be educated about the science and best practice of rostering schedules, and that regulators should change the existing regulations to reflect the science of fatigue, workload, and sleep. They also suggested a continuous discussion between relevant stakeholders to monitor, interrogate and adjust the scheduling regulations (Section 4.3.2, Category D, Sub-theme D1 and D2, pp. 101-102). From a literature perspective, D'Oliveira (2011) pointed out that airline management and regulators should revise work schedules so that they are no longer harmful to the pilots. In other words, schedules should be adjusted so that they avoid excessive wakefulness, and incorporate sufficient sleep and recovery periods. Similarly, a study by Co *et al.* (1999) suggests that aviation companies should review all scheduling practices that play a role in fatigue. Overall, this would ultimately limit the risk of fatigue in short-haul operations.

From a company perspective, airline management should also identify possible situations where factors that lead to fatigue may pose a risk to the safety and well-being of the flight crew (Dijkshoorn, 2008). Another possible solution to mitigate the effects of fatigue is to legislate that all aviation companies incorporate and apply Fatigue Risk Management systems (FRMS) (Gislason *et al.*, 2017). The ICAO defines a Fatigue Risk Management System as "a data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel is performing at adequate levels of alertness" (Stewart *et al.*, 2009). Stewart *et al.* (2009) pointed out that guidelines to incorporate such programs into an organisation can be found in ICAO Annex 6 and document 9966 (Fatigue Risk Management for Regulators).

From an individual perspective, flight crew should make responsible use of the opportunities afforded for rest and sleep, and avoid situations and activities (both on the job and during private time) that might detrimentally affect these factors

(Dijkshoorn, 2008). For example, flight crew should avoid the consumption of caffeine and alcohol before periods of sleep as these substances are widely known to contribute to fatigue (Gander *et al.*, 1998). Flight crew should also report possible work situations ahead of time where fatigue is anticipated (Dijkshoorn, 2008). Lastly, regular exercise as part of a healthy lifestyle is recommended, which has been shown to reduce the degree of fatigue resulting from stressful situations, and to aid recovery from fatigue (Dijkshoorn, 2008; Ferrer *et al.*, 1995).

Overall, implementation of these recommended solutions would vastly reduce the incidence of performance failures and impaired alertness, and it would improve the ability of crewmembers to safely operate an aircraft and perform safety-related tasks. In general, minimising crewmember fatigue would optimize performance and operational safety in the short-haul context, and make the work environment a safer and better place.

### 5.4 Implications for Denel SARA Development Project

Based on the study findings, many systemic drivers lead to the development of pilot fatigue and workload in the short-haul context. Given the potential consequences of fatigue outlined elsewhere in this study, the issue of fatigue is a serious one for aviation safety and should not be overlooked. The study is relevant to the Denel SARA project because of the inherently short-haul nature of this regional initiative. Virtually all of the aviation personnel will be subject to the contexts and factors discussed herein, and this study provides information and conclusions that will allow a better understanding of their work environment, facilitate more effective structuring and management of their workload, and simultaneously promote employee wellbeing and general safety in the short-haul context.

Scheduling practices were found in this study to be one of the main contributory factors to fatigue and high workload in aviation crewmembers. The study will provide SARA project developers, managers, and regulators with essential insights and information for the implementation of fair, sustainable and scientifically robust scheduling practices, optimal from the perspectives of employees, safe service delivery, and business interests. Such scheduling would be cognisant of crewmember needs, incorporating sufficient sleep and rest periods and avoiding excessive wakefulness. Policies should promote working conditions and scheduling practices commensurate with the capabilities and limitations of pilots. In the modern short-haul aviation context crewmembers are challenged and pushed beyond their capacities and limits, experiencing reduced rest periods, extended working hours and duty schedules, increased responsibilities and greater workload. Of particular importance to scheduling, the number of segments should be important factor to consider as flying 4 to 5 sectors per day might lead to pilot fatigue (due in large part to the workload-intensive nature of take-offs and landings). Flight duty period and long working hours should not exceed ten hours per day, and rest periods (between the end of one duty and the beginning of the next) should be more than 12 hours. The time spent commuting to and from work should be included as part of the duty period rather than the rest period. After performing consecutive duty periods pilots should be given two full days of uninterrupted rest (48 hours). Pilots should be strongly encouraged to make wise use of the rest and sleep opportunities afforded them, and wherever possible they should avoid performing consecutive early starts as this appears to be closely linked to fatigue in the short-haul context. Scheduling practices should ensure that pilots are not required to wake during the WOCL, when sleep is a physiological expectation and performance levels are low. As recommended by the expert interview respondents and by various literature sources, all SARA stakeholders should attend regular educational programs focused on the risk of fatigue and the importance of sleep and circadian physiology. Lastly, from an equipment perspective, the aircraft performing short-haul operations should be designed to accommodate three pilots to reduce the per capita workload. Rotational shifts would ensure that pilots get sufficient rest between flight duty periods.

Overall, due consideration of the insights and recommendations emerging from this study would minimise the risk of crewmember fatigue, promote their health and wellbeing, and optimize performance at the levels of both the individual and the organization. This would ultimately promote operational efficiency and safety in the SARA short-haul context.

### 5.5 Limitations

One possible limitation of the study is that the findings are based on the literature and expert interviews, rather than empirical investigation. This means that only the causes of fatigue that appear in the literature and have been experienced by interview respondents can be detected and addressed. Additionally, the qualitative nature of this research means that there is insufficient data to quantify the factors identified, and the relationships between them. Further empirical research is needed to investigate the relative importance and the degrees of interaction of the contributing factors in the South African short-haul context.

Another possible shortfall is that only four experts were recruited for interview. However, the information output of interviews apparently reached saturation after the third interview, with the final respondent adding no new information. Thus, it could be argued that in this instance four participants was a sufficient sample size.

The aim of the expert interviews was to gain the subjective and experiential insights of experts in the field, regarding the issues of fatigue and workload in short-haul operations. However, the interviews were fairly short and therefore not exhaustive, so important points could have been missed if participants forgot to mention certain issues due to insufficient prompting questions, or did not have time to discuss issues in full. Unfortunately, this is an unavoidable limitation of open-ended questions and limited duration interviews. A further limitation of the interview process was that certain questions on the interview sheet were very similar to each other, eliciting a high degree of repetition in responses. Several of these questions could have been left out, or replaced with different questions designed to increase the scope or depth of the responses.

