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IMPROVEMENT OF FATIGUE MANAGEMENT METHODOLOGY RELATED TO FLIGHT CREW

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Abstract. This research focuses on flight crew fatigue and the improvement of a fatigue management methodology that helps in reducing fatigue for flight crew members, aiming to improve their well-being and overall aviation safety of flights. A thorough literature review established a foundation for understating fatigue and the available methodologies for fatigue management for flight crew members. To make the picture clearer, an empirical study was conducted, and it included surveys and interviews with flight crew members. The gathered data underwent detailed statistical and thematic analysis to identify key factors influencing fatigue among flight crew members. Findings revealed multiple contributors to the flight crew member fatigue. Using these insights, a fatigue management methodology is proposed, integrating real-world experiences with evidence-based strategies. The proposed methodology and the recommendations that were formed are relevant for a company management which is facing flight crew fatigue management issues.

Keywords: aviation, fatigue, flight crew, crew resource management, safety.

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1. Introduction

Flight safety is an essential concern for both civil and military aviation, as it affects the lives of an enormous number of passengers, crew members, and personnel working on ground every day.

Flight safety is defined as a set of processes and policies, implemented in the aviation industry to minimize the risk of accidents and incidents throughout flights. Flight safety depends on many factors, such as weather, air traffic, aircraft design, maintenance, pilot training, human factors, and regulations. Human factors are often considered to have an essential impact, as they involve the performance, behaviour, and well-being of the flight crew and other aviation personnel.

One of the most prevalent and influential human factors in aviation is fatigue which is defined as an extreme state of exhaustion that impair the persons overall performance. This research presents and explains the in-depth definition of fatigue, flight crew fatigue, the types of fatigue, what affects it and how to manage it.

2. Literature review

2.1. Fatigue

Fatigue is a widely used word and is usually used as a substitute for the word "tired". Noticeable, these two words hold the same meaning.

Fatigue hardly is a synonym for tiredness. As it goes way deeper in terms of the feelings and the physiological state it brings along drawing a different path affecting our life, daily activities, and decisions in a way that a simple tiredness could never do.

Traditionally, fatigue was seen as a natural consequence timespan spent working on a specific assignment or task (Dawson & McCullough, 2005). That is usually applicable to muscle fatigue which results from physical.

Fatigue is defined as physical and/or mental weariness resulting from stress, that is, an incapacity to continue what one is doing with the same level of intensity and that results in a decrease in the quality of the performance (Evans & Lambert, 2007).

The International Civil Aviation Organization (ICAO) defines fatigue as a physiological state of reduced mental or physical performance capacity that results from sleep loss or extended hours of wakefulness, circadian phase, or the workload in general for both mental and/or physical activity that impairs a crew member's alertness and ability to operate an aircraft safely or perform safety-related duties (International Civil Aviation Organization [ICAO], 2013).

ICAO describes workload as a mental or physical activity and highlights three aspects of workload: the nature and amount of work that should be done; time limitations; and factors related to the performance abilities and capabilities of a person (ICAO, 2020). In both situations of high and low workloads, a reduction in performance might occur, and it would be classified as active and passive fatigue, correspondingly.

High workload situations may overwhelm a fatigued person due to the required high mental effort, while low workload situations might lack sufficient stimulation which can reveal underlying sleepiness.

The outcomes of high and low workloads might be different; a low workload often leads to reduced motivation and lower task engagement, whereas a high workload leads to distress and may impair sleep after work, due to the need to decompress (Hu & Lodewijks, 2020).

There are multiple types of fatigues; transient, cumulative, and circadian:

1. Transient fatigue is acute fatigue caused by extreme sleep restriction or extended hours of awakening within 1 or 2 days.
2. Cumulative fatigue is fatigue caused by repeated mild sleep restriction or extended hours of being awake across a series of days.

For both types, sleep is the cause. The preferable duration of sleep per night is different for different individuals, but as for now, 7–8 hours of sleep is the recommended duration for adults. Sleep loss is defined as acute when an individual does not sleep at all for an extended period (known as sleep deprivation) or as chronic "trimming" of sleep at night by 1 or 2 hours, also known as sleep restriction (Goel et al., 2013; ICAO, 2020).

Fatigue-related risks increase significantly when the waking period extends for longer than 16 hours, and the pre-duty sleep period is shorter than 6 hours, or the work period happens during the pilot's usual hours of sleep (Bendak & Rashid, 2020).

3. Circadian fatigue refers to reduced performance during nighttime hours, especially throughout an individual's "Window Of Circadian Low" (WOCL).

As per the Federal Aviation Administration (FAA), this time typically is between 2:00 a.m. and 05:59 a.m. (Federal Aviation Administration [FAA], 2012). During this period, the levels of attention are the lowest. Another widely known period is the post-lunch dip; which occurs between 2 and 4 PM. During this time the attention levels and the threshold for sleep lower again (Valdez, 2019).

Fatigue happens due to various reasons like irregular work schedules, jet lags, frequent change of time zones, extended duty hours, high workload, stress and pressure, unavailability of comfortable resting facilities in-flight for the crew, and the need for constant alertness and decision-making.

As per the International Air Transport Association (IATA), flying through multiple time zones can disrupt the circadian rhythm (International Air Transport Association [IATA] et al., 2015).

Extended duty hours, especially during international flights, is the reason for sleep deprivation and cumulative fatigue. Irregular shifts can cause sleep disturbances. Cabin noise, cosmic radiation, pressure, and vibration contribute to fatigue as well.

Furthermore, it is significant to differentiate between sleepiness and mental fatigue, mainly in their roots and sources, psychological and physical responses, while recognizing that they interactively contribute to reduced performance and alertness (Hu & Lodewijks, 2020). Sleepiness is predominantly caused by circadian rhythm disruptions, insomnia, and time awake, while mental fatigue is mainly caused by the time spent on a task and cognitive workload (Balkin & Wesensten, 2011).

Moreover, the flying process requires high working memory capability along with divided and focused attentional abilities, this leads to mental (cognitive) fatigue (MF) that promotes task disengagement, thus impairing

Table 1. Operational factors that can influence fatigue

Factors that can influence fatigue in operational context	
Specific fleet characteristics	▪ The quality of on-board rest facilities and the policies for their usage. ▪ Patterns and types of flying (long-haul versus short-haul).
Routes and destinations	▪ Airport traffic density. ▪ Air Traffic Control behaviours. ▪ The amount of time spent in transport on ground. ▪ The quality of the accommodation.
Experience in execution and management of operational demands	▪ Experience of crew members and the operator in operating a specific aircraft type. ▪ Experience in the type of operation. ▪ Experience in the position of pilot in command. ▪ Experience at a specific airline.
Staff	▪ The number of Staff members should be sufficient in order to be able to offer adequate rest opportunities to avoid cumulative fatigue. ▪ Sufficient staff members number to cover sickness and other absences.
Irregular operations	▪ Frequency of the need to use Captain's discretion/duty period[1] extensions. ▪ Frequency of disruption to schedules and the assignment of unscheduled duties and the pressures to keep up with the schedule.

[1] A duty period is a period that starts when a flight crew member is required by the operator to start the duty and ends when the person has finished all his duties.

the pilot's ability to react to changes to respond to unexpected events accordingly.

Mental fatigue is a state of reduced alertness and weariness that is caused by prolonged task execution and/or highly demanding tasks. It is decreased by taking breaks and it is a natural protective tool (Grandjean, 1979). However, physiological measures present a growing interest for the detection of MF because of their objectiveness, high temporal resolution, and ability to detect MF-related changes as early as 45 min into task execution (Trejo et al., 2007). Moreover, there are additional operational factors that may affect the state of fatigue and they are distributed as follows (see Table 1):

Moreover, all of the mentioned above can lead to multiple health and psychological issues like:

1. Depression, anxiety and neuroticism (Cahill et al., 2019).
2. Increased risk of type 2 diabetes (Axelsson & Puttonen, 2012).
3. Increased risk of cardiovascular problems (Lord & Conlon, 2018).

