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Pilots Performance and Flight Safety
The Case of Cognitive Fatigue in Unpressurized Aircraft Cabins

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Abstract

The purpose of this study is to understand the impact, evolution, and perception of cognitive fatigue as a contributory factor on the occurrence of incidents and accidents, on unpressurized aircraft.

This study uses the science principles present in the "Fatigue Management Guide for Airline Operators" (FMG) to evaluate data obtained by four methods of measuring cognitive fatigue. These consist of two objective measures, Psychomotor Vigilance Test (PVT) and an actiwatch (Readiband 5), and two subjective measures, Samn-Perelli 7-point fatigue Scale (SPS) and sleep diaries. It is also obtained results from a survey aimed to all national and international pilots and related to this theme.

From this research are draw conclusions of the influence and evolution of cognitive fatigue on the operations of unpressurized aircrafts and it is understood the difference between perceived cognitive fatigue and the real cognitive fatigue accumulated by the pilot. Is also drawn findings from a launched survey related to this theme.

In this case study the focus will fall upon general aviation where there are no ways to control and monitor the fatigue element, which is associated with the cause of most incidents and accidents that occur in Portugal as concluded by analyzing several GPIAAF (Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários) final reports using HFACS (Human Factor Analysis and Classification System). Normally this type of research is conducted within airline operators, that are already a very restricted and controlled domain of civil aviation.

Keywords

GPIAAF, Accidents Investigation, Accidents Prevention, Operational Safety, Flight Safety, Pilots Performance, Human Factors, Cognitive Fatigue, HFACS.

Resumo

O objetivo deste estudo é compreender o impacto, a evolução e a perceção da fadiga cognitiva como fator contribuinte na ocorrência de incidentes e acidentes em aeronaves não pressurizadas.

Este estudo utiliza os princípios científicos apresentados no ”Fatigue Management Guide for Airline Operators” (FMG) para avaliar os dados obtidos por quatro métodos de medição da fadiga cognitiva. Estes consistem em duas medidas objetivas, Psychomotor Vigilance Test (PVT) e um dispositivo de rastreio (Readiband 5), e duas medidas subjetivas, Samn-Perelli Escala de Fadiga de 7 pontos (SPS) e diários de sono. Também são obtidos resultados de um inquérito dirigido a todos os pilotos nacionais e internacionais relacionado a este tópico.

A partir desta pesquisa são tiradas conclusões da influência e evolução da fadiga cognitiva em operações de aeronaves não pressurizadas bem como a diferença entre a fadiga cognitiva percetível pelo piloto e a fadiga cognitiva real acumulada. Também são retiradas conclusões do inquérito lançado.

Este caso de estudo recairá sobre a aviação geral, onde não há formas de controlar e monitorizar o elemento de fadiga, que é a causa da maioria dos incidentes e acidentes que ocorrem em Portugal, o que se conclui da análise de vários relatórios finais do GPIAAF (Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários) usando o HFACS (Human Factor Analysis and Classification System). Normalmente este tipo de pesquisa é conduzida no seio de operadores aéreos, que já são um domínio muito restrito e controlado da aviação civil.

Palavras-chave

GPIAAF, Investigação Acidentes, Prevenção Acidentes, Segurança Operacional, Segurança de Voo, Desempenho de Pilotos, Fatores Humanos, Fadiga Cognitiva, HFACS.

Resumo Alargado

Introdução

Nos primeiros dias da aviação, sabe-se que aproximadamente 80% dos acidentes foram causados por falhas mecânicas e os outros 20% por erro humano. Hoje, devido ao desenvolvimento da tecnologia e à implementação de uma manutenção melhor e mais rigorosa em aeronaves, constata-se que as falhas mecânicas causam apenas 20% dos acidentes e os erros humanos ocupam os outros 80% [1], [2].

Em território nacional, e após uma análise de todos os relatórios finais de acidentes e incidentes de 2010 até 2017, foi facilmente verificável que a maioria dos acidentes ocorre no domínio da aviação geral.

Uma análise mais aprofundada aos dados de 66 relatórios finais relacionados ao domínio da aviação geral e utilizando o Sistema de Análise e Classificação de Fatores Humanos (HFACS) obtiveram-se resultados de onde se concluiu que 81.82% dos relatórios finais tinham indícios de Fatores Humanos (HF). Com base nestes resultados obtidos e exibidos acima, apercebeu-se da importância dos HF na aviação geral e que este é um tema onde há carência de estudos e regulamentações.

Assim, um dos principais objetivos deste estudo é encontrar as principais causas humanas de acidentes e incidentes em Portugal e perceber o impacto que este HF tem durante a operação de aviões não pressurizados, normalmente utilizados na aviação geral.

Enquadramento da Dissertação

A implementação do HFACS aos relatórios finais de incidentes e acidentes do Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários (GPIAAF) de 2010 a 2017 [3], permitiu a aquisição dos dados sobre os fatores humanos causadores de ocorrências na aviação geral e Operações Especializadas (SPO) de helicópteros e aviões, onde predomina o uso de aeronaves com cabines não pressurizadas. Neste tipo de aviação nem sempre há influências organizacionais, por isso os fatores relativos às influências organizacionais do HFACS não foram aplicados.

A partir dos dados obtidos, determinou-se que a causa da maioria dos acidentes / incidentes em Portugal esta ao nível dos atos inseguros. Os atos inseguros estão relacionados com a fadiga cognitiva que resulta em um comprometimento do desempenho normal individual que aumenta o risco de falha durante a operação, por exemplo [4]:

- Aumento do tempo de reação (RTi);
- Atenção reduzida;
- Memória prejudicada;
- Mudanças de humor;
- Voo impreciso;
- Tomadas de decisão erradas;
- Perda de consciência situacional.