## 5.6 Areas for Future Research

To address the issues raised in the Discussion and Limitations sections, the perspective of this project will need to be broadened in future studies. A fuller exploration, examination and quantification of fatigue in the aviation industry would involve a more detailed, nuanced and quantitative investigation of such factors as safety culture, individual time management, and management of fatigue in short-haul operations. These are factors that emerged only from the expert interviews, and were not mentioned in the literature. It is perhaps particularly important to prioritise these factors in future studies because whilst their importance is clear from the interviews, their absence from the literature suggests that they are poorly known and historically overlooked. Another important future direction is the broader effects of fatigue on human health. The expert interviews suggest that fatigue is a good point of departure from which to explore other issues of physical and psychological health in aviation, and this is considered a priority because of its far-reaching implications for the safety and wellbeing of crewmembers and passengers.

As has been mentioned already, empirical evidence is necessary to check, improve and extend the findings of this study. To gather these additional data, reliable and practical methods will need to be found to quantify the factors emerging from this study as important determinants of fatigue. For example, future studies could quantify actual fatigue levels by perception (direct measurements of fatigue in pilots). Appropriate tools for this would include such methods as the 7-point Samn-Perelli fatigue scale, the 10-item subjective stress scale, and the sleep quality self-rating five-point scale. These methods have been validated and are widely used in aviation research (Alcéu, 2015; Gander *et al.*, 2014; Petrilli, 2007; Samn and Perelli, 1982). They have several advantages, namely that they are easy to use in an operational environment, they are very quick, they involve only one score, and they are easily understood (Alcéu, 2015; Gander *et al.*, 2014; Petrilli, 2007; Samn and Perelli, 1982). To obtain sufficient sample sizes for quantitative analysis, it would be necessary to involve many short-haul aviation companies and perhaps even to provide incentives to increase the number of participants.

Another way of collecting relevant empirical data would be to include a quantitative component in surveys distributed to pilots. This could be an effective way to obtain the physiological measures needed to quantify the factors contributing to pilot/co-pilot fatigue in South African short-haul contexts. Such studies would involve collection of self-reported duty and sleep diaries, which could be used to investigate the subjective assessments of an individual's own sleep/wake patterns and flight/duty schedules (two key factors contributing to pilot/co-pilot fatigue). Sleep diaries and duty diaries have been widely used and validated in aviation studies (Gander *et al.*, 2013; Loh, 2004; Petrilli, 2007; Wegmann *et al.*, 1986). Sleep diaries have the advantage of being relatively simple, and duty diaries are considered a valuable and effective resource from which large quantities of information about crewmembers and operations can be quickly gleaned (Gander *et al.*, 2013; Loh, 2004). Further, methods such as actigraphy can be used to collect quantitative physiological measures for analysis of habitual sleep/wake behaviour (activity and movements) (Martin and Hakim, 2011; Noor *et al.*, 2013). This measure can record a variety of different sleep/wake behaviours without the disruption of usual activities (Sletten, 2007). It is used regularly in literature on sleep behaviour, and is considered a reliable alternative method to sleep diaries and polysomnography (PSG) for recording sleep data in operational settings (Noor *et al*., 2013; Otte *et al.*, 2011; Sletten, 2007).

Further data on crewmember workload could be collected via subjective perceived self-assessments such as the NASA Task Load Index (TLX) workload scale The NASA TLX is a multi-dimensional subjective workload assessment tool which allows operators to report their perceived mental workload using six dimensions (Federal Aviation Administration, 2010; Hart and Staveland, 1988; Loh 2004; Rubio *et al.*, 2004). This method is widely accepted and has been frequently used in aviation research (Kyongsun, 2010). Hart and Staveland (1988) considered it to be the most reliable method of assessing workload, especially during the flight phase when pilots are actually operating an aircraft. Butterbaugh (1982) stated that subjective methods such as the TLX are valuable tools, especially for pilots in the cockpit involved primarily in the monitoring and decision-making stages of flight.

Another potentially fruitful future research direction would be to investigate different airline companies (specifically the low-cost carriers) and systematically examine how their operators are experiencing fatigue.

A final recommendation for future research (and perhaps one of the areas most in need of critical assessment) would be to examine whether Flight Time Limitations and the associated regulations are appropriately supported by the latest scientific understanding of fatigue and its determinants in the aviation context. Regulations and protocols from different countries could be compared with a view to identifying which legislation is the most progressive with respect to fatigue and general safety in aviation. Other studies could examine the South African flight time and duty regulations with the aim of understanding the complexities of all parts of the aviation industry in relation to workload and fatigue. This could be done by developing an appropriate nationwide questionnaire distributed to all pilots/co-pilots in the South African aviation industry.

# CHAPTER 6

# CONCLUSION

## 6.1 Overall Remarks

This study represents an important step towards a better understanding of fatigue in the short-haul aviation industry. Overall, the study has embraced core human factor principles. The study is person-centred meaning that it emphasizes the centrality of the human being (in this case the pilot in the short-haul aviation context) within the work system.

The study acknowledges that short-haul pilots face considerable fatigue risks which have been highlighted as a serious safety concern. By adopting a systems approach, this study shifts the blame for aviation incidents and accidents away from simple human error. Instead, it has probed the complex nature of pilot fatigue and revealed some of the many factors that may affect it, and hence increase the risk of aviation incidents and accidents.

This study has examined the complex suite of influential factors present in aviation systems as modelled by Smith and Carayon-Sainfort (1989). These include technical, human, task, organizational and environmental aspects. The study has highlighted the fact that fatigue and workload are complex phenomena influenced by many interacting factors. Those encountered in the short-haul aviation context have been identified through literature analysis and expert interviews. Many factors in the short-haul context can lead to the development of pilot fatigue. Factors for which there was a lot of evidence of implication were generally highlighted in both in the literature analysis and the expert interviews. These included the following: high workload and stress associated with flying (especially multiple take-offs and landings); how tasks are organized according to scheduling practices; inadequate sleep; disturbed sleep because of early starts and late finishes; extended duty periods; multiple flight segments; environmental factors; and non-work-related factors (e.g. age, experience, family stress and more).

Fatigue-related factors mentioned during the expert interviews but not found in the literature included, organizational culture, time management, health implications of fatigue, and ways to mitigate fatigue. These aspects require specific focus in further studies. All of the factors identified in this study need to be considered as part of an integrated approach to managing and mitigating the risk of fatigue in short-haul operations. It must be borne in mind, however, that in a complex system, any change will have both intended and unintended effects and consequences. This study has not attempted to quantify the various factors or their effects, but it is clear that care should be taken when implementing any intervention within a complex system.

