A Comprehensive Literature Review on Crew Fatigue in the Aviation Sector

Aditya Sharma

Student of BBA in Aviation Management, School of Business, Galgotias University

ABSTRACT
Causes of human fatigue, such as lack of sleep, disruptions to the body's natural rhythm, health issues, and work-related factors, can have negative impacts on decision-making abilities, memory function, judgment skills, reaction time and awareness in aviation operations. These effects may lead to accidents. This comprehensive study aims to analyze the origins, repercussions, assessment methods and strategies for handling fatigue and associated risks in airline operations using a thorough review of existing literature from both academic and industry sources. The research included peer-reviewed articles as well as publications from various stakeholders within the aviation sector that addressed this topic. It was revealed that fatigue-related risks in aviation are multifaceted and at times unclear. Specifically noted was a significant increase in risk with workdays longer than 16 hours; insufficient pre-shift sleep durations of less than 6 hours; or when work coincides with regular sleep patterns for crew members. Additionally identified were aspects requiring further investigation related to these risks. The conclusion presents recommendations for future studies aimed at reducing these inherent dangers.

Keywords: Fatigue, Aviation, Sleep loss, Literature review, Aviation safety, Risk management, Safety management systems.

1. INTRODUCTION

The push to enhance productivity and flexibility in work schedules has occasionally resulted in longer workdays, shorter intervals between consecutive workdays, and a wider range of start and end times for the workday. As a result, fatigue is widely recognized as a prevalent aspect of modern life, with its impact ranging from occasional mild complaints to severe repercussions such as burnout and chronic fatigue syndrome. ((Dawson, 2011); (Mohren, D., 2007)).

The complete extent of fatigue is often difficult to discern, but much of its harmful consequences have been recognized for a long time. Individuals experiencing fatigue tend to exhibit slower thinking and movement, make more errors, and experience difficulties in memory when compared to well-rested individuals. These adverse effects can contribute to errors and accidents in aviation.((Caldwell et al., 2009);(Gawron, 2016); (Wang & Chuang, 2014)). In 28 well-known experts in the field of sleep research stated that fatigue is the "most significant identifiable and avoidable factor leading to accidents in transportation (accounting for 15-20% of all accidents).(Ahasan et al., 2001). Pilot fatigue presents a significant issue in modern aviation operations due to prolonged and varying duty schedules, disruptions to the body's internal clock, and insufficient sleep. Many of these negative impacts of fatigue also affect ground handling personnel in aircraft operations((Rashid et al., 2012).

There is currently no single definition of fatigue, as it is commonly used in various contexts ((Dawson, 2011); (Gawron, 2016); (Horrey et al., 2011)), For instance, it was stated that fatigue can be observed through mental decline, physical decline, and/or sleep disturbances. In a broader definition the National Road Transport Commission ((NRTC, 2001), 2001) Fatigue is described as a collection of symptoms (such as reduced alertness, decreased performance, impaired judgment, etc.) and causes (including inadequate sleep duration and breaks, prolonged physical or mental exertion, disruption of circadian rhythm, etc.). Some researchers have gone beyond this to encompass additional factors when defining fatigue For example, (Williamson et al., 2011) Scholars primarily attribute fatigue to the need for rest rather than a lack of sleep. They defined fatigue as the biological urge for rejuvenating rest, which may or may not involve sleeping, depending on the type of fatigue experienced. This can manifest as drowsiness and mental, physical, or muscular exhaustion based on its underlying cause. The authors also noted a definite link between fatigue and safety-related incidents in high-risk sectors. Fatigue gained attention among researchers towards the end of the nineteenth century through Edward Thorndike's studies on mental. Physiological aspects of sleep were then explored by Henri Piaeron in 1913. During the 1920s, Kleitman and his team conducted research on circadian rhythms, sleep-wake patterns, and the impact of lack of sleep. Since World War II, there has been growing significance in studying fatigue and its physiological effects on workers, leading to a decline in performance, particularly in high-risk sectors such as aviation(Horrey et al., 2011). Recently, theoretical concepts for circadian rhythm and sleep have been adapted from laboratory settings to forecast fatigue and, in turn, performance. (Dawson, 2011). These lifelike models aim to provide valuable quantitative data on potential fatigue levels and strategies for reducing the risk associated with specific work-sleep patterns. It has been demonstrated that consistent exposure to sleep deprivation, circadian misalignment, or excessive workload can lead to significant declines in human performance as well as various preventable health issues (NASA-ARC, 2016).

The particular circumstances and dynamic environment of aviation lead to various causes of fatigue, including factors like the quantity, timing, and quality of daily sleep (sleep/wake schedule), duration since last sleep period (continuous hours awake), time of day (circadian rhythm), travel across multiple time zones, workload, and duration of task (Bendak & Rashid, 2020). The transportation sector was among the earliest to address fatigue risk, implementing a range of intricate regulations aimed at managing factors that lead to exhaustion. While ground-based workforce in road and marine transportation encountered typical triggers for fatigue, aviation regulators have faced an even more complex challenge due to its unique nature, particularly with regards to rapid time zone changes (Bendak & Rashid, 2020).

Fatigue in the aviation industry has traditionally been considered from an academic perspective or from a practical, operational standpoint, often along separate paths. This study seeks to comprehensively explore the causes and impact of fatigue in airline operations through a systematic review of literature, encompassing peer-reviewed sources as well as industry documents. It specifically delves into strategies for managing fatigue risks, which involve assessing and minimizing fatigue. The aim of this review is to provide deeper insights into this complex issue with the goal of integrating fatigue risk within the broader safety management system in aviation operations and ultimately reducing its prevalence.

2. LITERATURE REVIEW

The exploration of literature regarding fatigue in aviation spans several critical dimensions, encompassing its underlying causes, consequential impacts, methods for measurement or prediction, available countermeasures, and future research avenues. This comprehensive examination sheds light on the multifaceted nature of fatigue within the aviation sector, providing essential insights for understanding and mitigating its adverse effects. Fatigue, widely acknowledged for its detrimental impact on both physical and mental well-being, is underscored by the consensus that an optimal sleep duration of approximately 8 hours per day is essential, albeit subject to individual variability ((Missoni et al., 2009);(Härmä, 1993); (UK-CAA, 2007); (Dongen, 2006)). Prolonged periods of wakefulness or inadequate sleep over consecutive days precipitate an accumulation of the body's sleep debt, intricately tied to the natural circadian rhythm that governs the body's urge to rest (Gander et al., 2013) Of particular concern is the intersection between sleep deprivation and circadian influences, wherein the circadian rhythm exerts pervasive effects on alertness and performance. Fluctuations in body temperature, reflective of the circadian cycle, play a pivotal role in modulating performance levels, with lower temperatures correlating with diminished alertness and slower reaction times. Night shift workers are especially vulnerable to compromised performance due to disruptions in their circadian rhythms, highlighting the critical importance of understanding and addressing these factors within the aviation context((Åkerstedt & Wright, 2009); (Bendak, 2003);(Lee & Kim, 2018)).

Within the realm of aviation operations, where activity is continuous, the impact of circadian rhythms and fatigue on performance assumes paramount significance. Studies utilizing flight simulation have elucidated the heightened propensity for attention lapses and reduced vigilance among pilots during nighttime operations compared to daytime flights(Williamson et al., 2011) . The factors contributing to aviation-related fatigue are multifaceted, encompassing both scheduling-related and non-scheduling-related factors. Scheduling-related causes include extended work durations, particularly prevalent in long-haul flights, leading to persistent exhaustion and disruptions in rest schedules(Lee & Kim, 2018) . Furthermore, commencing work at unconventional early or late times exacerbates fatigue levels, attributable to sleep deficits incurred. Pilots subjected to prolonged duty periods or early start times are susceptible to diminished performance, particularly during critical phases of flight operations (Gawron, 2016);(Hartzler, 2014); (Reis et al., 2016). To address the adverse effects of fatigue, a myriad of countermeasures has been proposed, ranging from enhancing fatigue risk management training to optimizing work schedules to align with circadian rhythms. Moreover, strategies aimed at ensuring adequate rest intervals between flights are imperative to mitigate fatigue-related risks effectively.