Flight crews perform their duties in conditions that are the reason for circadian dysrhythmia and, mild hypoxia. Also, they are exposed to reduced atmospheric pressure, low humidity, noise, vibration, cosmic radiation, and magnetic fields. These occupational exposures present physiological as well as mental challenges for the health and well-being of the crew in the long-term perspective.

2.2. Accidents and incidents caused by fatigue

National Transportation Safety Board (NTSB) reported that many lives through the years were lost in accidents as a result of flight crew fatigue. The Guantanamo Bay accident in 1993 was the first accident in history that recognized fatigue as the reason for the accident (National Transportation Safety Board [NTSB], 1993).

The next accident where fatigue was considered as the main cause is the Flight 702P of Air Algerie in 1994 at Coventry Airport happened due to the effects of fatigue on the flight crew, after completing over 10 hours of flight duty through the night during five flight sectors which included a total of six approaches to land (Department of Transport, 1995).

Colgan Air Flight 3407, Buffalo, USA in 2009 crashed into a house killing a man in the house and passengers on board. Both pilots had long commutes and slept in the crew lounge, instead of a hotel before the flight, and the pilot in command had failed three "check rides training program". Investigators examined possible crew fatigue (NTSB, 2010).

Another accident by Fly Dubai Flight FS981 in 2016 where the pilot's confusion and lack of psychological readiness for a second go-around; the possible operational tiredness of the crew; at the worst possible time in terms of the circadian rhythms, when the human performance is severely degraded and is at its lowest levels along with the increase of the risk of errors. Taking 55 passenger lives and seven crew members. Taking 55 passenger lives and seven crew members (Hornfeldt, 2019).

In general, for the period 1993–2016 twenty (20) aircraft crashes occur due to fatigue reasons (Predictive Safety, 2023).

National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System classified incident reports stated that 52,000 incidents have been classified as caused by fatigue, accounting for 21% of all incidents (NTSB, 2003).

A study performed on commercial airline pilots who were on duty for the past 6 months up to the time of the research showed that out of 224 (68.3%) pilots who participated in the study were severely fatigued and 221 (67.4%) reported making mistakes in the cockpit because of fatigue (Aljurf et al., 2018). Fortunately, not every instance of pilot fatigue leads to an incident or accident, due to safety procedures in place (Jackson & Earl, 2006).

2.3. Flight crew burnout

Burnout is a state of emotional, physical, and mental exhaustion that happens due to continuous stress (chronic) for a long time and overwork (Freudenberger, 1974). It is characterized by strong fatigue, detachment, and not feeling content when achieving a personal accomplishment. Burnout does not impact a sole individual but can affect organizations and society in general. A study on multiple airlines' pilots including airlines from low-cost to traditional flag carriers and operating both short-haul and long-haul flights conducted in 2019 has shown that the Pilots' burnout rate was found to be at 40% (Demerouti et al., 2019).

Burnout causes an individual's mental and physical energy to drain. Thus, pilots are more prone to make mistakes and less likely to act safely (Nahrgang et al., 2011). Fatigue, stress, burnout, and depression are interrelated. Emotional fatigue and physical fatigue are symptoms of both burnout and depression as a result of burnout (Plieger, 2015). Studies have shown that burnout is negatively related to performance at simulator checks/training (Carey et al., 2020).

2.4. Flight crew fatigue management

2.4.1. Flight crew fatigue

Flight crew fatigue is a critical concern in aviation safety, stemming from the demanding nature of aviation duties and the potential risks it poses to both crew members and passengers. These regulations, often grounded in scientific research and expert recommendations, set forth guidelines and requirements for managing and mitigating fatigue risks in flight operations.

The aviation industry is subject to a complex regulatory framework aimed at addressing and mitigating the risks associated with flight crew fatigue. These guidelines and requirements are issued by authorities like the FAA and ICAO. These regulations lay the foundation for fatigue risk management within the industry.

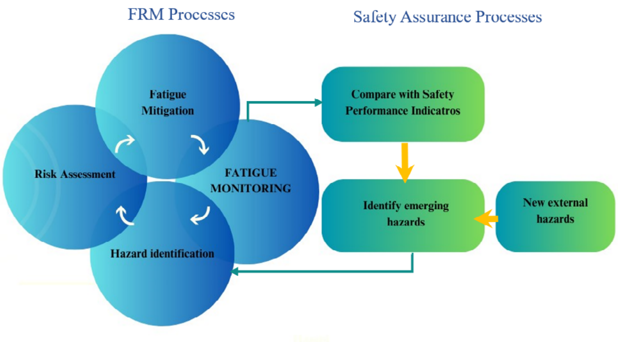

Figure 1. Fatigue management regulations (Gander, 2015)

The consequences of flight crew fatigue impact many aspects of aviation operations. Impaired cognitive performance can lead to decreased concentration, reduced coordination and motor skills, poor decision-making, delayed reactions, and decreased situational awareness. These effects increase the risk of incidents and accidents happening. Real incidents and case studies serve as reminders of the critical role that fatigue plays in aviation safety.

Various strategies and programs within the industry have been created and developed in efforts to manage flight crew fatigue. Such as Crew Resource Management (CRM), Fatigue Risk Management Systems (FRMS), and Flight Data Monitoring (FDM) (see Figure 1).

Fatigue Risk Management Systems (FRMS) is "a data-driven means of constant monitoring and maintaining fatigue-related safety risks, based on scientific principles and knowledge as well as operational experience that aims to ensure that relevant personnel perform their duties at adequate levels of alertness" (ICAO, 2012).

FRMS was created by a joint effort of f ICAO, IATA & IFALPA and was added to ICAO annex 6 in 2008 to provide guidance to regulatory authorities on the implementation process of the FRMS.

In practice, an FRMS represents a comprehensive risk management approach that includes hazard identification, risk assessments, mitigation strategies, training and education programs, fatigue monitoring systems, and ongoing adaptation processes that respond and reflect changing circumstances and feedback. Its operational point of view combines prevention, prediction, detection, and intervention strategies (Civil Aviation Safety Authority Australia, 2010). In October 2015 European Union Aviation Safety Agency (EASA) issued two Decisions on Crew Resource Management (CRM) training (AMC1 ORO.FC.115) that came into force in 2016 and these decisions aimed at enhancing the functionality and effectiveness of CRM training and provide operators with better tools to mitigate CRM-related hazards and risks for increased safety throughout all flight phases (European Union Aviation Safety Agency [EASA], 2015).

Furthermore, FDM systems analyze flight data to identify trends and anomalies related to fatigue issues. While these strategies have contributed to safety enhancements, they are not without limitations. Understanding these strengths and shortcomings sets the stage for our research into advancing fatigue risk management methods.

Flight crew fatigue management is a holistic process aimed at identifying, preventing and mitigating fatigue-related risks within the aviation industry. It involves various strategies and practices designed to ensure the well-being of flight crews while maintaining the highest standards of safety.

As per (European Cockpit Association [ECA], 2012) around 70–80% of fatigued pilots would not submit a fatigue report or state to be unfit to fly due to the fear of disciplinary actions or stigmatization by their employer or colleagues and only 20–30% would report unfit for duty or file a report under such circumstances. More than 50% of surveyed pilots experienced fatigue as an impairing way of their ability to perform well while on flight duty.

The same study showed that 4 out of 5 pilots had to cope with fatigue while in the cockpit. The pilots who took part in the survey reported falling asleep unpredictably and involuntarily in the cockpit while flying. In the UK, a third of the pilots said that when they woke up, they found their co-pilots sleeping as well.

The following pie chart (Figure 2) demonstrates the reasons for under-reporting pilot fatigue (ECA, 2012). The Figure 2 shows pilots' answers to why they have not submitted a fatigue report.

In a study performed in 2018 on 328 commercial airlines pilots who were on active duty for the preceding 6 months showed that 34.1% of pilots had excessive daytime sleepiness and 148 (45.1%) reported falling asleep at the controls at least once without a previous agreement with their colleagues (Aljurf et al., 2018) (see Figure 3).

Moreover, a survey conducted in 2023 during high season has shown that 75.9% of the respondents reported that they have had at least one microsleep episode on the flight deck while operating within 4 weeks preceding the survey (Baines Simmons Safety Services, 2023).