The study takes an initial step toward supporting pilots by highlighting the need to design work systems that are aligned with their capabilities, limitations, and performance abilities. The study found that there are various organizational structures and practices in the short-haul aviation context that need to be re-designed to incorporate HF/E knowledge and practice with regards to fatigue, workload, sleep, and physiological aspects. Such redesign could ultimately help to prevent performance failures, improve pilot alertness, and enhance the ability of crewmembers to safely operate their aircraft and perform safety-related tasks.

A holistic approach to balancing the components of the aviation work system is essential to maximizing the safety and well-being of the pilot which, in turn, will optimize overall operational safety and performance of the aviation system.

### 6.2 Practical Implications of the Research Study

This study represents a first step in examining short-haul pilots/co-pilots holistically within their work systems. The study contributes toward a growing understanding of workload and fatigue allowing a more accurate representation of their complexity in aviation systems. The establishment of this approach provides a foundation on which further studies can build to investigate the intricate and complex relationship between humans and the various work system components in the short-haul aviation context.

The theoretical findings with respect to the short-haul aviation industry can be applied to other aviation operations (e.g. military, charter, ultra-long-range operations). It is also very likely that fatigue issues raised with respect to pilots may also be relevant to other crewmembers such as cabin crew, air traffic controllers, maintenance crew and others. Aspects of this study will also be applicable to other high-risk industries besides aviation.

The new knowledge produced through this research will, it is hoped, increase awareness in the aviation industry regarding pilot fatigue and give airline companies impetus to promote measures by which to prevent and alleviate the risk of fatigue and excessive workloads for pilots in the short-haul aviation context.

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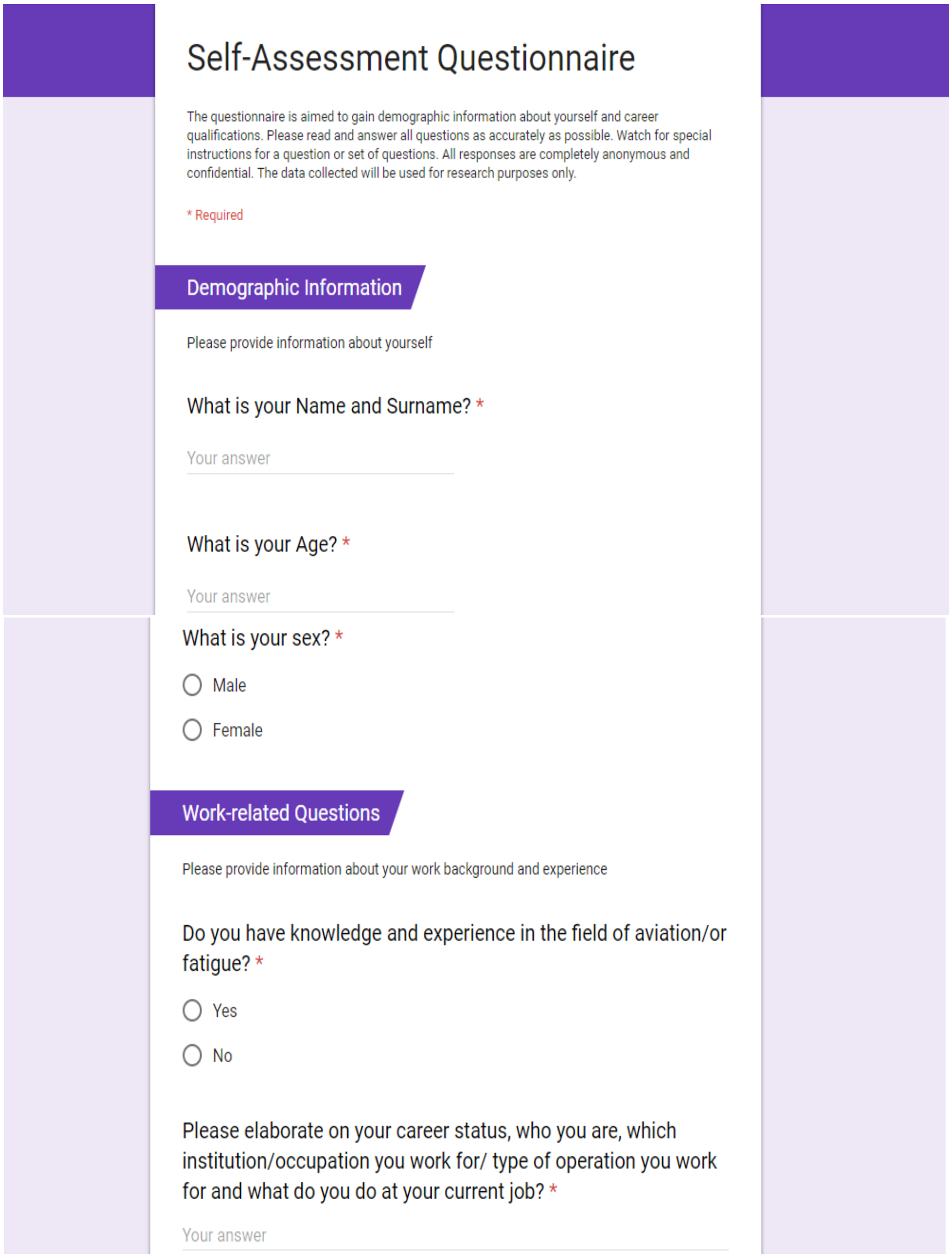
# APPENDICES

## APPENDIX A: Data Collection

### APPENDIX A1: Pre-screening Self-Assessment Questionnaire



Self-Assessment Questionnaire

The questionnaire is aimed to gain demographic information about yourself and career qualifications. Please read and answer all questions as accurately as possible. Watch for special instructions for a question or set of questions. All responses are completely anonymous and confidential. The data collected will be used for research purposes only.