3. METHODOLOGY

This research depended on a structured analysis of the published scientific literature concerning fatigue in aviation, primarily focusing on the PreferredReporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The current investigation included published articles from peer-reviewed journals in English, focusing directly on fatigue within the aviation industry.

Repetitive studies or those not meeting all three conditions were eliminated. This involved searching four electronic databases, namely Science Direct, MEDLINE, ProQuest and SafetyLit using keywords such as aviation, fatigue, sleep loss, and safety. Initial screening relied on titles and abstracts to identify potential studies which were then further filtered through a full review of the article text and removal of duplications. Concurrently, a panel of experts followed suggested procedures to carry out another activity by (Davis, 1992), A team was established to search for, assess, and gather pertinent documents used in aviation operations to combat fatigue. The panel included five experts from different areas of aviation: a certified pilot, a licensed maintenance engineer, an aviation psychologist, an airline administrator, and an aviation safety specialist with 23, 20,,11, 9,and15 years of experience respectively.

The committee compiled a set of relevant materials on the causes and management of fatigue in aviation, including regulations, manuals, advisory material, industry research reports, discussion papers from specialized symposia, and operational practice notes and books. This collection of 100 documents comprised 70 (70.0%) peer-reviewed journal articles, 19 (19.0%) industrial reports and regulations, nine (9.0%) conference papers and other symposia contributions,and two (2.0%) books along with the identified industry-produced documents formed the primary source of information.Source: Original documents

4. LITERATURE ANALYSIS

This review of fatigue in aviation covered five distinct aspects, including the reasons for fatigue, its impacts, methods for measurement or prediction of fatigue, available countermeasures to mitigate its negative effects, and future directions for research on fatigue. The summarized findings are outlined in Table 1 and further elaborated upon in the following five subsections.

4.1. Causes of fatigue

It is widely accepted that the optimal amount of sleep for maintaining mental and physical well-being is around 8 hours per day, although this varies greatly from person to person. ((Missoni et al., 2009);(Härmä, 1993); (UK-CAA, 2007); (Dongen, 2006)). when you stay awake for a long time, or don't get enough sleep over several days, the body's need to sleep builds up. This need also changes throughout the day as part of the natural biological clock, which influences our urge to sleep at night(Gander et al., 2013). An illustration of how these essential physiological factors can have an impact is the difference in quality and quantity of sleep obtained from a 12-hour rest break during the day compared to at night. Work schedules frequently overlook the importance of considering sleep and circadian rhythms, ultimately resulting in insufficient sleep. Consequently, this can lead to accumulating fatigue and a subsequent decrease in productivity and safety. ((Bendak, 2003); (Lee & Kim, 2018)).

The combination of sleep deprivation and circadian influences is particularly concerning, given that the circadian rhythm affects nearly all aspects of alertness and performance in humans. ((Caldwell et al., 2008); (Dongen, 2006)). The internal body temperature pattern is widely viewed as a key indicator of the human biological clock. Performance aligns with this temperature pattern, where lower body temperature (typically seen between 3:00 and 5:00 a.m.) is linked to slower reaction time, decreased alertness, and reduced accuracy compared to periods of higher body temperature. It's understandable that night shift workers often exhibit poorer performance than their day shift counterparts, as frequently reported in literature. ((Åkerstedt & Wright, 2009); (Bendak, 2003);(Lee & Kim, 2018)).

Given the 24-hour nature of aviation operations, it is important to thoroughly examine the impact of circadian rhythm and fatigue on performance. In a study using flight simulation, these factors were investigated extensively(Caldwell et al., 2009). Nine out of fourteen pilots reported having full periods of sleep during simulated night-time flights. The researchers concluded that pilots are more likely to doze off at the controls during night-time compared to daytime. In two separate studies, it was discovered that brief instances of brain activity associated with sleeping lapses are up to nine times more probable and lapses in psychomotor vigilance are five times greater(Rosekind et al., 1994) Many factors contribute to aviation fatigue according to various sources. These can be classified into two main categories: causes related to scheduling and non-scheduling related causes.

4.1.1. Scheduling related causes

Extended periods of wakefulness and limited pre-rest significantly contribute to operator fatigue in aviation. Long-haul flight crew members are also affected by time-zone changes, which can result in intricate links between circadian lows and fatigue, ultimately leading to impaired performance.((Gander et al., 2013);(Hartzler, 2014);(Reis et al., 2016). Scheduling considerations in high-risk industries such as aviation are a major focus due to their ability to impact the onset and buildup of fatigue ((Dawson, 2011)). These considerations encompass factors like length of workday, start time of workday, rest periods, and more (Reis et al., 2016).

4.1.1.1. Workday duration.

The prolonged length of duty often linked with long-distance flights may contribute to the persistent exhaustion felt by pilots and other crew members.((Gawron, 2016);(Hartzler, 2014); (Lee & Kim, 2018); (Reis et al., 2016);(Williamson et al., 2011)). Extended periods of time spent working can lead to both tiredness and disruption of rest schedules. Pilots who are tasked with flights lasting more than 8 hours are particularly susceptible to decreased performance caused by fatigue. For instance, a 9-hour flight may require a duty period of 12 hours or longer, raising concerns about the potential hazards related to long-haul flights and prolonged work times. (Goode, 2003) There was a notable connection discovered between the length of flights and the frequency of accidents. The study revealed that 20% of accidents were attributed to human error when pilots had been working for more than 10 hours, and this percentage decreased to five percent when pilots had been working for over 13 hours.

4.1.1.2. Workday starting time.

Starting work at unusual early or late times significantly increases the tiredness that pilots experience because of the sleep they lose. ((Reis et al., 2016);(Roach et al., 2012); (Roach et al., 2012)) Pilots are thought to lose between fifteen and 30 minutes of sleep for every hour that a duty period begins before 09:00 a.m. Additionally, when pilots have several early starts in consecutive days, the detrimental effects of sleep deprivation accumulate rapidly. Furthermore, it was stated that each subsequent day was associated with an increase in fatigue similar to an extra 40 minutes of work (Olaganathan et al., 2021). As a result, pilots' performance may suffer during the approach and landing stages of a flight when they are scheduled for extended duty with an unusually early start, especially if no measures are taken to address fatigue. Recently (Flynn-Evans et al., 2018) The impact of different start times on neurobehavioral performance and sleep was investigated in individuals with non-traditional daytime shifts. The study found that limited sleep opportunities due to these shifts can lead to decreased performance if not addressed. It was suggested that industries employing such schedules should enhance their fatigue risk management training for day shift workers.

Table 1- Summary of fatigue in aviation aspects as discussed in existing literature.