The last known case of pilots falling asleep during their flight time happened in March 2024 when both the pilot and co-pilot fell asleep at the same time for close

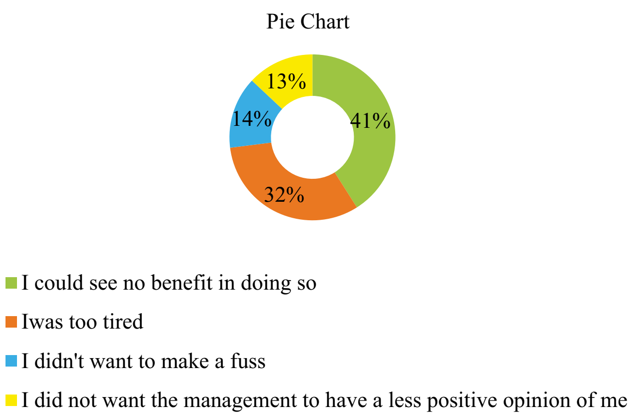

Figure 2. Reasons for under-reporting pilot fatigue from (ECA, 2012)

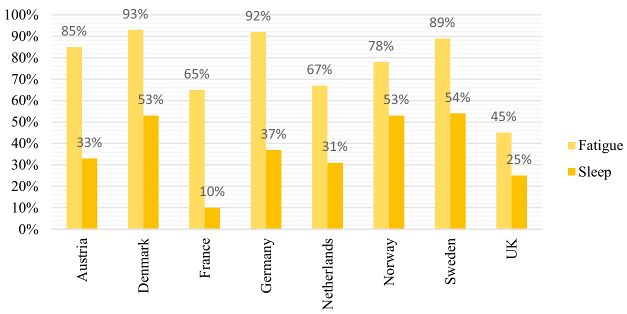

Figure 3. Percentage of pilots who have experienced fatigue and fell asleep during a FDP (ECA, 2012)

to 30 minutes during a flight from Kendari in Southeast Sulawesi with 153 passengers on board with aircraft deviated from its path (Suri & Stambaugh, 2024).

2.4.2. Scheduling

Scheduling plays an important role in fatigue management as well. A study found that the likelihood of a commercial aviation accident grows immensely with increasing duty hours and that 20% of the United States commercial aviation accidents happened on duty of 10 hours or more (Goode, 2003).

A high workload might exceed the capacity of the fatigued member of the crew due to the high mental effort required on-duty time, while low workload situations lead to a lack of sufficient stimulation which may uncover excessive sleepiness (Hu & Lodewijks, 2020).

Pilots of long-haul usually link their fatigue to jet lag, as a reason for trans-meridian flights, while SM-H pilots link their fatigue with the high workload during the flight duty period (FDP), as they perform multiple take-offs and landings per duty period, and these stages of a flight have the highest workload intensity (Reis et al., 2016).

Nonetheless, in both categories of pilots (long-haul and short to medium-haul), fatigue can demonstrate itself, for instance, in the following situations missed: radio calls, equipment malfunctions not being detected, the performance of routine tasks inaccurately or sometimes they might be even forgotten, lining up with the wrong runway, landing without clearance; in extreme occurrences, falling asleep during FDP. Short-haul flight duration is up to 3 hours, while long-haul flights usually last for 6–12 hours. In the past long-haul operations were contemplated to impose a greater risk of fatigue than short-haul operations, with fatigue reported by 60% of long-haul pilots and 49% of short-haul pilots as evidence (Bourgeois-Bougrine et al., 2003). However, there is a study that discovered that fatigue for significantly higher in SH than in LH operations with the following percentage (93% vs. 84.3%), with a 2.945 added risk of fatigue in SH pilots (Reis et al., 2016).

2.4.3. Education and training

Education and training are essential for both flight crews and airline management. Comprehensive education programs give flight crews the knowledge and awareness that they need to recognize the signs of fatigue, understand its effects on their performance, and learn about countermeasures and strategies to cope with it effectively. Moreover, they learn the importance of reporting fatigue-related concerns. Proper training equips flight crew members with practical tools to manage fatigue-related risks during duty. These trainings include understanding duty and rest regulations, effective crew communication, and utilizing fatigue risk assessment tools and for enhancing safety and operational performance. Hence, training crew members about fatigue and sleep hygiene is of a great importance and is currently regarded as a mandatory aspect of Fatigue Management.

2.4.4. Regulatory compliance

The governments are responsible for establishing the regulations that allow for the effective management of fatigue. Additionally, it must ensure that the service provider is actively addressing the risks associated with fatigue to attain an acceptable level of safety performance.

Airlines or Service Providers must adhere to regulatory requirements regarding flight crew duty hours, rest periods, and fatigue risk management. They must provide fatigue-management education as well.

There are two regulatory approaches to fatigue management: the prescriptive limitation regulation and FRMS approach. The prescriptive limitation regulation approach defines maximum working duration (duty time) and minimum rest intervals for particular categories of aviation professionals. These established limitations, established by the government, serve as clear guidelines that service providers to adhere to when addressing the risks associated with fatigue within their safety management procedures. This approach considers fatigue as a possible hazard that should be taken into consideration by SMS.

The FRMS approach offers the possibility and opportunity for service providers to use scientific advancements and research to improve safety and implement better strategies and resources. It is focused on managing the actual fatigue risk rather than addressing the predicted fatigue risk and it allows it to go beyond prescribed limits. Certainly, there are Flight Times and Duty Periods limitations. The European limitations were set in 2008 by EU member states Subpart Q of the EU-OPS Regulation 1899/2006 representing the minimal standards. Each EU member country has the right to make amendments but without lowering the official EU bar. It is significant to highlight that these standards were not decided on based on any sound scientific evidence or medical research (ECA, 2007).

A crew member might be assigned a total duty period that does not exceed the limits listed in Table 2.

The total flight time of the sectors that are assigned to a crew member as an operating crew member should not exceed:

1. 100 hours of flight time in any 28 consecutive days
2. 900 hours of flight time in any calendar year.
3. 1,000 hours of flight time in any 12 consecutive flight months.

Table 2. Maximum total duty periods (Eur-lex, 2014)

Duty Hours	Consecutive days
60 duty hours	7
110 duty hours	14
190 duty hours	28

The minimum rest period to be provided before starting an FDP to be started at home shall be at least as long as the preceding duty period, or 12 hours, whichever is greater.

FAA has limitations similar to the EASA ones. It is 60 hours in any 168 consecutive hours (7 days), 190 hours in any 672 consecutive hours (28 days).

Although the rules for duty hours are strict and regulated there were cases when pilots took their companies to court for fatigue reasons and pilot's unions raised concerns about it. An example of such a case is Thomas Cook Airlines which happened in 2016. The company threatened to dismiss a pilot after refusing to fly with 200 passengers on board because he was fatigued (BALPA, 2016).

Another recent case is Southwest Airlines. Pilots' Union raised safety concerns because of an epidemic of fatigue among pilots (Genovese, 2022). The number of pilots asking to be relieved from flights has jumped up to 330% in comparison to the pre-pandemic times (CBS News, 2022).

These cases are examples of that fatigue regulations need to be studied more and updated to adhere to new realities and demands of the market without putting lives at risk.

Furthermore, there is a Commander's Discretion, and it is applied in the event of unforeseen circumstances, and it allows the commander to extend or modify the flight duty period and rest time after consulting all of their crew members. However, a late survey on fatigue among European Pilots by the request of the European Cockpit Association was conducted in 2023 by Baines Simmons and this survey showed that a considerable amount of the crews used Commander's Discretion (CD) to extend Flight Duty Periods (FDPs) within the 4 weeks prior to the survey (see Figure 4).