* Required

**Demographic Information**

Please provide information about yourself

What is your Name and Surname? *

Your answer

What is your Age? *

Your answer

What is your sex? *

○ Male
○ Female

**Work-related Questions**

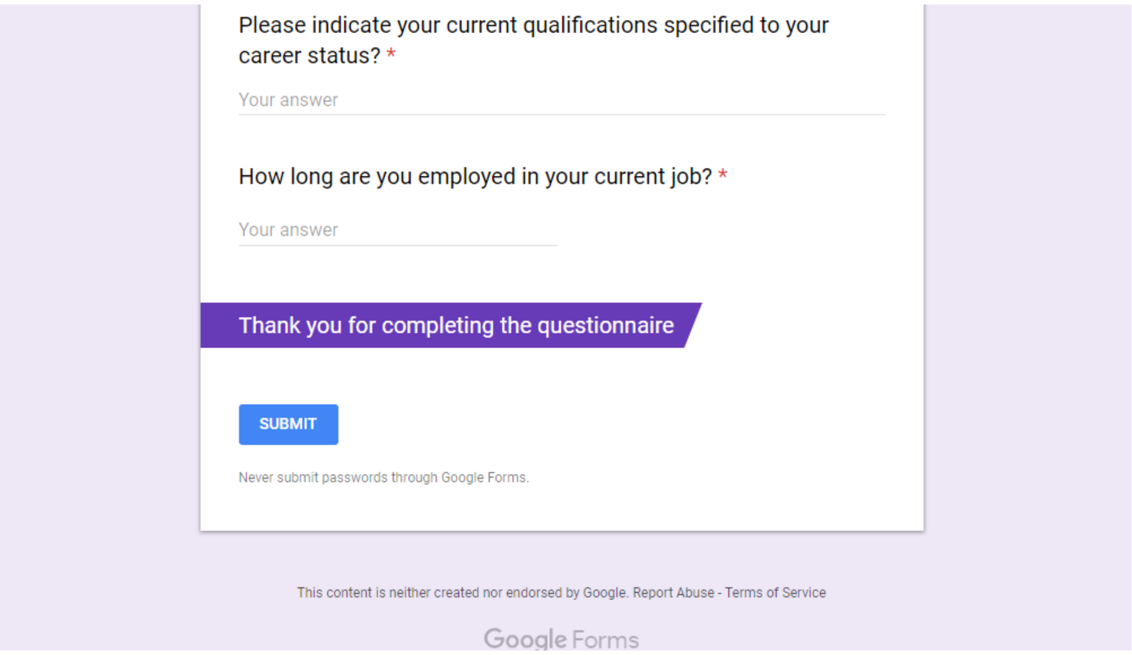
Please provide information about your work background and experience

Do you have knowledge and experience in the field of aviation/or fatigue? *

○ Yes
○ No

Please elaborate on your career status, who you are, which institution/occupation you work for/ type of operation you work for and what do you do at your current job? *

Your answer



Please indicate your current qualifications specified to your career status? *

Your answer

How long are you employed in your current job? *

Your answer

Thank you for completing the questionnaire

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## APPENDIX A2: Expert Interview Sheet

Date: ____________________

Good morning/afternoon. My name is Cleo Bennett, and I am currently completing a thesis on the fatigue of pilots/co-pilots executing short-haul operations. Thank you for agreeing to talk to me today. I am interested in understanding your thoughts and opinions regarding the aviation context/ fatigue in the aviation context and what you perceive the biggest contributing factors to fatigue in aircrew. To identify current issues that you find problematic. I will be asking you some questions. Please feel free to elaborate on any of your points. Some questions have options below it, but it will be as a guide to how you can answer the question and elaborate. You are free to answer the questions in any way you wish. If a question is unclear, don't hesitate to ask me to clarify it clearer. You may choose not to answer any of the questions and can terminate the interview at any time. All responses are completely anonymous and confidential. Any information regarding your airline affiliation (who you fly/work for) and name will not be asked in the interview to ensure privacy. The data collected will be used for research purposes only. The interview would only take 30-45 minutes of your time, and the information would be beneficial to my research. I will be writing down your answers in full, so please be patient if I ask you to pause at any stage. However, I would like to audio/tape-record the interview as well, so I do not miss anything that you say, but will not include your name on any documents or in the audio/tape recording. Lastly, your answers will be kept confidential. Is it okay if I audio/tape record our discussion?

Briefly, interviewees will ask about the following:

1) Interviewee background and experience. Give a brief overview of your education/yourself and expertise in the aviation context?

2) Do you have any idea of what fatigue means? What does fatigue, mean to you? Can you elaborate on your expertise/knowledge of fatigue?

3) In terms of fatigue, in your opinion, what extent is fatigue a concern in the aviation industry (please elaborate)?

Not at all? Minor? Moderate? Serious?

4) In your opinion, which aircrew members (role types) are most likely to be affected by fatigue and why?

5) Which operations are mostly affected by fatigue in the aviation industry, please elaborate on your answer? a) short-haul (commercial, domestic/regional); or b) long-haul, ultra-long-haul or c) both.

6) In your opinion, what do you think are the causes of fatigue?

a) Do you think that the current regulations into duty schedules or shift schedules are one of the main issues contributing to fatigue and why?

b) Do you see any trend in how the working hours have evolved in the industry?

c) Is their pressure for aircrew members to work more than their normal duty schedule?

d) Where do you think the problem lies?

7) In your opinion, what other factors apart from the duty and shift schedules could contribute to fatigue (task-related, non-work-related, individual factors, etc.).

8) In your opinion, in what way do you think fatigue can affect aircrew performance?

9) In your opinion, what can be done individually, on a company level, at a governmental level to mitigate fatigue?

a) What steps/ideas would you consider appropriate?

b) Describe how you would like fatigue to be handled/spoken about in an airline?

10) Are there any other important factors that have not been raised in the interview, that you find problematic concerning fatigue in the aviation context?

Thank you for your time and participation. It is much appreciated.

## APPENDIX A3: Zoom Instruction Sheet

Please follow the set of instructions carefully once you have clicked on the link it takes about 5 to 10 minutes to connect.

1) Click on the link in the email
2) A Redirect Notice page will appear on the screen, click on the first message stating "The page you were on is trying to send you to http.(click on this link)
3) The link will send you to the Zoom program and it will automatically download the program. If it does not download automatically then click "Download Here"
4) Then open the program that you downloaded, it should run till 100%
5) At the bottom of the screen click on the icon illustrated with a video camera in blue which is the program you just downloaded.
6) In the Zoom program a box will pop-up which states open Zoom meeting.
7) Click on open Zoom meeting to proceed in order for it to connect.
8) Once you are in, a video computer audio will appear on the screen, then click join with computer audio.
9) The program will ask you to provide your name (type in your name).
10)Thereafter the interview session will proceed. Thanks

Note: Please make sure the speaker or volume on your laptop, smartphone or tablet is on high volume.

# APPENDIX B: General Information

## APPENDIX B1: Ethical Clearance Letter for new method

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

**HUMAN KINETICS & ERGONOMICS**
**Tel: +27 (0)46 6038468**
**Fax: +27 (0)46 6038934**
**Email: m.mattison@ru.ac.za**

16 November 2018

Cleo Bennett – g13b7205@campus.ru.ac.za
Swantje Zschernack – s.zschernack@ru.ac.za

Dear Cleo and Swantje,

**Final Ethical Clearance – Application HKE-2018-02**

Your application for ethical clearance for the study titled "*Workload of pilots and co-pilots executing short-haul flight operations"* (reference number HKE-2018-02) has been approved by the HKE Ethics Committee. This clearance is valid until the end of 2018. Should your data collection extend into 2019, please notify the HKE Ethics chair, so that an extended letter for ethical clearance can be provided.