Study Dimensions	Attributes	Description
Causes of Fatigue	Scheduling-related causes	Workday duration, workday starting time, available recovery time, number of segments flown, other scheduling-related factors
	Non-scheduling causal factors	Reduced levels of stimulation in cockpit, dim lighting and the absence of tangible feedback through analogue controls, Health

		disorders
Fatigue Measurement and Prediction	Objective assessment of fatigue	Fitness-for-duty tests, Online operator monitoring, Performance-based monitoring, Flight data monitoring
	Subjective measures of fatigue	Self-rating scales, Air safety reports
	Fatigue prediction (fatigue modelling)	One-step and two-step models of prediction, Traditional Biomathematical models, New Generation Traditional Biomathematical models
Consequences of Fatigue	Operational consequences	Implications in long-haul operations, Implications in short-haul operations
	Impairment of critical skills and functions	Physiological skills impairment, Cognitive functions impairment, Deterioration of mode, attitude, social interaction and general well being
Fatigue mitigation and intervention	In-flight countermeasures	Napping, In-flight breaks, Bunk sleep and in-flight rostering, Use of bright light in cockpits, Pharmacological alertness aids, Scheduling of workday and rest times for crews
	Pre/post flight countermeasures	Pre-flight and on-flight live readiness checks, Hypnotics and other non-regulated substances, Life-style as a countermeasure of fatigue
	Systematic/holistic management of fatigue	Fatigue Risk Management Systems

4.1.1.3. Available recovery time.

Jet lag, also known as circadian dysrhythmia, can lead to increased feelings of fatigue by disrupting the sleep/wake cycle when rapidly changing time zones. This disruption can negatively affect performance during or after long-haul flights.(Eriksen & Åkerstedt, 2006). Jet lag occurs when the body's internal clock, regulated by hormonal rhythms, is out of sync with the new environment. For example, a person may feel high pressure to sleep at 11 a.m. local time due to it being 2 a.m. in their original location. This mismatch can result in reduced alertness and increased fatigue (Caldwell et al., 2008) and heightened challenge in achieving recuperative sleep during layovers (Eriksen & Åkerstedt, 2006).

4.1.1.4. Number of segments flown.

The number of segments flown during the workday has been discovered to be directly related to the level of fatigue that pilots experience. (Gawron, 2016);(Reis et al., 2016)). (Honn et al., 2016)The objective and subjective fatigue levels of 24 regional airline pilots were assessed during a 9-hour workday with both single and multiple segments. The results indicated that pilots experienced a higher level of objective and subjective fatigue on multi-segment workdays compared to single-segment workdays. These findings align with the results of laboratory studies on simulated single-segment and multi-segment workdays but the variations were more conservative compared to the differences that were documented by (Honn et al., 2016).

4.1.1.5. Other scheduling-related factors.

The Civil Aviation Authority of UK ((UK-CAA, 2007)Several studies have summarized the impact of various scheduling-related issues on fatigue. The research revealed that time of day significantly influenced fatigue levels, with the lowest levels recorded in the late afternoon. Changes in duty times also had a significant effect on fatigue. Additionally, an increase in the number of flight segments was found to be equivalent to an extra 2.8 hours on duty. Furthermore, there was clear evidence indicating reduced sleep duration following progressively later work duties at night. Consecutive workdays and late finishes were also identified as factors affecting fatigue levels induced by scheduling. Other causal factors included rest periods given during high circadian level times, which diminished their recuperative value, and night duty combining low circadian level times with work obligations. Split shifts were highlighted as problematic and potentially equally tiring as regular duty assignments (Roach et al., 2012).

These scheduling-related influences also differ based on the category of flight. In a study involving 739 pilots,(Boureois-Bougrine, 2003) The study found that fatigue during long-haul flights was primarily linked to night flying (59 percent) and crossing multiple time zones (45 percent). On the other hand, pilots attributed fatigue during short-haul flights to prolonged workdays (53 percent) and successive early wake-ups (41 percent). Additionally, the research highlighted that extended work hours, particularly when paired with consecutive overnight shifts, can excessively strain the physiological and mental capabilities of pilots.

4.1.2. Non-scheduling causal factors

Environmental and contextual factors, in addition to scheduling considerations, can lead to increased fatigue and have a negative impact on performance within the aviation sector (Lee & Kim, 2018) The study revealed that fatigue is influenced by the collaboration of crew members, hotel and aircraft environments, and diverse ethnic backgrounds. These findings were based on a survey of 929 pilots regarding the factors contributing to work-related tiredness.

Advanced automation has been instrumental in minimizing the workload for pilots and reducing the number of personnel required in the cockpit. However, this efficient working environment can lead to decreased mental stimulation, reduced vigilance, and heightened boredom during long-haul flights. These factors contribute to an increased sense of fatigue, which may also be influenced by additional elements such as inadequate lighting and lack of tactile feedback from analogue controls(Roach et al., 2012) Moreover, any health issue that affects pilots' ability to get quality sleep could lead to reduced alertness and increased fatigue while on duty. One particularly worrisome condition is known as Obstructive Sleep Apnea (Williamson et al., 2011) sleep disturbances could result in reduced sleep quality, higher daytime fatigue, and an increased risk of cardiovascular disease(Shamsuzzaman et al., 2003).

4.2. Fatigue measurement and prediction

Measurement and prediction of fatigue can be accomplished through various methods and tools, which fall into two categories: objective and subjective approaches. ((Gawron, 2016); (Lee & Kim, 2018)).

4.2.1. Objective assessment of fatigue

4.2.1.1. Fitness-for-duty tests.

Pre-employment assessment is utilized in fitness-for-duty evaluations to determine if operators possess adequate alertness and performance capacity before starting a work shift. These assessments gauge operator performance or oculomotor responses, such as eye movements and pupil responsiveness to light, although the accuracy of the latter measurements has not been thoroughly established. While these tests are typically straightforward to administer and aid in identifying and measuring sleep deficit prior to the start of the workday, they do not identify sleep debt that accrues after the workday commences (Balkin et al., 2011).

4.2.1.2. Online operator monitoring.

Online operator monitoring technology includes standard fatigue monitoring tools that can offer valuable performance and alertness measurements in real time. This technology tracks the physiological behavior of individuals (such as EEG, eye gaze, percent eye closure) or their physical characteristics (like muscle tone, head position, wrist immobility). For example, a decrease in pupil diameter indicates higher levels of fatigue and potentially less responsiveness. This kind of technology shows promise for pilots who struggle to stay alert and perform well during long and uneventful flights(Bee, 2006).

4.2.1.3. Performance-based monitoring.

Performance monitoring systems typically do not intrude as they rely on built-in performance metrics. Performance can be assessed based on the primary tasks associated with the operator's main role (e.g., tracking speed while driving), or from secondary tasks (e.g., reaction time). Ideally, early declines in performance in either task (primary or secondary) would act as an early indication of potential decreases in actual performance (Balkin et al., 2004). In a more recent example, The National Aeronautics and Space Administration (NASA) in USA introduced a Psychomotor Vigilance
Task (NASA-PVT) Tests have been performed to confirm the accuracy of this secondary fatigue measurement tool, which operates on a touchscreen hand-held device and is based on reaction time(Arsintescu et al., 2017). The PVT visual assessment, lasting 5 minutes, evaluates decreased performance caused by fatigue in both laboratory and field settings. The test uses inter-stimulus intervals ranging from 2 to 10 seconds based on a rectangular distribution to assess changes in reaction time after participants have been awake for over 24 hours(Arsintescu et al., 2017).

4.2.1.4. Flight data monitoring.

Flight data monitoring involves the systematic evaluation of flight variables to detect important safety occurrences, identify operational risk areas, and measure current safety reserves(Cabon et al., 2012).