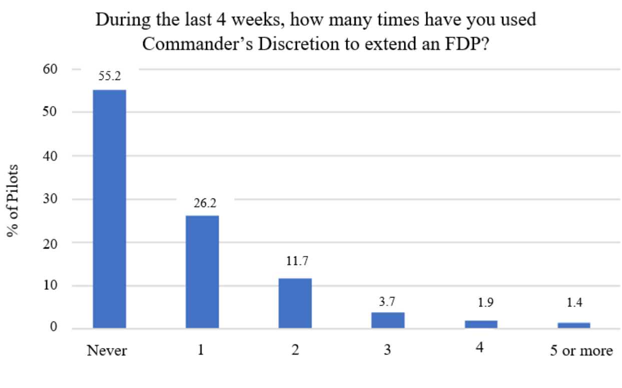

Figure 4. The utilization of Commander's Discretion to extend an FDP in the month (Baines Simmons Safety Services, 2023)

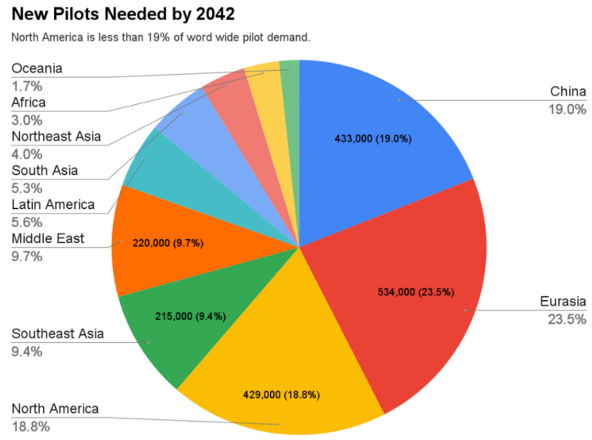

Figure 5. Pilots needed by 4042 (Wynns, 2023)

Taking into consideration the aviation transport has witnessed exponential growth in recent decades. According to the International Air Transport Association (IATA), global passenger numbers reached 4.5 billion in 2019, and it was projected to exceed 8 billion by 2037 (Figure 5). This data highlights the remarkable demand in new pilot for upcoming fifteen years which leads to increasing of the flight's intensity and pilot fatigue.

3. Navigating fatigue challenges: a data-driven survey analysis approach

To come to logical conclusions and recommendations an analysis of the acquired data from both the survey and the interviews were performed.

The focus of this chapter lies in the responses gathered from a comprehensive survey distributed among professionals with varying degrees of experience in the field. This ensures that author's research and proposed methodology for improving fatigue management methodologies are not only based on statistical trends but also on practical knowledge gained from professionals.

3.1. Survey analysis of flight crew professionals in relation to fatigue

The survey participants were 56 flight crew professionals including representatives of both male and female genders with different experience. They have answered total of 9 questions.

As part of this comprehensive study of flight crew fatigue management methodologies, participants were asked to provide detailed information about their professional experiences in aviation. This question is important as it seeks to identify potential differences in fatigue-related problems across years of experience. Figure 6 demonstrates the experience (flight hours).

The next question was assigned to the preference of flight type represented by Figure 7.

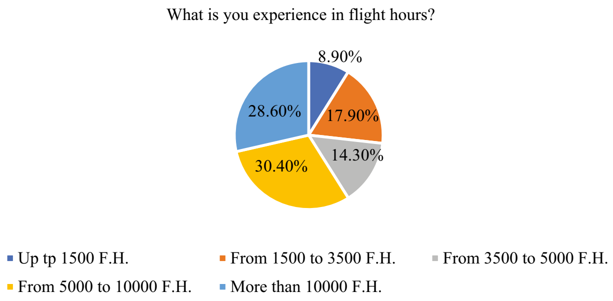

Figure 6. Experience of the survey participants (developed by the authors)

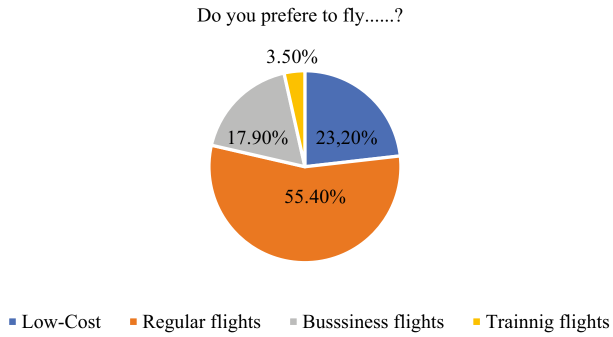

Figure 7. Flight type preference (developed by the authors)

By asking about flight preferences, insights into the specific types of flights that pilots' favour were gained. This understanding is valuable for airlines, aviation companies, and training institutions to tailor their programs and services to better align with pilot preferences. Different types of flights may pose unique challenges related to fatigue management. Understanding pilot preferences in this context can contribute to the development of more targeted and effective fatigue management strategies for specific flight types.

The next question directly resorts to the subjective experience of pilots regarding the alignment of their compensation with the demands of their work, particularly in relation to flight schedules and fatigue. Understanding whether pilots feel their compensation is fair can provide insights into overall job satisfaction and well-being (see Figure 8).

The following question was assigned to understand whether flight crew members receive effective and up-to-date training in fatigue management strategies (see Figure 9).

More than half of the respondents express dissatisfaction or perceive gaps in their training and it indicates areas that might need improvement or additional focus. Ensuring that pilots receive comprehensive and up-to-date training in fatigue management strategies contributes to a safer operating environment by equipping them with the knowledge and tools to mitigate fatigue-related risks. The question addresses the pilots' confidence in the training they've received.

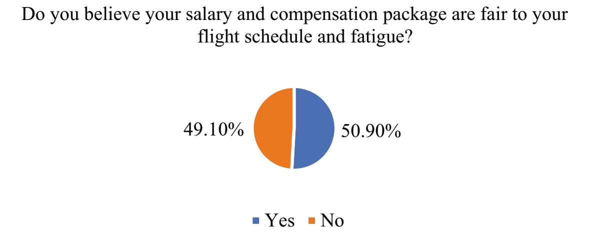

Figure 8. Flight type preference (developed by the authors)

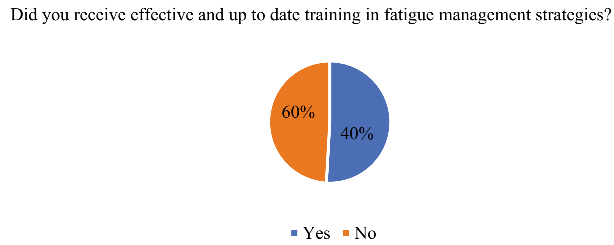

Figure 9. Reception of effective and up-to-date fatigue management strategies (developed by the authors)

If pilots feel well-trained in fatigue management, it can positively impact their confidence in handling fatigue-related challenges, contributing to overall job satisfaction and well-being.

Understanding the patterns of fatigue in relation to flight duration helps in recognizing when fatigue is more likely to occur. Thus, the responses for the question in Figure 10 are important for developing or updating existing targeted fatigue management strategies as a proactive measure.

The question "Do you think the rest time you get after your shift is sufficient?" holds significant importance in assessing pilot well-being, fatigue management, and overall safety within the aviation industry. Pilots' perceptions of the adequacy of rest time directly impact their physical and mental states, with implications for job satisfaction and safety. The responses provide valuable insights into potential areas for improvement in scheduling practices, helping organizations align with regulatory requirements and enhance crew satisfaction (see Figure 11).

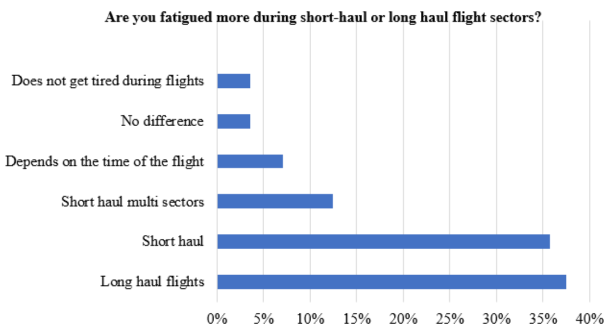

Figure 10. Fatigue during different types of flight (developed by the authors)

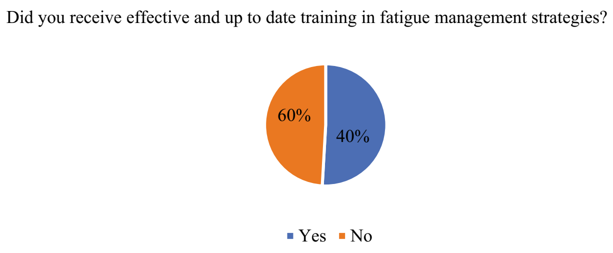

Figure 11. Sufficiency of rest time after duty (developed by the authors)

3.2. Statistical analysis of survey results

This sub-chapter contains SPSS analysis to conduct an accurate analysis of the data collected in the study. SPSS is a powerful tool for statistical analysis, that gives the possibility to collect substantial insights and draw evidence-based conclusions from the gathered dataset.