Please also note that this final approval relates to the amended application you submitted, and that any significant changes made to the study and procedures need to be communicated to the HKE Ethics Committee (this includes changes in investigators), and another full review may be requested. Should you fall back onto the protocol of your initial application, you will need to provided gatekeeper permission letters from the various airlines that you will be sampling your participants from.

Upon completion of your study, please submit a short report indicating when and whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the HKE Ethics committee should be aware of.

Sincerely,

Miriam Mattison

M.C. Mattison
2018 HKE Ethics Chairperson
Department of Human Kinetics and Ergonomics
Rhodes University; Grahamstown
Tel: + 27-46-603 8468
Cell: +27-82 319 4626

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## APPENDIX B2: Director of Human Resources Ethical Clearance

RHODES UNIVERSITY
*Where leaders learn*

**Human Resources Division**
Office of the HR Director
Administration Building, Grahamstown, 6139, South Africa
PO Box 94, Grahamstown, 6140
South Africa
t: +27 (0)46 603 8114
f: +27 (0)46 603 8046
e:l.govender@ru.ac.za

www.ru.ac.za

14 November 2018

Cleo Bennett
Human Kinetics & Ergonomics
RHODES UNIVERSITY
G13b7205@camput.ru.ac.za

Dear Cleo Bennett

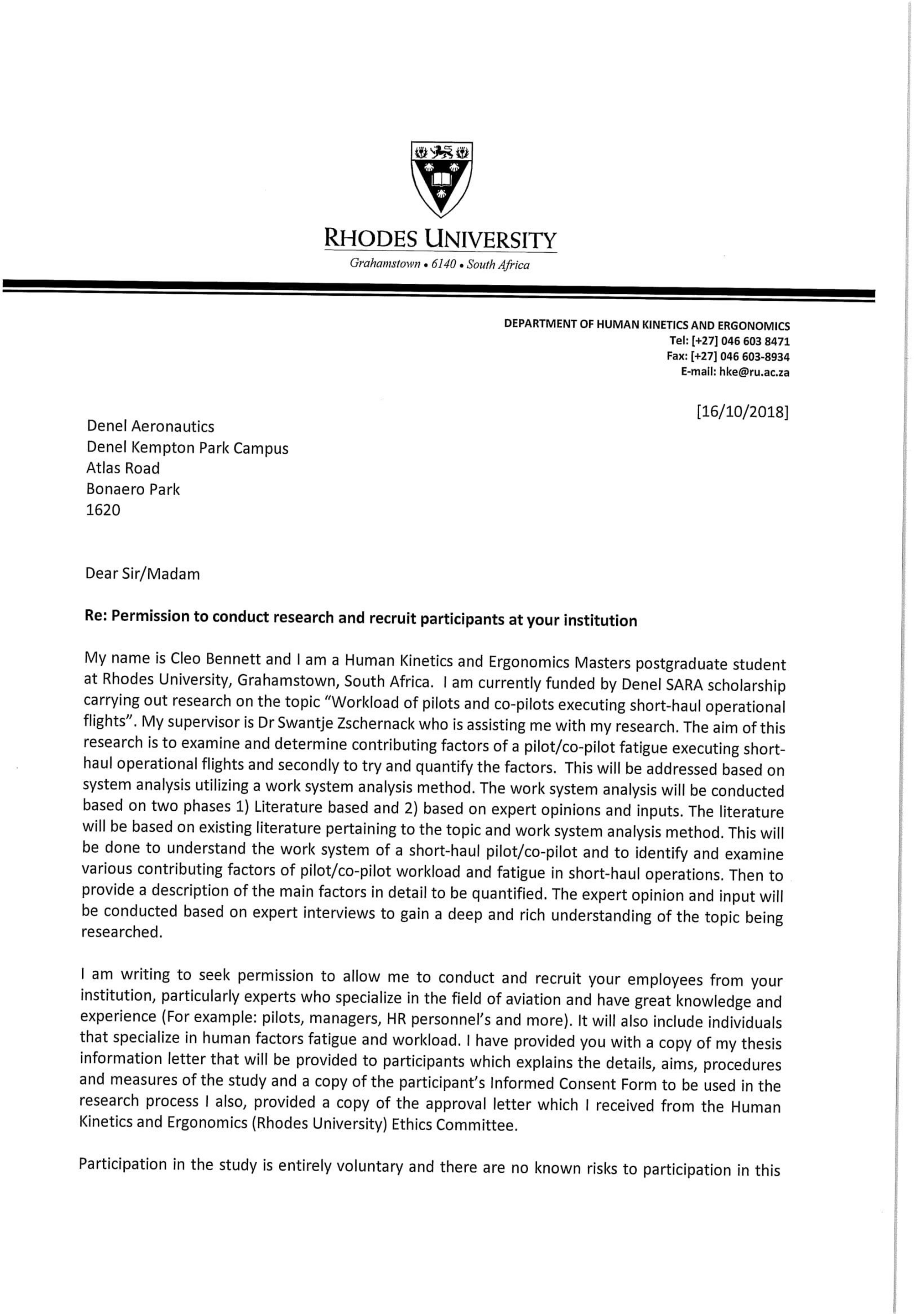
**REQUEST TO CONDUCT RESEARCH WITH RHODES UNIVERSITY STAFF AND/OR STUDENTS**

This letter is to confirm that your request to conduct research on ***"Workload of pilots and co-pilots executing short-haul flight operations"*** topic has been approved by the Ethics Committee. In my capacity as HR Director, I do not have any objection should you wish to follow a coordinated approach by surveying and/or interviewing staff.