4.2.1.5. Selection of objective methods of fatigue assessment.

Given the limitations of individual measures in capturing all aspects of fatigue, researchers should consider integrating multiple metrics that cover a wide range of factors. It can be assumed that the most dependable indications of fatigue will involve both physiological and non-intrusive objective performance assessments(Caldwell et al., 2008). Several fatigue-detection devices have been created and sold commercially. There are also multiple factors to consider when evaluating and selecting these devices. (Balkin et al., 2011) stated that the system needs to be valid, dependable, responsive (with few missed fatigue events), suitable (with few false alarms), and applicable across various situations.

4.2.2. Subjective measures of fatigue

Objective assessments of performance decline due to fatigue hold significant scientific merit in terms of reliability and validity. However, translating various laboratory-based psychomotor or neurocognitive tests into practical tools for quantifying risk assessment presents challenges, particularly when it comes to the diverse skill sets required for ensuring flight safety (Gaydos et al., 2013). Subjective rating scales also hold scientific value, as there are numerous self-reported fatigue assessment instruments with different levels of complexity and accuracy.

4.2.2.1. Two well-known and validated subjective scales for measuring fatigue and sleepiness are the Karolinska Sleepiness Scale and the Samn-Perelli Checklist.(Samn, 1982). Nevertheless, evaluating one's own fatigue-related performance deficiencies can produce inconsistent outcomes and should be approached carefully. (Tremaine et al., 2010). A “Barometer on Pilot Fatigue” report published by the European

Cockpit Association (ECA, 2012) It was disclosed that just half of UK pilots acknowledged experiencing fatigue, which is a higher rate compared to the rest of Europe at 20 to 30 percent. Another approach involves using peer-rating scales.(Gaydos et al., 2013) initiated a new peer-to-peer system for rating fatigue subjectively, where pilots anonymously provide a weekly (or other appropriate time interval) score to rate the fatigue of all other pilots in the unit. The scoring system uses a simple 1–10 Likert-type scale with specific instructions for each rank to ensure consistent subjective assessment. This method led to a gradual shift from reactive-type fatigue management to a more proactive approach over the long term.

4.2.2.2. Air safety reports.

Air safety report (ASR) is a mandatory report written by the captain whenever a safety event has happened during a flight. (Cabon et al., 2012) Studied 563 instances of fatigue-related ASR’s and discovered an evident correlation between the length of previous rest and workday duration. For shorter workdays, rest duration does not have a notable impact on ASR frequency. However, during duty periods lasting between three and 5 hours, the frequency of ASRs is significantly higher following reduced rest compared to normal rest durations. Surprisingly, for longer work durations, the frequency of ASRs is no longer significantly different between reduced and standard rest durations. This can be attributed to aircrews developing strategies to maintain performance as fatigue levels rise in order to minimize risk.

4.2.2.3. Fatigue prediction.

Traditional models for predicting fatigue forecast alertness, performance, and/or risk by requiring input of work and sleep schedules to anticipate fatigue levels hourly on the workday (Dawson, 2011). Biomathematical models have been utilized to forecast the duration of sleep and anticipated performance level, considering factors such as time spent on tasks, predicted sleep patterns, circadian rhythm, and projected amount and timing of recovery on rest days (Balkin et al., 2011). However, the trustworthiness of these models still needs to be determined (Dongen et al., 2007).

A new breed of biomathematical models is currently in the works to forecast individual responses to fatigue. These models are known as Readiness Screening Tools (Chandler et al., 2013) RSTs regularly gather cognitive, behavioral, and physiological data from individuals to anticipate their preparedness for specific tasks. While these tools have the capability to more accurately capture variations in how individuals respond to fatigue, they do not effectively forecast long-term performance.

5. KEY FINDINGS AND RESULTANTS

The effects of fatigue in the aviation sector can be categorized into operational impacts and other significant but less apparent outcomes.

5.1. Operational consequences

As tiredness increases, performance becomes increasingly unpredictable, especially at night when there is frequently a five-fold rise in lapses in alertness ((Åkerstedt & Wright, 2009);(Rosekind et al., 1994)). Furthermore, as tiredness builds up, the ability to focus decreases and human precision in accuracy and timing diminishes, resulting in a tolerance for lower performance standards. This may lead to important aspects of flight tasks being missed or delayed in the cockpit. Additionally, the capacity to effectively divide mental resources and synthesize information into a coherent whole diminishes. Overall, cognitive processes slow down, motor skills decline, and there is an increase in erroneous responses due to fatigue. Pilots who are extremely fatigued may even experience sensory distortions caused by brief unintended periods of sleepiness.(Caldwell et al., 2009).

Despite the complex nature of fatigue, its impact on operational outcomes is consistently observed across various aviation operations. Research indicates that fatigue and sleep loss significantly affect the prefrontal cortex of the human brain, impacting tasks that require executive cognitive functions such as innovative thinking, verbal fluency, and emotional control. This vulnerability to fatigue has crucial implications for successful and safe operational performance in aviation. Additionally, other areas of the brain may also be affected by fatigue and sleep loss leading to impairment in memory and learning performance, thereby increasing the risk of human error in the aviation industry. (Leeuwen et al., 2013); (Latorella & Prabhu, 2000)) Generally, the human brain requires a consistent amount of rest (approximately 8 hours per day) to function at its best and regulates the urge to sleep in order to restore alertness and performance. Fatigue can have enduring negative impacts on crew health, leading to a notable rise in sick leave and decreased work productivity. Additionally, working overtime or extended hours is linked to heightened psychological distress, cardiovascular diseases, and self-reported health issues(Härmä, 2006). It has also been confirmed that insufficient sleep raises the risk of developing obesity and diabetes. This indicates an additional physiological factor connecting work-related fatigue to adverse health markers (Cauter et al., 2008). Concerns about these issues have resulted in the recognition of shift work, sleep deprivation, and fatigue as important contributors to lifestyle-related illnesses. Recent estimates indicate that 10% of night and rotating shift workers have been diagnosed with a disorder related to their working schedule (Dawson, 2011).

5.1.1 Implications in long-haul operations.

(Roach et al., 2012) The impact of fatigue on 19 male pilots during extended flights and layover periods was investigated. According to the authors, these pilots commonly endure heightened levels of fatigue as a result of longer work hours and disruptions to their sleep-wake patterns due to circadian rhythm misalignment. Additionally, the study noted that pilots with shorter layovers in the middle of their trip reported experiencing increased subjective fatigue and reduced sustained attention compared to those with longer layovers.

5.1.2. Implications in short-haul operations.

In another study on 70 short-haul flight pilots, (Roach et al., 2012) The study investigated the effects of early start times on sleep duration before duty and fatigue levels at the beginning of work. Data was gathered from pilots' work schedules and their self-reported sleep patterns using diaries and wrist activity monitors for a minimum of two weeks. The results indicated that pilots had the shortest sleep duration (average 5.4 hours) when starting work between 04:00 and 05:00 a.m., while they had the longest sleep duration (average 6.6 hours) when starting between 09:00 and 10:00 a.m. Furthermore, self-reported fatigue levels were highest for those starting between 04:00 and 05:00 a.m., but lowest for those starting between 09:00 and 10:00 a.m.