The use of this program supports a comprehensive examination of the acquired feedback from the surveys and allows for the exploration of patterns, associations, and trends that may be present within the data. This sub-chapter acts as a bridge between the raw data and the synthesized outcomes to extract meaningful knowledge from the dataset.

First of all, it is important to understand whether there is a connection between the gender of the flight crew member and their flight preference. To find whether there is a relationship between these two variables crosstabulation analysis was performed with the following results (see Table 3).

After processing the data with a chi-square test it is noticeable that it is not possible to conclude if gender has an impact on flight preference as the significance of the Pearson chi-square shows 0.318 and it is greater than the significance α 0.5. The numbers in the table indicate that there is not enough data to establish a link between the two variables (see Table 4).

Then the relationship between Flight preference and the experience, Flight preference and the rest time flight crew members get after their shifts and Flight preference and salary satisfaction were established. The case processing summary indicates that all of the cases were analyzed and there are no missing cases.

The following Table 5 and Figure 12 demonstrate that 81.25% of professionals with experience of more than 10000 (yen thousand) hours prefer to fly regular flights, 12.5% prefer business aviation and only 6.25% agree to a low-cost. Pilots with experience within the range of 1500–3500 hours evenly prefer regular flights and low-cost

Table 3. Gender relationship with flight preference crosstabulation (calculated by the authors)

Gender. * Flight preference Crosstabulation						
–		Regular Flights	Low-Cost Flights	Business aviation	Training Flights	Total
Gender	Female	3	4	2	0	0
	Male	28	8	8	2	2
Total		31	13	10	2	56

Table 4. Gender relation to flight preference (calculated by the authors)

Chi-Square Tests			
–	Value	df	Asymptotic significance (s-sided)
Pearson Chi-Square	3.319a	3	0.318
Likelihood Ratio	3.607	3	0.317
N of Valid Cases	363	–	–

Table 5. Preference of flight relation to experience crosstab (calculated by the authors)

Crosstab							
What is your experience?							
Flight preference	Type of operation	>10000 h.	<1500< 3500 h.	<3500 < 5000 h.	<5000 < 10000 h.	< 1500 h.	Total
	a low-cost	1	4	2	5	1	13
	business aviation	2	1	2	4	1	10
	regular flights	13	4	4	8	2	31
	training flights	0	1	0	0	1	2
Total		16	10	8	17	5	56

flights. It is interesting to note that those who have experience up to 1500 hours, i.e. are in the early stages of their career show almost even distribution for all types of flight.

Regular flights are usually provided by full-service airlines. They have higher ticket prices that include different kinds of amenities and services, in-flight entertainment, meals, and the convenience of services such as checked baggage and seat selection.

Such airlines usually operate on a global scale, have regular flight intervals serving major airports and hubs, and offer a diverse fleet of aircraft to match various routes and destinations.

Then it was essential to understand the correlation between the rest time flight crew members receive and their flight preference. Low-cost carriers often concentrate on specific routes and airports and choose a no-frills approach to reduce operational costs. The initial ticket price is lower than a regular flights price, however, passengers need to pay extra for additional services such as checked baggage, in-flight meals, and seat selection. Business aviation refers to the use of private or chartered aircraft for transporting persons or groups primarily for business purposes. Business aviation accommodates to specific travel needs of companies, executives, and people who can afford such flights. It is about time-efficiency, convenience, and the ability to customize travel plans, allowing for direct flights to various destinations with no need to depend on commercial airline schedules and routes. Figure 13 shows that business aviation flight crew members split in half with their opinion about the sufficiency of rest time 50% for each of the answers "yes" and "no". Regular flights are more correlated with sufficient rest time after duty; however, it is possible to note that the opinions are quite diverse as 38.71% of the respondents consider the rest time as insufficient, meanwhile 58.06% of respondents believe in sufficiency. Low cost is considered not to provide enough rest time by 84.62% of respondents and only 15.38% think there is enough rest time after the shift. The next analysis was performed to see the correlation between flight preference and salary compensation satisfaction. Figure 14 demonstrates that 92.31% of respondents believe that the salary and compensation are not satisfactory in a low-cost system while 7.69% think it is enough.

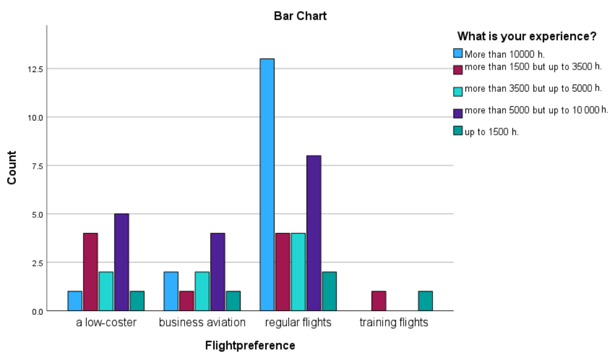

Figure 12. Preference of flight in relation to experience

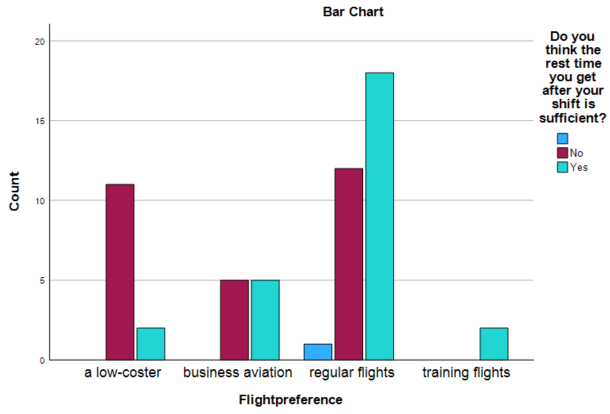

Figure 13. Preference of flight in relation to rest time after duty

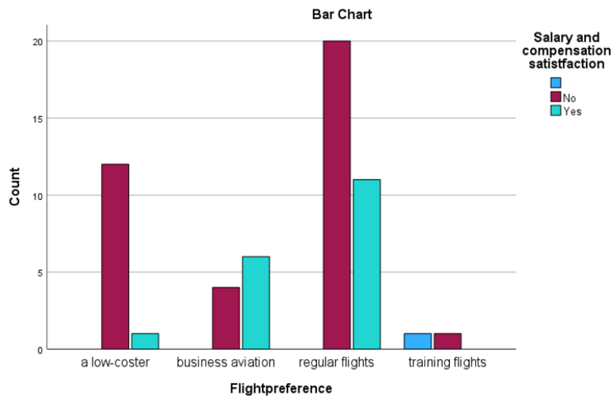

Figure 14. Preference of flight in relation to compensation satisfaction

64.52% of the Regular flight respondents think that the salary is not sufficient while 35.48% disagree disagrees and think that it is satisfactory.

Business aviation respondents have a slight discrepancy 40% of them think that business aviation provides an unsatisfactory compensation package while 60% have a different opinion on the matter and think that it is satisfactory.

The next Table 6 represents the number of processed cases of the experience to salary and compensation satisfaction. Table 8 displays the count of respondents and the distribution of their answers in terms of their experience and its connection to their salary and compensation satisfaction. The highest amount of dissatisfaction 70.59% goes to flight crew members who have experience more than 5000 h but up to 10 000 h.

The most satisfied are the ones of more than 10 000 h of experience and they account for 56.25% (Table 6).

The following Chi-Square test Table 7 for experience and salary satisfaction demonstrates a clear relationship of these two parameters. Both the Pearson Chi-Square and Likelihood Ratio tests indicate that there is a significant relationship between experience levels and salary and compensation satisfaction.