Yours sincerely

Loshni Govender
HR Director

## APPENDIX B3: Denel Management Institution Clearance



RHODES UNIVERSITY
*Grahamstown • 6140 • South Africa*

**DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS**
**Tel: [+27] 046 603 8471**
**Fax: [+27] 046 603-8934**
**E-mail: hke@ru.ac.za**

[16/10/2018]

Denel Aeronautics
Denel Kempton Park Campus
Atlas Road
Bonaero Park
1620

Dear Sir/Madam

**Re: Permission to conduct research and recruit participants at your institution**

My name is Cleo Bennett and I am a Human Kinetics and Ergonomics Masters postgraduate student at Rhodes University, Grahamstown, South Africa. I am currently funded by Denel SARA scholarship carrying out research on the topic "Workload of pilots and co-pilots executing short-haul operational flights". My supervisor is Dr Swantje Zschernack who is assisting me with my research. The aim of this research is to examine and determine contributing factors of a pilot/co-pilot fatigue executing short-haul operational flights and secondly to try and quantify the factors. This will be addressed based on system analysis utilizing a work system analysis method. The work system analysis will be conducted based on two phases 1) Literature based and 2) based on expert opinions and inputs. The literature will be based on existing literature pertaining to the topic and work system analysis method. This will be done to understand the work system of a short-haul pilot/co-pilot and to identify and examine various contributing factors of pilot/co-pilot workload and fatigue in short-haul operations. Then to provide a description of the main factors in detail to be quantified. The expert opinion and input will be conducted based on expert interviews to gain a deep and rich understanding of the topic being researched.

I am writing to seek permission to allow me to conduct and recruit your employees from your institution, particularly experts who specialize in the field of aviation and have great knowledge and experience (For example: pilots, managers, HR personnel's and more). It will also include individuals that specialize in human factors fatigue and workload. I have provided you with a copy of my thesis information letter that will be provided to participants which explains the details, aims, procedures and measures of the study and a copy of the participant's Informed Consent Form to be used in the research process I also, provided a copy of the approval letter which I received from the Human Kinetics and Ergonomics (Rhodes University) Ethics Committee.

Participation in the study is entirely voluntary and there are no known risks to participation in this

study. All information that will be provided will be kept strictly confidential and would be used only for academic purposes. The identity of your institution/airline and name of respondents will be treated with complete confidentiality and will not appear in any thesis or publications resulting from the study unless agreed to.
After the data has been analyzed you will receive a copy of it and if you are interested in greater detail, an electronic copy of the entire thesis can be made available to you once my thesis is completed.

If you agree, kindly sign below acknowledging your consent and permission for me to approach your employees and return the signed form via email. Your approval to conduct this study will be greatly appreciated. If you have questions or wish to verify the research, please feel free to contact me. Thank you for your time and I hope that you will find our request favourable.

Yours sincerely,

Ms Cleo Bennett (Rhodes University Human Kinetics and Ergonomics MSc Student)

## Institution Consent Form

**Participation Consent**

I consent for you to approach experts who specialize in the field of aviation (pilots, researchers and managers) and experts who specialize in fatigue and workload research.

**I acknowledge and understand:**

- The role of the institution is voluntary.
- I may decide to withdraw the institution's participation at any time without penalty.
- Individual experts in the field of aviation, fatigue and workload will be invited to participate, and that permission will be sought from them too.
- All information obtained will be treated in strictest confidence.
- The respondent's names will not be used and will not be identifiable in any written reports about the study.
- The institution will not be identifiable in any written reports about the study.
- Participants may withdraw from the study at any time without penalty.
- A report of the findings will be made available to the institution and participants.

| | |
|---|---|
| **Full Name:** | CHRISTIAAN DIRK VERSLUIS |
| **Position:** | MANAGER: R&D AND ENG TRAINING |
| **Signature:** | |
| **Date:** | 2018-10-24 |

## APPENDIX B4: Information Letter to Experts

**Cleo Bennett, 0835080653 • E-mail: g13b7205@campus.ru.ac.za or bennettct94@gmail.com**

### INFORMATION TO EXPERTS

Dear Participant,

Thank you for showing interest in taking part in this study titled “System Analysis of the workload of pilots and co-pilots executing short-haul flight operations”. The purpose of this letter is for you to obtain an understanding of the project, to ensure that you understand what is expected of you and the risks and benefits associated with the study. Please ensure that you read through the letter carefully and the accompanying consent form. The consent form will be signed at your respective workplace. You will then email the consent form required back to the researcher.

### INFORMATION ABOUT THE RESEARCHER AND SUPERVISORS:

My name is Cleo Taylor Bennett and I am a Human Kinetics and Ergonomics Masters student at Rhodes University and the researcher for this study. My supervisor is Dr Swantje Zschernack who is assisting me with my research.

### PURPOSE OF RESEARCH PROJECT AND AIM:

Fatigue is considered as one of the key problems in many industries worldwide impacting on performance levels, efficiency and productivity. In today’s modern aviation industry worldwide, competition between aviation and airline companies has become intense and the demand for air travel has increased from that of the past relying heavily on 24-hour operations. To support 24-hour demands, crewmembers are challenged and pushed beyond their capabilities and limits having to reduce their rest periods, extend their working hours, duty schedules, increase responsibilities and workload. These demands are predominately driven and very often associated with company and ecological goals aiming for maximum profit and growth. Despite the economic benefits of these factors, it has however resulted to crewmembers experiencing high risk of fatigue which has ultimately been recognised as a safety concern in many aviation industries worldwide. Aviation or crewmember fatigue is described as a reduced physical and mental capability, which is caused from high workload (mental and physical), sleep loss and sleep deprivation, thus associated with the responsibilities and nature of the job. Fatigue in pilots can impair alertness and ability of crewmembers to safely operate an aircraft and perform safety related tasks. The job of a pilot is often seen as high workload, stress-inducing occupation because it would include long duty periods, unpredictable working hours, rotating schedules, flying multiple flights, travelling across multiple time zones, circadian disruptions and insufficient sleep. Flying an aircraft is requires many tasks and imposes demands on the pilot’s mental workload (cognitive processes). High workload has a direct correlation to fatigue and may impact negatively on the pilot’s performance and safety.

Much of interest in literature with respect to pilot fatigue have been attributed to underlying sleep related aspects such as sleep disruption and sleep loss in relation to pilots executing long-haul flight operations. Long-haul flight operations also referred to as International flights usually travel across multiple times zones in a different country. Long-haul pilots are responsible for a range of convenient departures and arrival schedules with the ability to travel long distance (6 hours and above) daily. The situation with short-haul operations flights is an area that has received comparatively little attention, despite the nature of their profession have been associated with considerable fatigue risk effects. There are a variety of attributes of short-haul operations that set it apart from long-haul operations. Short-haul operations also referred to as domestic or regional flights travel in the same time zone, where humans sleep at their own home base. This environment is predominately characterised by daytime flying with several scheduled flights and short distance travelling (30 minutes to 3 hours). However, in today’s short-haul operations the requirement for high crew and aircraft utilization with tight work schedules, responsibilities and prescribed duties contribute to increased perception of high workload. Short-haul (domestic/regional) pilots commonly identify sleep deprivation and high workload as the main contributing factors to fatigue.