5.1.2. Other consequences

(Caldwell et al., 2008) and (Rosekind et al., 1994)It has been noted that fatigue can have detrimental effects on numerous critical skills and functions essential for aviation task performance. These effects include decreased precision and prolonged task duration, as well as an increased acceptance of lower performance levels. Additionally, fatigue can lead to a greater effort required for multitasking and activities that were previously well-practiced. It may also result in deterioration in attitude, mood, and situational awareness, along with greater variability in performance. Furthermore, fatigue can reduce social interactions vital for information exchange on the flight deck and impair attention, reasoning, and information integration. In some cases, fatigue can even lead to the onset of involuntary episodes of sleep. Sleep deprivation heightens feelings of drowsiness, stress, and mental fog while reducing energy. Just a few hours of sleep loss in one night can cause noticeable rises in exhaustion and reduced performance across various activities. After more than 40 continuous hours without sleep, the resulting decline in cognitive function can be severe and crippling ((Dawson, 2011). Above all,(Hartzler, 2014). The research showed that being awake for 24 hours straight led to a notable decrease in reasoning and alertness, comparable to the effects seen in individuals with a blood alcohol level of .10. This heightened impairment is worsened by the fact that tired people are often unaware of how much their performance has deteriorated (Gawron, 2016) and may believe they are safe to operate an aircraft when in reality, it is not the case.

Numerous studies indicate that fatigue and sleep deprivation can impair performance and increase the risk of accidents. Furthermore, performance degradation due to fatigue is more prevalent in tasks requiring sustained or continuous attention, particularly over extended periods - a relevant concern in aviation (Williamson et al., 2011) in addition to other sectors like the maritime industry, where comparable signs such as difficulty concentrating, impaired decision-making, memory loss, slow reaction time and shifts in mood and behavior have been noted among maritime pilots (Hobbs, 2018).

5.2 Fatigue mitigation and intervention

In the aviation sector, there are numerous strategies for managing fatigue. These methods fall into categories including in-flight and pre/post flight measures, as well as safety management systems.

5.2.1. In-flight countermeasures of fatigue

In-flight strategies to combat fatigue include taking naps on the flight deck, periodic activity breaks, in-flight scheduling, bunk sleep during long-haul flights, increased exposure to flight-deck lighting, and using pharmacological aids for alertness. The extent to which these measures are used differs greatly among airlines and some may not be officially authorized (Rose & Giray, 2013):

5.2.2. Napping.

Napping is commonly utilized by aircrew as a way to counteract fatigue, whether it's before overnight duties, during flights, or after completing overnight shifts ((UK-CAA, 2007); (Gregory et al., 2010). Stimulants such as caffeine can help with staying alert and performing well, but they don't solve the problem of not getting enough sleep. Therefore, taking a nap is suggested for improving performance while reducing the overall amount of missed sleep (Brooks and Lack, 2006; (Hartzler, 2014) but it is not intended to replace sleeping in the bunk during long-haul flights(Caldwell et al., 2009).

Reported benefits of napping include preserving cognitive performance and reducing both objective and subjective sleepiness. ((Hartzler, 2014);(Dawson, 2011)). Performance on assessments measuring memory and recall, cognitive arithmetic, critical thinking, and reaction time indicated better results for individuals who took a nap compared to those who did not. Napping also showed improvements in attention, alertness, and faster response times.((Rosekind et al., 1994); (Vgontzas et al., 2007)).

5.2.3. In-flight breaks.

In-flight activity pauses are advised under the right conditions and in accordance with specific guidelines to maintain operational safety. Similar to in-flight napping, these breaks should be viewed as a way to manage risks. Research has demonstrated that taking time away from a task can enhance focus and vigilance (Caldwell et al., 2009).In a cockpit setting, where sleeping may be possible, taking breaks that involve less physical activity and more social interaction or a break from repetitive tasks has been found to temporarily boost alertness. To counter fatigue with breaks, it is suggested to take shorter breaks (e.g. 10-minute intervals) on an hourly basis or even more frequently as opposed to longer but less frequent breaks. Recent regulations have allowed for extended rest periods during flying duty hours in order to mitigate any potential negative impact on flight safety due to severe crew fatigue conditions(Hilditch et al., 2020).

5.2.4. Bunk sleep and in-flight rostering.

Scheduling practices for important flight phases and in-flight sleep breaks should take into account research findings on sleep and circadian processes. Rostering patterns need to be established to minimize fatigue during long-haul flights, particularly by considering the impact of circadian and environmental factors on in-flight bunk rest quality. It is crucial to educate aircrew members about these factors and have them use validated work/rest scheduling measures to create an effective in-flight rest pattern(Caldwell et al., 2009).

5.2.5 Use of bright light in cockpits.

Enhancing the brightness of the flight deck, particularly during nighttime, may help to temporarily boost alertness and performance in the cockpit. Although not fully researched, various laboratory studies have confirmed positive effects from increased lighting. The dark environment of the flight deck can induce drowsiness, so additional light, including blue light specifically (Rose & Giray, 2013), Exposure to 100 lux of light may have a positive impact on boosting alertness, with shorter wavelength light demonstrating the most significant influence (Caldwell et al., 2009).

5.2.6. Pharmacological alertness aids.

Pharmacological alertness aids could be beneficial when behavioral interventions are no longer effective. Prescription alertness aids, such as stimulants like dextroamphetamine or modafinil, may also improve alertness in the cockpit. While these substances are typically prohibited, they may be permitted in specific military operations and exceptionally rarely in commercial operations under stringent regulation (e.g. (Gregory et al., 2010);(Rose & Giray, 2013)).

5.3 Pre/post flight countermeasures of fatigue

5.3.1. Scheduling of workdays and rest times for crews.

Regulating fatigue risk is difficult because individuals respond differently to sleep loss and there is a complex relationship between work-hour regulation and an individual's actual sleep habits. Therefore, enforcing work hours may not always ensure that crew members get more sleep (Flynn-Evans et al., 2018). Regulatory authorities set rules to manage crew work and rest times, but these regulations may not consider scientific research on circadian rhythm, sleep, and their impact on performance. For instance, some regulations treat workday duration the same across all 24 hours of the day without distinguishing between day and night work for scheduling rest and sleep. There are also discrepancies in policies such as specifying maximum annual flight times; for example, the U.S. allows 1400 hours while Australia permits 900 hours which suggests that these regulations may not be informed by relevant sleep and circadian science(Caldwell et al., 2009).Similarly, (Missoni et al., 2009) The air crew scheduling tactics and rules of ten ICAO member countries were analyzed, including Australia, Croatia, France, GB, Germany, Japan, Russia,,SCA, Switzerland and USA. These nations have regulations in three categories: operations, scheduling and crew. It was discovered that all ten countries enforce specified restrictions on flight time and/or workday duration; six also have provisions concerning the previous night's sleep and/or rest period. Seven different countries have rules about flying at night, but they differ in their definitions of "night" and the longest amount of time allowed for working at night. For example, Japan requires crew members to have a minimum rest period of six hours within 24 hours, while Australia and the UK require ten and twelve hours respectively. Only three countries take into account crossing time zones (circadian dysrhythmia) when determining duty times, while eight focus more on duty duration rather than specific flight requirements. This means that traveling between the hotel and airport for approximately two hours is not considered part of the workday duration in these cases.