Table 6 and 7 shows that the expected counts were below 5 because of the small number of respondents in a specific category "flight instructor". This situation naturally led to lower expected frequencies in the contingency table. However, the table shows a pattern for the rest of the groups and categories, thus in a future research with a larger sample sizes in smaller subgroups the Chi-square test will highly likely support the information.

The next shows information on flight preference in relation to training effectiveness (see Table 8).

Table 12 demonstrates the result of the Chi-square test flight preference in relation to training effectiveness. The low Pearson p-value 0.000 suggests that there is a significant association between flight preference and training effectiveness. And the p-value 0.001 indicates that there is a significant association as well (see Table 9).

The following Figure 15 demonstrates the clear discrepancy in the fatigue training effectiveness that the flight crew members receive based on the flight type. The highest number of respondents (80%) who believe that the provided fatigue training is effective chose business aviation as their preference and only 20% of the respondents consider the training as ineffective. The opinion on the provided training for regular flights has division. 58% of the respondents consider the fatigue training as ineffective while 41.94% consider it as effective. The low cost is considered to have ineffective fatigue training by 92.31% of respondents and only 7.69% consider it as effective.

Table 6. The relationship between experience and salary satisfaction (calculated by the authors)

	Pilot experience in Flight hours	Salary and compensation satisfaction		Total
		No	Yes	
What is your experience?	> 10000 h	7	9	16
	< 1500 < 3500 h	7	3	10
	< 3500 < 5000 h	8	0	8
	< 5000 < 10000 h	12	5	17
	< 1500 h	3	1	5
	Total	37	18	56

Table 7. Chi-Square test for experience and salary satisfaction (calculated by the authors)

Chi-Square Tests			
–	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18.652a	8	0.017
Likelihood Ratio	15.331	8	0.053
N of Valid Cases	56	–	–

Table 8. Flight preference in relation to training effectiveness (calculated by the author)

	–	Flight preference * Training effectiveness Crosstabulation		Total
		No	Yes	
Flight preference	a low-coster	12	1	13
	business aviation	2	8	10
	regular flights	18	13	31
	training flights	1	0	2
	Total	33	22	56

Table 9. Flight preference relation to Training Chi-Square Tests (calculated by the authors)

Chi-Square Tests			
–	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	40.424a	6	0.000
Likelihood Ratio	22.067	6	0.001
N of Valid Cases	56	–	–

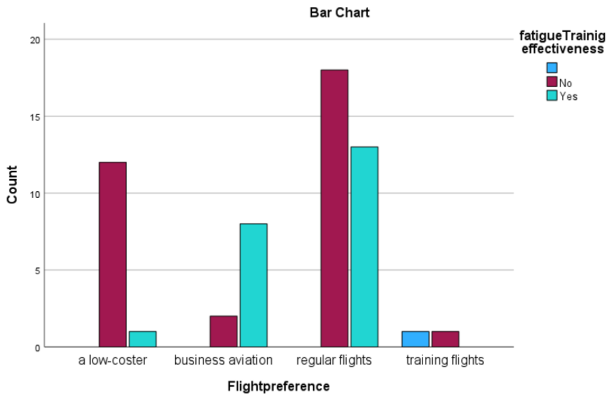

Figure 15. Preference of flight in relation to training effectiveness (developed by the authors)

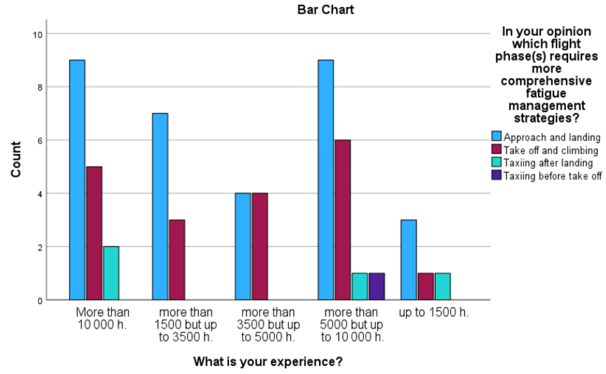

Figure 16. Experience in relation to required fatigue management strategies

A hypothesis that there is a relationship between the experience of pilots and their opinions on the required fatigue management training was made. The chi-square test for this hypothesis resulted in a p-value of 0.869 (see Table 10) which is much higher than α, meaning that the number is insignificant, thus this hypothesis was rejected and Figure 16 shows that as well.

An analysis to see if there is a relationship between the experience and the kind of stimulants pilots use proved to be negative by the Pearson Chi-square test (see Table 11).

As the p-value is 0.841, that is greatly above the significance level. Thus, the hypothesis that there is a positive relationship between the experience and the stimulants was rejected.

Figure 17 shows that coffee is preferred by most of the flight crew members regardless of their experience.

It was of an importance to see whether there is a difference in the salary satisfaction rate between male and female flight crew members. However, the p-value is 0.285 (see Table 12) which is greater than α, hence the hypothesis of this relationship was rejected. However, it is possible that 88.89% of female pilots are not satisfied with the offered salary and compensation package and the amount of unsatisfied male pilots is 61.7% (see Figure 18). The statistical analysis provided in this chapter has been instrumental in exploring the complex patterns and relationships based on the dataset, offering a quantitative lens on the topic of flight crew fatigue and its management.

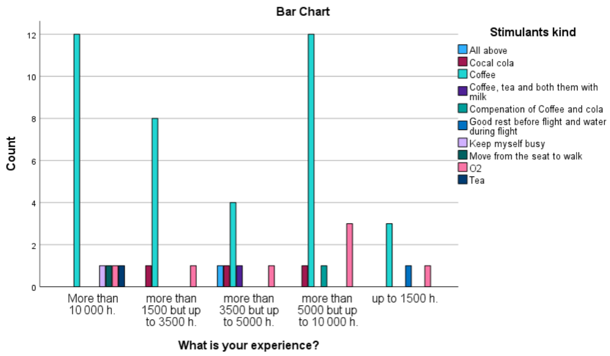

Figure 17. Experience in relation to used stimulants

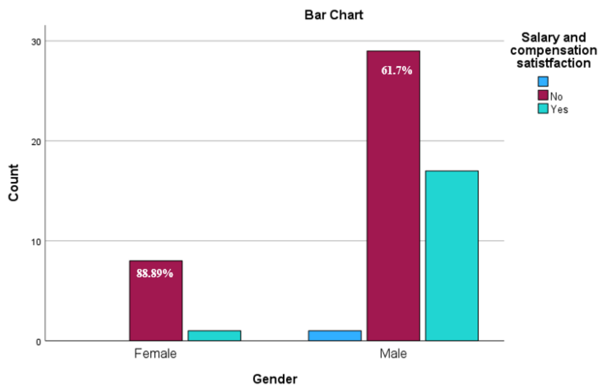

Figure 18. Salary satisfaction rate Relationship male to female flight pilots (developed by the author)

Table 10. Experience relation to required fatigue management strategies Chi-Square Tests (calculated by the authors)

Chi-Square Tests			
–	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6.824a	12	0.869
Likelihood Ratio	7.659	12	0.811
N of Valid Cases	56	–	–

Table 11. Experience relation to stimulants pilots use Chi-Square Tests (calculated by the authors)

Chi-Square Tests			
–	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	36.160a	36	0.461
Likelihood Ratio	27.598	36	0.841
N of Valid Cases	56	–	–

Table 12. Salary satisfaction rate in relation male to female flight pilots Chi-Square Tests (calculated by the authors)

Chi-Square Tests			
–	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2.512	2	0.285
Likelihood Ratio	3.018	2	0.221
N of Valid Cases	56	–	–

3.3. Expert interviews on flight crew fatigue and its management

In the pursuit of understanding complex phenomena and gaining detailed insights, interviews with experts stand as an imperative tool for researchers. This sub-chapter seeks to share and highlight the significance of expert interviews in shaping the narrative of our thesis. It gives the possibility to gain valuable insights and perspectives to the research. By delving into expert knowledge qualitatively, interviews provide a nuanced understanding beyond quantitative measures.