Therefore, pilots working for such operation may be becoming seriously fatigued. However, the knowledge of fatigue relating to which factors contribute the most during short-haul operations is not well understood. It is not clear as to where the workload lies in this profession. Pilot fatigue has always been an issue in the aviation world but has often been overlooked. This poses a very troubling threat to aviation safety and should be taken seriously. Therefore, the study aims to examine and determine contributing factors of a pilot/co-pilot fatigue executing short-haul operational flights and secondly to try and quantify the factors.

**Overview of procedure:** A key process to examine the contributing factors pertaining to the research aim would be through a complete understanding of the pilots work system in short-haul operations. To achieve the study objectives, a work system analysis will be conducted as the system analysis method to identify the contributing factors of pilot/co-pilot fatigue in short-haul operations. The work system analysis will be conducted based on two phases 1) Literature based and 2) expert interviews. The literature will provide a description of the main factors in detail to be quantified and expert opinions will be done utilizing expert interviews in order to gain a deep and rich understanding of the topic being researched.

The interview will be conducted to seek experts who specialize in the field of aviation and have great knowledge and experience (for example: pilots, managers, HR personnel’s and more) and expertise of fatigue in the aviation context. The expert interview will be conducted through one-on-one interviews (face to face or via telephone). Expert interviews are considered the most commonly and widely used method in present-day qualitative research. Interviews in research can provide a flexible, valuable and participatory method to obtain depth of information on a topic based on participants experiences and perceptions.

Interview sessions will be conducted to those experts that volunteer to participate in the study. The aim of the interview is to gain an understanding about your thoughts and opinions regarding the aviation context/ fatigue in the aviation context or fatigue in pilots/co-pilots and what you perceive are the biggest contributing factors to aircrew fatigue. A set of questions will be prepared to guide the interview. Semi-structured interviews will be performed consisting of open-ended questions. The researcher will have the freedom to ask follow-up questions and to ask for clarification. The aim of the interview will be to turn it into a discussion in order to gain valuable insight on the topic being researched. Interview sessions will be organised according to your availability and schedule. The researcher will schedule an appointment and time that best suits you prior to the interview. You will be required to fill in a pre-screening self-assessment questionnaire online before commencement of the interview. You will be interviewed either face to face at your respective workplace or via telephone for those who I will not be able to meet at your respective workplace. All interviews will be recorded in full writing and via voice record using the researcher’s cell phone and tape record. Permission for the recording will be granted by you at the start of the interview session. The time frame of the interview will only last between 30 to 45 minutes.

**Anonymity**: Information that will be obtained in connection with the study will remain strictly confidential. Confidentiality is maintained by means of assigning you to a code for identification purposes and thus you will remain anonymous with regards to your data and results. Any information regarding your airline affiliation (who you fly/work for), aviation industry or university institution you work for will not be mentioned anywhere in the study. Audio and tape recordings will remain strictly confidential and will be stored in a password protected computer. Audio recordings will be granted only if you grant the researcher to do so. Data will be collected by means of paper and a computer (laptop) which is password protected. All information will be stored indefinitely for use in future publications, in conferences and seminars but will remain coded as well to guarantee your anonymity.

**Risks and Benefits**: It is unlikely that you will experience any injuries, risk of harm or embarrassment during this study, as the procedures are not considered harmful in any way because it will only require interviews. You might however feel uncomfortable answering some of the questions during the one-on-one interview sessions. However, the questions been asked were not designed to make you feel uncomfortable in any sort. You do not have to answer some questions if you feel uncomfortable or not allowed to do so. You will have some direct benefits from the study. Feedback of the results from the study will be provided to you after the completion of the thesis. The results and research conducted may contribute to an improved understanding of the nature of your work better and improved understanding of the contributing factors of fatigue and demands placed on pilots executing short-haul flight operations. You will be part of an important research.

**PARTICIPATION AND WITHDRAWAL:**

You can choose whether you want to participate in the study or not. If you volunteer to participate in the study, you will be reminded that you can withdraw at any time. If you have any queries, questions regarding the project or need assistance in any way, please do not hesitate to contact the researcher. Furthermore, if at any stage, or for whatever reason you are unable to comply with the requirements before testing occurs, please would you kindly inform the researcher. Your participation is highly appreciated. Thank you for showing an interest in this study. I hope you will learn a lot from this and that you enjoy the experience.

Yours Sincerely,

| | |
|---|---|
| Ms Cleo Bennett | Dr Swantje Zschernack |
| 0835080653 | 0466038470 |
| bennettct94@gmail.com/ | s.zschernack@ru.ac.za |
| g13b7205@campus.ru.ac.za | Supervisor |
| Rhodes University MSc Student (Researcher) | |

## APPENDIX B5: Expert Consent Form

**DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS**
Cleo Bennett, Cell: 0835080653 • E-mail: g13b7205@campus.ru.ac.za or
bennettct94@gmail.com

### EXPERT CONSENT FORM

I, ____________________________, agree that I have been informed as far as possible by the researcher both verbally and in written form, of the purpose, experimental procedure, measurements and testing in the following research project entitled:

**System Analysis of the workload of pilots/co-pilots executing short-haul operations**

I have read the information letter and understand what is expected of me. Any queries concerning this study have been answered to my satisfaction.

By voluntarily consenting to participate in the study, I am fully eligible to participate in the study and I fit in the participation criteria as listed in the letter of information. In, agreeing to participate I accept joint responsibility together with the Human Kinetics and Ergonomics Department; that in the case of an unforeseen incident occurring because of the study, the Human Kinetics and Ergonomics department will be responsible for compensation costs ensuring the participant has fully recovered. The Department will, however, waiver any legal recourse against the researchers of Rhodes University, from all claims resulting from negligence on my part. Further, I am aware that I can withdraw from the study at any stage and that this will not affect my status now or in the future. I will not receive any payment for participating in the study over and above my usual salary.

I understand that although my anonymity, privacy and confidentiality will always be continually protected, the results obtained from this study may be published for statistical and scientific purposes. I agree to allow the information collected to be used for scientific purposes. I have read and fully understood the above information and information in the letter accompanying this form.