Research also examined the impact of different scheduling strategies on the quality of sleep during flights and on the ground, as well as the influence of varying pilot numbers on fatigue. For example,(Holmes et al., 2012) The sleep and alertness of 44 pilots working on an ultra-long (i.e. longer than 16 hours) round-trip operation were analyzed using activity monitors and self-reported sleep diaries. The study revealed that during climbing and descending, KSS values did not go beyond 5, indicating that the pilots were neither fully awake nor sleepy. Additionally, the average daily sleep duration remained at more than 6.3 hours throughout the operation. Moreover, it was noted that during in-flight rest periods, 98 percent of participants reported sleeping which led to a decrease in levels of drowsiness. During the 49.5-hour layover, the researchers found that crew members were advised to rest according to their home time, but they observed that 64% of them slept during the local night time at the layover region. They concluded that the operation was effectively designed for fatigue management and maintained an acceptable level of alertness. On the return flight, pilots obtained about 3.7 hours of sleep, which was notably more than on the longer outbound flight. This finding corresponds with another study's results by (Folkard et al., 2007). Both research findings indicated that team members remained significantly influenced by the local day/night cycle and established social activity schedules prior to departing on the return flight, despite being advised not to adjust their sleep patterns according to the local time. It is important to highlight that even though pilots and flight attendants may work on the same flight, they might have different reporting times due to certain airlines mandating that flight attendants arrive an hour earlier than pilots for pre-flight tasks and briefings. Airlines should consider using more effective briefing methods to allow cabin crew to have equivalent rest time as pilots and reduce their fatigue(Gander et al., 2013)Furthermore, certain regulations suggest that crew members and pilots need to have at least 9 hours of rest between flights. However, the specific content of this 9-hour period is not clearly defined in some cases. As a result, some airlines consider time for meals and travel between airports and rest facilities as part of these 9 hours. Therefore, it is advisable for regulations to exclude travel and meal times from the designated resting periods(Zaslona et al., 2018).

Resting time, particularly between flights, greatly depends on the availability of a suitable environment that promotes better quality and longer duration of sleep (Caddick et al., 2018) The authors emphasized the importance of keeping noise in the sleep environment below 35 dB, maintaining ambient temperature and relative humidity between 17 and 28 °C, and 40–60% respectively. They also recommended sleeping in complete darkness and ensuring sea level air quality for optimal ventilation, with the possibility of using supplemental oxygen at high altitudes.

5.3.2 Pre-flight and on-flight live readiness checks.

Operators in safety-critical roles may undergo fitness-for-duty alertness assessments before beginning their workday to determine their readiness for work. However, this data could potentially be used to validate or influence performance on subsequent tests during the workday (Balkin et al., 2011). Similarly, real-time automated monitoring of alertness and performance could be carried out during flights. These methods can identify declining levels of alertness and performance before they fall below a critical threshold that impacts operational effectiveness. This would allow for the implementation of suitable countermeasures such as naps with appropriate dosage levels (Balkin et al., 2011).

5.3.3 Hypnotics and other non-regulated substances.

The disruption of sleep patterns can be caused by jet lag, shift work, or trying to sleep at times different from the regular bedtime. In such situations, using certain hypnotic medications in moderation may help people get some rest when they have the opportunity but find it difficult to do so. The choice of which type of hypnotic is most suitable for each situation should take into account the time of day, duration of available sleep time and the chance of waking up earlier than expected, which could worsen the effects of grogginess upon waking. However, it is recommended that if any hypnotics are used, this should not occur more than four times per week. Additionally, proper health assessments and evaluation for unusual reactions to medication before flying and a minimum 12-hour gap between taking the medication and returning to work are necessary to ensure complete recovery (Caldwell et al., 2009).

5.3.4 Life-style as a countermeasure of fatigue.

In addition to the various fatigue countermeasures mentioned, aviation personnel, including those involved in ground operations, must adopt a well-informed and carefully planned lifestyle to enhance their ability to combat fatigue and its effects.. In this regard, the European Organisation for the Safety of Air Navigation (EUROCONTROL, 2018) A set of lifestyle habits has been identified to prevent tiredness or reduce its impact. These practices consist of regular physical activity for staying fit, taking breaks for stretching, making time for adequate relaxation, managing emotions (such as depression, stress, and anxiety), finding a balance between work and personal life, and consuming foods that support good sleep and following a healthy diet.

5. CONCLUSIONS

Fatigue, with its wide range of interpretations, is often associated with an imbalance between the intensity, duration and timing of work and the subsequent recovery time. This discrepancy is frequently connected to prolonged periods of work and the resulting inability to sustain optimal performance at work. Diminished sleep duration leading to fatigue is a common explanation for the connections between long working hours, shift work, workplace stress, diminished cognitive abilities, reduced safety levels and higher risk of lifestyle-related illnesses. This demonstration clearly illustrates how extended working hours can impact various aspects of health and well-being. Contemporary research has studied the effects of fatigue on safety, the relationship between demographic characteristics and fatigue, predicting fatigue, management of fatigue, and effects of organizational factors on fatigue. Within the aviation industry, it is noted that there is a substantial increase in risk related to fatigue when the workday duration exceeds 16 hours, pre-duty sleep duration is shorter than 6 hours or when the workday coincides with crew members' usual sleeping hours. Studies have highlighted these critical thresholds for understanding and mitigating potential risks associated with pilot and crew member performance due to exhaustion.

Consequences of fatigue can be short-term risks leading to poorer safety outcomes and long-term risks affecting psychological, physical health, and overall well-being. Airlines are encouraged to implement a flexible Fatigue Risk Management System for both short- and long-haul crew members. This system should seek innovative alternatives to manage crew fatigue effectively while reducing operational risk levels beyond just compliance with written regulations by delving into social and cultural aspects in order to promote holistic wellness among the workforce. Existing models for predicting fatigue provide only point values without adequately detecting probable variability in typical populations due to differences in sleep-wake behavior during shift work patterns. This limitation affects how these models are perceived and utilized in real-life settings, ultimately impacting the effectiveness of interventions. Therefore, future research should focus on developing multi-component systems incorporating components such as monitors for fitness-for-duty tests together to provide a more comprehensive and precise picture of crew members' current and future state of performance capacity related to their level of exhaustion. Crew work is characterized by high physical and cognitive demands, regular changes in schedule, early morning starts, and long workdays, leading to inevitable fatigue. It is crucial to have science-based fatigue countermeasures available to minimize the devastating consequences of exhaustion and sleep deprivation while also minimizing associated risks. These countermeasures should involve optimizing work schedules, monitoring sleep and fatigue levels, implementing policies for mitigating in-flight tiredness, as well as providing support for overall crew well-being through appropriate resources and strategies.

References

1. (NRTC, 2001). (2001, January 28). https://www.ntc.gov.au/sites/default/files/assets/files/Fatigue-Expert-Group-Options-for-Regulatory-Approach-to-Fatigue-in-Drivers-of-Heavy-Vehicles-in-Australia-and-New-Zealand-2001.pdf
2. Ahasan, R., Lewko, J H., Campbell, D., & Salmoni, A W. (2001, January 1). Adaptation to Night Shifts and Synchronisation Processes of Night Workers. , 20(4), 215-226. https://doi.org/10.2114/jpa.20.215
3. Åkerstedt, T., & Wright, K P. (2009, June 1). Sleep Loss and Fatigue in Shift Work and Shift Work Disorder. Elsevier BV, 4(2), 257-271. https://doi.org/10.1016/j.jsmc.2009.03.001
4. Arsintescu, L., Mulligan, J B., & Flynn-Evans, E E. (2017, January 17). Evaluation of a Psychomotor Vigilance Task for Touch Screen Devices. SAGE Publishing, 59(4), 661-670. https://doi.org/10.1177/0018720816688394
5. Authority, A C A S. (2004, April 29). Fatigue Management—Suggested Alternatives to Prescribed Flight and Duty Times.. https://www.casa.gov.au/operations-safety-and-travel/safety-advice/fatigue-management
6. Balkin, T J., Bliese, P D., Belenky, G., Sing, H C., Thorne, D R., Thomas, M., Redmond, D P., Russo, M B., & Wesensten, N J. (2004, September 1). Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. Wiley, 13(3), 219-227. https://doi.org/10.1111/j.1365-2869.2004.00407.x