Expert interviews, characterized by their dynamic and interactive nature, enable researchers to engage with individuals possessing real-life experience. In the context of this thesis, three distinguished experts in the aviation sector serve an important part in the apprehension of things that cannot be attained through other means. Through detailed discussions, the interviews not only answer research questions but also shed light on complexities in flight crew members' professional lives. Bridging theoretical knowledge with practical applications, they offer insights into fatigue management.

Methodological considerations, participant profiles, and overall impacts of expert interviews were analyzed. Three experts, including a Human Factors expert, a pilot, and a seasoned aviation professional, shared their experiences and perspectives.

Throughout the interviews, experts explained in detail various aspects of flight crew fatigue, recounting instances where it played a pivotal role in aviation incidents. They shared anecdotes highlighting the detrimental effects of prolonged work hours and demanding schedules on pilots' cognitive abilities. These narratives underscored the critical need for effective fatigue management strategies within the aviation industry.

The experts shared their personal experiences with fatigue, the experts offered insights into its identification and impact. They discussed the multifaceted nature of fatigue, citing symptoms such as memory lapses, diminished concentration, and impaired communication with air traffic control. These firsthand accounts show the complex interplay between fatigue and flight safety, emphasizing the imperative of proactive measures to mitigate its adverse effects.

In response to questions about existing fatigue management strategies, the experts unanimously agreed on the unavailability of coping mechanisms once fatigue sets in. They elaborated on the physiological basis of fatigue, explaining how drained cognitive resources hinder pilots' ability to perform optimally. This prompted a discussion on the necessity of preventative approaches, advocating for clearer reporting systems and enhanced training protocols.

The experts offered constructive suggestions to improve fatigue management practices within the industry as well. They highlighted the importance of comprehensive Crew Resource Management training and emphasized the need for greater collaboration among all involved parties to promote and foster a safety culture. Additionally, they called for enhancements in training quality and raised concerns about the efficacy of online training platforms compared to traditional classroom settings.

Also, all experts highlighted the need for educating the managers and professionals who are involved and responsible for flight planning, the need for more awareness initiatives to address fatigue-related issues effectively and the dire need for a just culture. They emphasized that ensuring the safety and well-being of flight crews is a collective responsibility of all aviation professionals. Altogether, the interviews provided valuable insights into the complexities of fatigue management within the aviation sector.

4. Discussion

Based on studying relevant literate review, the responses from the survey and the information gathered through statistical analysis and interviews, a fatigue Management Methodology that consists of 5 steps was developed:

Step 1:

The first step would be to study all relevant literature and scientific research in order to get a deeper understanding of fatigue, flight crew fatigue and what influences it. This part is significant as science evolves and develops, and new and critical information is found in scientific research.

Step 2:

Study all ICAO and EASA (or FAA or related authorities) regulations and laws related to fatigue management of flight crew in order to make sure that the company complies with all the rules and then see if there are any concerns in regards of some parts and seek a solution for them.

Step 3:

Compose questions for survey and conduct a survey at the company. The season when the survey is conducted should be taken into consideration. The result for the surveys during high seasons may differ from the results of the survey carried out in other times of the year.

Step 4:

Analyze the gathered data using Statistical Method approaches. For this, "SPSS Statistics" or other statistical programs are recommended. When the data is processed using "SPSS Statistics," various methods will provide detailed information and confirm or deny the hypotheses. For example, chi-square tests are appropriate for categorical data, while for numerical data, Linear Regression and T-tests are very useful.

Step 5:

After gathering all the information from the surveys, processing them, an interview or interviews are carried out with people from related fields. These interviews will include experts from Crew Resource Management or form Safety Management side in order to see what kind of actions should be taken in order to eliminate or reduce the hazards for the flight safety operations and improve the general well-being of flight crew members.

The methodological choice was guided by a thoughtful and contemplative consideration of the research objectives, ensuring a firm and systematic approach to data collection, analysis, and interpretation.

This methodology is recommended to airline companies that struggle with fatigue Management for their flight crews.

5. Conclusions

This research involves a comprehensive and thorough examination of the definition of fatigue, its kinds and impacts, the existing regulatory compliance, and different ways of fatigue management for flight crews within the aviation industry.

By employing a firm methodology that involved accurate statistical analysis, insightful expert interviews, and comprehensive surveys, a detailed understanding of the challenges of the flight crew fatigue at hand was obtained.

The research established that fatigue leads to impaired cognitive functions, decreased situational awareness, inability to focus and communicate implicating emergency responses and increased error rates that can lead to accidents. Moreover, it was proved that, the scheduling and duty and rest hours, circadian rhythm disruptions, and sleep disruptions are key factors that affect flight crew members' fatigue.

While EASA and FAA regulations exist, challenges in consistent implementation across different regions and airlines may limit their effectiveness.

The novelty of the presented research lies in the development of a methodology for managing and reducing fatigue for flight crews. This methodology has been explained in detail in the discussion chapter of this research.

Continuous advancements in the understanding of fatigue require ongoing updates to regulations to reflect the latest scientific knowledge.

Some regulations allow for operator discretion in managing fatigue, raising concerns about potential variations in fatigue risk management practices.

Moreover, the study cases within this research show that there is a need for improvement and more research into the issue in order to preserve safety alongside with keeping up with the market standards.

Beyond the immediate focus on flight safety, this study sheds light on the intertwined relationship between fatigue, fatigue management and flight safety, economic considerations within aviation, and the well-being of flight crew members in general.

While this research has mainly focused on the influence of fatigue on flight crew members and its repercussions on flight safety, it is essential to recognize that a growing and prospering aviation sector is an integral part of economic growth. As the research shows the industry is experiencing substantial growth and with the industry growth the demand for flight crew members gets bigger and as a consequence the fatigue issue of flight crew members will get bigger. That is why it is important to study the new realia and update the training and regulations where possible and make them more precise.

The key findings of this research shows that there are no mitigation strategies that can fully eliminate flight crew fatigue. In order to be able to reduce the fatigue levels and mitigate it, the, Authors propose and recommend the companies to use multiple strategies like:

1. Fatigue Risk Management Systems.
2. Software for scheduling which lessens human errors while creating timetables and assigning duties.
3. CRM Training and Education programs to teach about sleep hygiene and personal responsibility and raise awareness of fatigue.
4. Appropriate rest facilities.

By taking into consideration and taking measures to manage fatigue, and ensuring the well-being of flight crews, not only flight safety is consolidated and increased, but it also fortifies the economic resilience of the aviation sector solidifying its position as an important player in the prosperity of economics alongside connecting the world.

The overall result of this research has demonstrated the importance of managing flight crew member fatigue to advance the well-being of flight crew members that directly affects the safety of everyone on flight and ground, and as a result, has a huge financial impact on the economy of countries around the world.

References

Aljurf, T. M., Olaish, A. H., & BaHammam, A. S. (2018). Assessment of sleepiness, fatigue, and depression among Gulf Cooperation Council commercial airline pilots. *Sleep and Breathing*, *22*(2), 411–419. https://doi.org/10.1007/s11325-017-1565-7

Axelsson, J., & Puttonen, S. (2012). Night shift work increases the risk for type 2 diabetes. *Evidence-Based Medicine*, *17*(6), 193–194. https://doi.org/10.1136/ebmed-2012-100649

Baines Simmons Safety Services. (2023). *A fatigue survey of European pilots*. https://www.eurocockpit.eu/sites/default/files/2023-08/A%20report%20on%20a%20fatigue%20survey%20of%20European%20Pilots_2023_FINAL.pdf

Balkin, T. T. J., & Wesensten, N. J. (2011). Differentiation of sleepiness and mental fatigue effects. In P. L. Ackerman (Ed.), *Cognitive fatigue: Multidisciplinary perspectives on current research and future applications* (pp. 47–66). American Psychological Association. https://doi.org/10.1037/12343-002

British Airline Pilots' Association. (2016). *Airline pilot wins major legal victory on fatigue.* BALPA.

Bendak, S., & Rashid, H. S. J. (2020). Fatigue in aviation: A systematic review of the literature. *International Journal of Industrial Ergonomics*, *76*, Article 102928. https://doi.org/10.1016/j.ergon.2020.102928

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

Cahill, J., Cullen, P., & Gaynor, K. (2019). Estimating the impact of work-related stress on pilot wellbeing and flight safety. In *The 2nd International Symposium on Human Mental Workload: Models and Applications* (*H-WORKLOAD 2018*). ResearchGate.