***I therefore consent to voluntary participate in this study.***

**PARTICIPANT (OR LEGAL REPRESENTATIVE):**

| | | |
|---|---|---|
| (Print name) | (Signed) | (Date) |

**PERSON ADMINISTERING INFORMED CONSENT:**

| | | |
|---|---|---|
| (Print name) | (Signed) | (Date) |

**WITNESS:**

| | | |
|---|---|---|
| (Print name) | (Signed) | (Date) |

**WITNESS:**

| | | |
|---|---|---|
| (Print name) | (Signed) | (Date) |

## APPENDIX B6: Ethical Clearance Letter for initial envisioned method

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

**HUMAN KINETICS & ERGONOMICS**
**Tel: +27 (0)46 6038468**
**Fax: +27 (0)46 6038934**
**Email: m.mattison@ru.ac.za**

04 May 2018

Cleo Bennett – g13b7205@campus.ru.ac.za

Dear Cleo Bennett,

**Re: Ethical Clearance – Application HKE-2018-02**

Your application for ethical clearance for the study titled *“Workload of pilots and co-pilots executing short-haul flight operations”* (reference number HKE-2018-02) has been approved with stipulations by the HKE Ethics Committee.

These stipulations include:

- Gatekeeper permission required

This permission should be submitted to the HKE Ethics Committee for record keeping purposes.

Any significant changes made to the study and procedures need to be communicated to the HKE Ethics Committee, and another full review may be requested.

Upon completion of your study, please submit a short report indicating whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the HKE Ethics committee should be aware of.

Sincerely,

Miriam Mattison

M.C. Mattison
2018 HKE Ethics Chairperson
Department of Human Kinetics and Ergonomics
Rhodes University; Grahamstown
Tel: + 27-46-603 8468
Cell: +27-82 319 4626

www.ru.ac.za

## APPENDIX C: Papers selected for Literature Analysis

Alcéu, P.M.D.M. (2015). *Managing fatigue in a regional aircraft operator: fatigue and workload on multi-segment operations*. Unpublished Master's thesis, Lusophone University of Humanities and Technology School of Economics and Organizations, Lisboa, Portugal.

Arthur, W., Bennet, W., Stanush, P.L., & McNelly, T.L. (1998). Factors that influence skill decay and retention: a quantitative review and analysis. *Human Performance, 11(1*), 57-101.

Ashley, N.J. (2013). *Setting a baseline for cognitive fatigue in student pilots.* Unpublished Master's thesis, Massey University, Palmerston North, New Zealand.

Avers, K., & Johnson, W.B. (2011). A review of Federal Aviation Administration fatigue research: Transitioning scientific results to the aviation industry. *Aviation Psychology and Applied Human Factors*, *1(2)*, 87-98.

Bainbridge, L. (1983). Ironies of automation. *Automatica, 19(6)*, 775 779.

Baxter, G.D., Rooksby, J., Wang, Y., & Khajeh-Hosseini, A. (2012). The ironies of automation: still going strong at 30?. *Proceedings: ECCE 2012 Conference. Edinburgh, North Britain, 29-31 August*, 65-71.

Bourgeois-Bougrine, S., Cabon, P., Mollard, R., Coblentz, A., & Speyer, J.J. (2003a). Fatigue on aircrew from short-haul flights in civil aviation: the effects of work schedules. *Human Factors and Aerospace Safety*, 3, 177-188.

Bourgeois-Bougrine, S., Carbon, P., Gounelle, C., Mollard, R., & Coblentz, A. (2003b). Perceived fatigue for short-and long-haul flights: a survey of 739 airline pilots. *Aviation, space, and environmental medicine*, *74(10)*, 1072-1077.

Broo, S. (2013). *Experiencing Long Haul Flight*. Unpublished Bachelor's thesis, Vaasa University of Applied Sciences, Finland.

Brown, J. P. (2016). The Effect of Automation on Human Factors in Aviation. *The Journal of Instrumentation, Automation and Systems*, 31-46.

Caldwell, J.A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease, 3(2)*, 85-96.

Caldwell, J.A., Mallis, M.M., Caldwell, J.L., Paul, M.A., Miller, J.C., & Neri, D.F. (2009). Fatigue countermeasures in aviation. *Aviation, Space, and Environmental Medicine, 80(1)*, 29-59.

Caldwell, J.A., & Caldwell, J.L. (2016). *Fatigue in Aviation: A Guide to Staying Awake at the stick (2nd ed.)*. London and New York: Routledge.

Chang, S.C. (2002). A new aircrew-scheduling model for short-haul routes. *Journal of Air Transport Management*, *8(4)*, 249-260.

Chialastri, A. (2012). Automation in Aviation. In K. Florian (Eds.), *Automation* (pp. 79–102). Rijeka: InTech.

Civil Aviation Authority (2004). *CAP 371 The Avoidance of Fatigue in Aircrews, Guide to Requirements*. URL: https://publicapps.caa.co.uk/docs/33/CAP371.PDF. Last accessed: 13 November 2018.

Co, E.L., Gregory, K.B., Johnson, J.M., & Rosekind, M.R. (1999). *Crew Factors in Flight Operations XI: A Survey of Fatigue Factors in Regional Airline Operations* (Report No: NASA Technical Memorandum 208799). Moffett Field, California: NASA Ames Research Center.

David-Cooper, M.R. (2018). *Pilot Fatigue A Study on the Effectiveness of Flight & Duty Time Regulations for Professional Pilots in Canada*. URL: http://www.onthemovepartnership.ca/wp-content/uploads/2018/04/FDT-Study-Final-Report.pdf. Last accessed: 13 November 2018.

De Gray Birch, C. (2012). *The effects of sustained attention, workloads and task-related fatigue on physiological measures and performance during a tracking task*. Unpublished Master's thesis, Rhodes University, Grahamstown, South Africa.

Desmond, P.A., Neubauer, M.C., Matthews, G., & Hancock, P.A.  (2012). *The Handbook of Operator Fatigue*. USA: Ashgate Publishing, Ltd.

Deros, B.M., Daruis, D.D.I., & Bahurudeen, N. (2012). Fatigue factors among regional pilots in Malaysia. *International Journal of Medicine and Medical Sciences*, *4(5)*, 115-122.

Dijkshoorn, R. (2008). *Flightcrew fatigue recommendations for airlines on reducing and preventing crew fatigue*. Unpublished Master's thesis, Delft University of Technology, Delft, Netherlands.

Diken, A.F. (2011). *Analysis of different phases of a commercial flight using radio call response times, workload, situation awareness and fatigue ratings*. Unpublished Master's thesis, University of Iowa, Iowa City, Iowa.

Dinges, D.F., Graeber, R.C., Rosekind, M.R., & Samel, A. (1996). *Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation* (Report No: NASA Technical Memorandum 110404). Moffett Field, California: Ames Research Center.

Dumitru, I.M., & Boşcoianu, M. (2015). Human factors contribution to aviation safety. *Proceedings: International Conference of Scientific paper AFASES. Brasov, 28-30 May 2015*, 49-53.

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