7. Balkin, T J., Horrey, W J., Graeber, R C., Czeisler, C A., & Dinges, D F. (2011, March 1). The challenges and opportunities of technological approaches to fatigue management. Elsevier BV, 43(2), 565-572. https://doi.org/10.1016/j.aap.2009.12.006
8. Bee. (2006, May 12). AutoSelect: what you want is what you get: real-time processing of visual attention and affect. Percept. Interact. Techno. https://link.springer.com/chapter/10.1007/978-1-4614-4794-8_5
9. Bendak, S. (2003, October 1). 12-h workdays: current knowledge and future directions. Taylor & Francis, 17(4), 321-336. https://doi.org/10.1080/02678370310001643478
10. Bendak, S., & Rashid, H. (2020, March 1). Fatigue in aviation: A systematic review of the literature. International Journal of Industrial Ergonomics, 76, 102928-102928. https://doi.org/10.1016/j.ergon.2020.102928
11. Boureois-Bougrine. (2003, April 1). Perceived fatigue for short- and long-haul flights: a survey of 739 airline pilots. https://pubmed.ncbi.nlm.nih.gov/14556570/
12. Cabon, P., Deharvengt, S., Grau, J Y., Maille, N., Berechet, I., & Mollard, R. (2012, March 1). Research and guidelines for implementing Fatigue Risk Management Systems for the French regional airlines. Elsevier BV, 45, 41-44. https://doi.org/10.1016/j.aap.2011.09.024
13. Caddick, Z A., Gregory, K B., Arsintescu, L., & Flynn-Evans, E E. (2018, March 1). A review of the environmental parameters necessary for an optimal sleep environment. Elsevier BV, 132, 11-20. https://doi.org/10.1016/j.buildenv.2018.01.020
14. Caldwell, J A., Caldwell, J L., & Schmidt, R. (2008, August 1). Alertness management strategies for operational contexts. Elsevier BV, 12(4), 257-273. https://doi.org/10.1016/j.smrv.2008.01.002
15. Caldwell, J A., Mallis, M M., Caldwell, J L., Paul, M., Miller, J C., & Neri, D F. (2009, January 1). Fatigue Countermeasures in Aviation. Aerospace Medical Association, 80(1), 29-59. https://doi.org/10.3357/asem.2435.2009
16. Cauter, E V., Spiegel, K., Tasali, E., & Leproult, R. (2008, September 1). Metabolic consequences of sleep and sleep loss. Elsevier BV, 9, S23-S28. https://doi.org/10.1016/s1389-9457(08)70013-3
17. Chandler, J F., Arnold, R T., Phillips, J B., & Turnmire, A E. (2013, September 1). Predicting Individual Differences in Response to Sleep Loss: Application of Current Techniques. Aerospace Medical Association, 84(9), 927-937. https://doi.org/10.3357/asem.3581.2013
18. Davis, L L. (1992, November 1). Instrument review: Getting the most from a panel of experts. Elsevier BV, 5(4), 194-197. https://doi.org/10.1016/s0897-1897(05)80008-4
19. Dawson. (2011, January 1). Long-haul pilots use in-flight napping as a countermeasure to fatigue. Elsevier BV, 42(2), 214-218. https://doi.org/10.1016/j.apergo.2010.06.016
20. Dongen, H P A V. (2006, January 1). Shift Work and Inter-Individual Differences in Sleep and Sleepiness. Taylor & Francis, 23(6), 1139-1147. https://doi.org/10.1080/07420520601100971
21. Dongen, H P A V., Mott, C G., Huang, J., Mollicone, D J., McKenzie, F D., & Dinges, D F. (2007, September 1). Optimization of Biomathematical Model Predictions for Cognitive Performance Impairment in Individuals: Accounting for Unknown Traits and Uncertain States in Homeostatic and Circadian Processes. Oxford University Press, 30(9), 1129-1143. https://doi.org/10.1093/sleep/30.9.1129
22. ECA. (2012, February 2). Pilot fatigue barometer. The European cockpit association. https://www.eurocockpit.be/sites/default/files/eca_barometer_on_pilot_fatigue_12_1107_f.pdf

23. Eriksen, C A., & Åkerstedt, T. (2006, January 1). Aircrew Fatigue in Trans-Atlantic Morning and Evening Flights. Taylor & Francis, 23(4), 843-858. https://doi.org/10.1080/07420520600865574
24. EUROCONTROL. (2018, September 8). Fatigue and Sleep Management: Personal Strategies for Decreasing the Effects of Fatigue in Air Traffic Control.. https://www.eurocontrol.int/sites/default/files/publication/files/sleep-mgnt-online-13032018.pdf
25. Flynn-Evans, E E., Arsintescu, L., Gregory, K B., Mulligan, J B., Nowinski, J., & Feary, M. (2018, October 1). Sleep and neurobehavioral performance vary by work start time during non-traditional day shifts. Elsevier BV, 4(5), 476-484. https://doi.org/10.1016/j.sleh.2018.08.002
26. Folkard, S., Robertson, K A., & Spencer, M B. (2007, May 24). A Fatigue/Risk Index to assess work schedules. Springer Science+Business Media, 11(3), 177-185. https://doi.org/10.1007/s11818-007-0308-6
27. Gander, P H., Berg, M V D., Mulrine, H M., Signal, L., & Mangie, J. (2013, July 8). Circadian adaptation of airline pilots during extended duration operations between the USA and Asia. Taylor & Francis, 30(8), 963-972. https://doi.org/10.3109/07420528.2013.790042
28. Gander, P H., Hartley, L R., Powell, D., Cabon, P., Hitchcock, E M., Mills, A., & Popkin, S. (2011, March 1). Fatigue risk management: Organizational factors at the regulatory and industry/company level. Elsevier BV, 43(2), 573-590. https://doi.org/10.1016/j.aap.2009.11.007
29. Gawron, V J. (2016, January 2). Summary of Fatigue Research for Civilian and Military Pilots. Taylor & Francis, 4(1), 1-18. https://doi.org/10.1080/21577323.2015.1046093
30. Gaydos, S., Curry, I P., & Bushby, A. (2013, October 1). Fatigue Assessment: Subjective Peer-to-Peer Fatigue Scoring. Aerospace Medical Association, 84(10), 1105-1108. https://doi.org/10.3357/asem.3728.2013
31. Goode, J H. (2003, August 1). Are pilots at risk of accidents due to fatigue?. Elsevier BV, 34(3), 309-313. https://doi.org/10.1016/s0022-4375(03)00033-1
32. Gregory, K B., Winn, W., Johnson, K., & Rosekind, M R. (2010, November 1). Pilot Fatigue Survey: Exploring Fatigue Factors in Air Medical Operations. Elsevier BV, 29(6), 309-319. https://doi.org/10.1016/j.amj.2010.07.002
33. Härmä, M. (1993, January 1). Individual differences in tolerance to shiftwork: a review. Taylor & Francis, 36(1-3), 101-109. https://doi.org/10.1080/00140139308967860
34. Härmä, M. (2006, December 1). Workhours in relation to work stress, recovery and health. Nordic Association of Occupational Safety and Health, 32(6), 502-514. https://doi.org/10.5271/sjweh.1055
35. Hartzler, B M. (2014, January 1). Fatigue on the flight deck: The consequences of sleep loss and the benefits of napping. Elsevier BV, 62, 309-318. https://doi.org/10.1016/j.aap.2013.10.010
36. Hilditch, C J., Arsintescu, L., Gregory, K B., & Flynn-Evans, E E. (2020, August 24). Mitigating fatigue on the flight deck: how is controlled rest used in practice?. Chronobiology International, 37(9-10), 1483-1491. https://doi.org/10.1080/07420528.2020.1803898
37. Hobbs. (2018, July 1). San Francisco Bar Pilot Fatigue Study. https://ntrs.nasa.gov/citations/20190002704
38. Holmes, A., Al-Bayat, S., Hilditch, C J., & Bourgeois-Bougrine, S. (2012, March 1). Sleep and sleepiness during an ultra long-range flight operation between the Middle East and United States. Elsevier BV, 45, 27-31. https://doi.org/10.1016/j.aap.2011.09.021