Carey, M. A., Steiner, K. L., & Petri, W. A. Jr. (2020). Ten simple rules for reading a scientific paper. *PLoS Computational Biology*, *16*(7), Article e1008032. https://doi.org/10.1371/journal.pcbi.1008032

CBS News. (2022). *Southwest Airlines pilots' union raises safety concerns over fatigue*. https://www.cbsnews.com/news/southwest-airlines-pilot-fatigue-air-travel-safety-concerns/

Civil Aviation Safety Authority Australia. (2010). *Biomathematical fatigue modelling* (*Guidance document*). CASA. https://www.icao.int/safety/fatiguemanagement/ArticlesPublications/biomathematical_fatigue_models.pdf

Dawson, D., & McCulloch, K. (2005). Managing fatigue: It's about sleep. *Sleep Medicine Reviews*, *9*(5), 365–380. https://doi.org/10.1016/j.smrv.2005.03.002

Dehais, F., Duprès, A., Di Flumeri, G., Verdière, K., Borghini, G., Babiloni, F., & Roy, R. (2018). Monitoring pilot's cognitive fatigue with engagement features in simulated and actual flight conditions using an hybrid fNIRS-EEG passive BCI. In *2018 IEEE International Conference on Systems, Man, and Cybernetics* (*SMC*) (pp. 544–549). IEEE. https://doi.org/10.1109/SMC.2018.00102

Demerouti, E., Veldhuis, W., Coombes, C., & Hunter, R. (2019). Burnout among pilots: Psychosocial factors related to happiness and performance at simulator training. *Ergonomics*, *62*(2), 233–245. https://doi.org/10.1080/00140139.2018.1464667

Department of Transport. (1995). *Air Accidents Investigation Branch. Defence Research Agency* (Aircraft Accident report 1/96). https://assets.publishing.service.gov.uk/media/5423010440f0b61346000b5b/1-1996_7T-VEE.pdf

European Union Aviation Safety Agency. (2015). *Annex II to ED Decision 2015/022/R*. https://www.easa.europa.eu/en/document-library/agency-decisions/ed-decision-2015022r

Eur-lex. (2014). Commission Regulation (EU) No 83/2014. *Official Journal of the European Union*, *28/17*. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2014:028:0017:0029:EN:PDF

European Cockpit Association. (2007). *Quick reference guide. European flight time limitations*. https://www.eurocockpit.eu/sites/default/files/SubpartQ_Reference_Guide_07_0822_F.pdf

European Cockpit Association. (2012). *Pilot fatigue barometer*. https://www.eurocockpit.eu/sites/default/files/eca_barometer_on_pilot_fatigue_12_1107_f.pdf

Evans, W. J., & Lambert, C. P. (2007). Physiological basis of fatigue. *American Journal of Physical Medicine & Rehabilitation*, *86*(1 Suppl), S29–46. https://doi.org/10.1097/PHM.0b013e31802ba53c

Federal Aviation Administration. (2012). *Advisory Circular. AC No: 117-3*. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%20117-3.pdf

Freudenberger, H. J. (1974). "Staff Burn-out." *Journal of Social Issues*, *30*(1), 159–165. https://doi.org/10.1111/j.1540-4560.1974.tb00706.x

Gander, P. H. (2015). Evolving regulatory approaches for managing fatigue risk in transport operations. *Reviews of Human Factors and Ergonomics*, *10*(1), 253–271. https://doi.org/10.1177/1557234X15576510

Genovese, D. (2022, April 13). Southwest Airlines pilot union says fatigue is 'number-one' safety threat. *Fox Business*. https://www.foxbusiness.com/lifestyle/southwest-airlines-pilot-fatigue-2022

Goel, N., Basner, M., Rao, H., & Dinges, D. F. (2013). Circadian rhythms, sleep deprivation, and human performance. *Progress in Molecular Biology and Translational Science*, *119*, 155–190. https://doi.org/10.1016/B978-0-12-396971-2.00007-5

Goode, J. H. (2003). Are pilots at risk of accidents due to fatigue? *Journal of Safety Research*, *34*(3), 309–313. https://doi.org/10.1016/S0022-4375(03)00033-1

Grandjean, E. (1979). Fatigue in industry. *British Journal of Industrial Medicine*, *36*(3), 175–186. https://doi.org/10.1136/oem.36.3.175

Hornfeldt, P. (2019). *The Final report of Fly Dubai FS981 disaster*. https://mentourpilot.com/the-final-report-of-fly-dubai-fs981-rostov-on-don-disaster/

Hu, X., & Lodewijks, G. (2020). Detecting fatigue in car drivers and aircraft pilots by using non-invasive measures: The value of differentiation of sleepiness and mental fatigue. *Journal of Safety Research*, *72*, 173–187. https://doi.org/10.1016/j.jsr.2019.12.015

International Civil Aviation Organization. (2012). *Fatigue risk management systems – Manual for regulators* (Doc 9966) (1st ed.). https://tinyurl.com/3hvjmd22

International Civil Aviation Organization. (2020). *Manual for the oversight of fatigue management approaches* (Doc 9966) (Report). ICAO.

International Air Transport Association, International Civil Aviation Organization, & International Federation of Air Line Pilots' Associations. (2015). *Fatigue management guide for airline operators* (2^{nd} ed.). https://www.icao.int/safety/fatiguemanagement/FRMS%20Tools/FMG%20for%20Airline%20Operators%202nd%20Ed%20(Final)%20EN.pdf

Jackson, C. A., & Earl, L. (2006). Prevalence of fatigue among commercial pilots. *Occupational Medicine*, *56*(4), 263–268. https://doi.org/10.1093/occmed/kql021

Lord, D., & Conlon, H. A. (2018). Cardiovascular risk factors in airline pilots. *Workplace Health & Safety*, *66*(10), 471–474. https://doi.org/10.1177/2165079917751478

Nahrgang, J. D., Morgeson, F. P., & Hofmann, D. A. (2011). Safety at work: A meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes. *Journal of Applied Psychology*, *96*(1), 71–94. https://doi.org/10.1037/a0021484

National Transportation Safety Board. (1993). *Aircraft Accident Report: Uncontrolled Collision with Terrain American International Airways flight*. National Transportation Safety Board.

National Transportation Safety Board. (2003). *Commercial transportation operator fatigue management*. NTSB.

National Transportation Safety Board. (2010). *Accident Report NTSB/AAR-10/01. PB2010-910401*. NTSB.

Plieger, T., Melchers, M., Montag, C., Meermann, R., & Reuter, M. (2015). Life stress as a potential risk factor for depression and burnout. *Burnout Research*, *2*(1), 19–24. https://doi.org/10.1016/j.burn.2015.03.001

Predective Safety. (2023). *16 plane crashes caused by fatigued aircrew*. https://blog.predictivesafety.com/16-plane-crashes-caused-by-fatigued-aircrew

Reis, C., Mestre C., Canhão, H., Gradwell, D., & Paiva, T. (2016). Sleep complaints and fatigue of airline pilots. *Sleep Science*, *9*(2), 73–77. https://doi.org/10.1016/j.slsci.2016.05.003

Suri, M., & Stambaugh, A. (2024). Plane veered off flight path after both pilots fell asleep, Indonesian authorities say. *CNN Travel*. https://edition.cnn.com/2024/03/10/asia/batik-air-pilots-asleep-indonesia-intl-hnk/index.html

Trejo, L. J., Knuth, K., Prado, R., Rosipal, R., Kubitz, K., Kochavi, R., Matthews, B., & Zhang, Y. (2007). EEG-based estimation of mental fatigue: Convergent evidence for a three-state model. *Lecture Notes in Computer Science*, *4565*, 201–211. https://doi.org/10.1007/978-3-540-73216-7_23

Valdez, P. (2019). Circadian rhythms in attention. *Yale Journal of Biology and Medicine*, *92*(1), 81–92.

Wynns, P. (2023, September 6). The pilot shortage is not over. *Flexair*. https://aviex.goflexair.com/blog/the-pilot-shortage