39. Honn, K., Satterfield, B C., McCauley, P., Caldwell, J L., & Dongen, H P A V. (2016, January 1). Fatiguing effect of multiple take-offs and landings in regional airline operations. Elsevier BV, 86, 199-208. https://doi.org/10.1016/j.aap.2015.10.005
40. Horrey, W J., Noy, Y I., Folkard, S., Popkin, S., Howarth, H D., & Courtney, T K. (2011, March 1). Research needs and opportunities for reducing the adverse safety consequences of fatigue. Elsevier BV, 43(2), 591-594. https://doi.org/10.1016/j.aap.2010.01.014
41. Latorella, K A., & Prabhu, P. (2000, August 1). A review of human error in aviation maintenance and inspection. Elsevier BV, 26(2), 133-161. https://doi.org/10.1016/s0169-8141(99)00063-3
42. Lee, S., & Kim, J K. (2018, March 1). Factors contributing to the risk of airline pilot fatigue. Elsevier BV, 67, 197-207. https://doi.org/10.1016/j.jairtraman.2017.12.009
43. Leeuwen, W V., Kircher, A., Dahlgren, A., Lützhöft, M., Barnett, M., Kecklund, G., & Åkerstedt, T. (2013, July 23). Sleep, Sleepiness, and Neurobehavioral Performance While on Watch in a Simulated 4 Hours on/8 Hours off Maritime Watch System. Taylor & Francis, 30(9), 1108-1115. https://doi.org/10.3109/07420528.2013.800874
44. Missoni, E., Nikolić, N., & Missoni, I. (2009, February 1). Civil Aviation Rules on Crew Flight Time, Flight Duty, And Rest: Comparison of 10 ICAO Member States. Aerospace Medical Association, 80(2), 135-138. https://doi.org/10.3357/asem.1960.2009
45. Moher et al.. (2009, May 23). https://www.easa.europa.eu/en/document-library/research-reports/tseasa2007op08
46. Mohren, D.. (2007, January 2). https://www.researchgate.net/publication/301771894_An_Epidemiological_approach_of_fatigue_and_work_Experiences_from_the_Maastricht_Cohort_Study
47. NASA-ARC. (2016, February 4). https://ntrs.nasa.gov/citations/20190002704
48. Olaganathan, R., Holt, T B., Luedtke, J., & Bowen, B D. (2021, June 2). Fatigue and Its Management in the Aviation Industry, with Special Reference to Pilots. Purdue University Press, 10(1), 45-45. https://doi.org/10.7771/2159-6670.1208
49. Rashid, H., Place, S., & Braithwaite, G. (2012, September 2). Eradicating root causes of aviation maintenance errors: introducing the AMMP. Springer Science+Business Media, 16(1), 71-90. https://doi.org/10.1007/s10111-012-0245-4
50. Reis, C., Mestre, C., Canhão, H., Gradwell, D., & Paiva, T. (2016, April 1). Sleep complaints and fatigue of airline pilots. Brazilian Association of Sleep and Latin American Federation of Sleep Societies, 9(2), 73-77. https://doi.org/10.1016/j.slsci.2016.05.003
51. Roach, G D., Petrilli, R M., Dawson, D., & Lamond, N. (2012, May 23). Impact of Layover Length on Sleep, Subjective Fatigue Levels, and Sustained Attention of Long-Haul Airline Pilots. Taylor & Francis, 29(5), 580-586. https://doi.org/10.3109/07420528.2012.675222
52. Roach, G D., Sargent, C., Darwent, D., & Dawson, D. (2012, March 1). Duty periods with early start times restrict the amount of sleep obtained by short-haul airline pilots. Elsevier BV, 45, 22-26. https://doi.org/10.1016/j.aap.2011.09.020
53. Rose, M B., & Giray, N. (2013, June 1). Universal Fatigue Management Strategies. Elsevier BV, 8(2), 255-263. https://doi.org/10.1016/j.jsmc.2013.02.004
54. Rosekind, M R., Gander, P H., Miller, D L., Gregory, K B., Smith, R M., Weldon, K J., Co, E L., Mcnally, K L., & Lebacqz, J V. (1994, June 1). Fatigue in Operational Settings: Examples from the

Aviation Environment. SAGE Publishing, 36(2), 327-338. https://doi.org/10.1177/001872089403600212
55. Samn. (1982, March 7). Estimating Aircrew Fatigue: a Technique with Application to Airlift Operations. . https://apps.dtic.mil/sti/pdfs/ADA125319.pdf
56. Shamsuzzaman, A., Gersh, B J., & Somers, V K. (2003, October 8). Obstructive Sleep Apnea. American Medical Association, 290(14), 1906-1906. https://doi.org/10.1001/jama.290.14.1906
57. Tremaine, R., Dorrian, J., Lack, L., Lovato, N., Ferguson, S A., Zhou, X., & Roach, G D. (2010, December 1). The relationship between subjective and objective sleepiness and performance during a simulated night-shift with a nap countermeasure. Elsevier BV, 42(1), 52-61. https://doi.org/10.1016/j.apergo.2010.04.005
58. UK-CAA. (2007, August 9). https://www.caa.co.uk/our-work/publications/documents/content/caa-paper-2005-04/
59. UK-CAA. (2007, February 15). https://www.caa.co.uk/our-work/publications/documents/content/caa-paper-2005-04/
60. UK-CAA. (2007, February 22). https://www.caa.co.uk/our-work/publications/documents/content/caa-paper-2005-04/
61. Vgontzas, A N., Pejovic, S., Zoumakis, E., Lin, H., Bixler, E O., Basta, M., Fang, J., Sarrigiannidis, A., & Chrousos, G P. (2007, January 1). Daytime napping after a night of sleep loss decreases sleepiness, improves performance, and causes beneficial changes in cortisol and interleukin-6 secretion. American Physiological Society, 292(1), E253-E261. https://doi.org/10.1152/ajpendo.00651.2005
62. Wang, T C., & Chuang, L H. (2014, January 1). Psychological and physiological fatigue variation and fatigue factors in aircraft line maintenance crews. Elsevier BV, 44(1), 107-113. https://doi.org/10.1016/j.ergon.2013.11.003
63. Weiland, M Z., Nesthus, T E., Compatore, C., Popkin, S., Mangie, J., Thomas, L., & Flynn-Evans, E E. (2013, September 1). Aviation Fatigue. SAGE Publishing, 57(1), 1-5. https://doi.org/10.1177/1541931213571001
64. Williamson, A., Lombardi, D A., Folkard, S., Stutts, J C., Courtney, T K., & Connor, J. (2011, March 1). The link between fatigue and safety. Elsevier BV, 43(2), 498-515. https://doi.org/10.1016/j.aap.2009.11.011
65. Wright, K P., Bogan, R., & Wyatt, J K. (2013, February 1). Shift work and the assessment and management of shift work disorder (SWD). Elsevier BV, 17(1), 41-54. https://doi.org/10.1016/j.smrv.2012.02.002
66. Zaslona, J L., O’Keeffe, K., Signal, T L., & Gander, P H. (2018, May 21). Shared responsibility for managing fatigue: Hearing the pilots. PLOS ONE, 13(5), e0195530-e0195530. https://doi.org/10.1371/journal.pone.0195530