De acordo com a ICAO, a fadiga é caracterizada como um estado fisiológico de capacidade de desempenho mental ou físico reduzido, resultado da falta de sono, vigília prolongada, fase circadiana ou carga de trabalho (atividade mental e / ou física), e pode prejudicar o nível e a capacidade de um membro da tripulação para operar uma aeronave ou realizar tarefas relacionadas com a segurança [5].

Assim, a fadiga pode ser descrita como uma capacidade reduzida de executar tarefas operacionais e pode ser considerada como um desequilíbrio entre [6]:

- Esforço físico e mental de todas as atividades de despertar (não apenas as de operação);
- Recuperação deste esforço, que requer sono (exceto recuperação da fadiga muscular).

A fadiga física é definida como uma incapacidade de exercer força com os músculos, na medida do que é normalmente esperado. Pode ser específico para uma parte do corpo ou cansaço geral. Fadiga física é um resultado do exercício físico ou uma perda de sono, esta fadiga muitas vezes leva a fadiga mental / cognitiva [4].

A fadiga mental/cognitiva, que pode incluir sonolência, está relacionada com a diminuição da atenção e a capacidade de realizar tarefas complexas ou simples quando comparada com a eficiência regular de um indivíduo [4].

A fadiga que é estudada nesta dissertação é aquela causada pela falta de sono ou sono inadequado. Este tipo de fadiga é conhecido como "fadiga cognitiva" ou fadiga mental e está diretamente ligada à redução do estado de alerta, tempo de reação (RTI), prejudicando a tomada de decisão do operador [7].

Objetos e Objetivos

Neste estudo, o objeto sob avaliação será o desempenho dos pilotos em aeronaves não pressurizadas, mais especificamente no caso de fadiga cognitiva e segurança de voo.

O objetivo desta dissertação é compreender o impacto da fadiga cognitiva como fator contribuinte na ocorrência de incidentes e acidentes, utilizando os princípios científicos presentes no Fatigue Management Guide for Airline Operators (FMG) [6]. Será interpretada a evolução da fadiga cognitiva e seu impacto no desempenho do piloto durante toda a operação da aeronave; em simultâneo será efetuada a comparação da fadiga experimentada pelos indivíduos que participaram deste estudo e a real deterioração de seu estado de alerta medido pelos equipamentos utilizados.

As conclusões serão auxiliadas por comparação com: a análise dos relatórios finais de ocorrências do GPIAAF, utilizando o HFACS; os dados adquiridos experimentalmente durante e fora da operação da aeronave; e os resultados obtidos através de um inquérito lançado aos pilotos, sobre o assunto da fadiga cognitiva.

Principais Conclusões

Os HF sempre foram uma grande preocupação no setor de aviação e ainda mais para os subsetores que têm quase nenhuma ou nenhuma regulamentação para atenuar os problemas associados a este elemento.

A partir do inquérito lançado aos pilotos foram obtidas 41 respostas. A partir deste levantamento concluiu-se que a maioria dos participantes tem uma quantidade de sono perto do recomendado, mas com uma boa qualidade. Os inquiridos consideraram o álcool e o tempo de sono como os fatores que mais afetam os níveis de fadiga e que na sua maioria já teriam experienciado efeitos da fadiga cognitiva. A maioria dos indivíduos inquiridos não voava em dias em que tivessem atividades laborais, não relacionadas à operação de aeronaves. A partir das questões finais da pesquisa, também foi percetível que alguns dos indivíduos inquiridos apresentavam problemas relacionados com a fadiga cognitiva.

A partir do caso de estudo, foi também possível observar a influência da cafeína e do exercício físico no desempenho do piloto, sendo que a cafeína disfarçou o desempenho real de um dos indivíduos e o exercício físico piorou os seus níveis de desempenho. Perceberam-se também alguns dos efeitos da quantidade e qualidade do sono no desempenho e na recuperação da fadiga.

Os pilotos que participaram neste caso de estudo tiveram uma vida normal durante o tempo de teste, o que possibilitou que se constatasse que estes já apresentavam fadiga cumulativa. Não foi possível aprofundar o estudo sobre esta fadiga acumulada, uma vez que não havia dados relacionados à carga de trabalho das atividades laborais do dia-a-dia executadas por estes pilotos.

A partir dos dados recolhidos, não foi possível visualizar quaisquer relações entre a Samn-Perelli Escala de Fadiga de 7 pontos (SPS) e os dados objetivos do Psychomotor Vigilance Test (PVT) e os valores de alerta SAFTE (Sleep, Activity, Fatigue, and Task Effectiveness). Apenas em alguns dias mais extremos de fadiga, ocorreram algumas mudanças nos valores de SPS.

Antes, durante e depois dos voos, os níveis de pontuação do SAFTE nunca passaram do ponto de menor risco de acidente ou erro grave, mas isso pode ser explicado pelos curtos tempos de voo realizados neste tipo de aviação. Nos testes de PVT, alguns pilotos tinham valores que os colocaram próximo ou de um risco elevado de acidente ou erro grave, mas na maioria dos casos eles permaneceram no espectro de risco muito baixo a baixo.

Para a questão mais importante desta dissertação é necessário ter em conta que a maioria dos indivíduos que voam neste segmento da aviação têm vidas normais e empregos o que promove algum tipo de fadiga acumulada devido a horários de trabalho, restrição de horas de sono e cargas de trabalho. Cabe ao piloto entender a sua condição antes de operar uma aeronave, e é aí que está o maior problema, porque somos maus juízes do nosso próprio desempenho. Assim, a fadiga cognitiva pode ser uma causa ou uma das causas de ocorrências relacionadas a atos inseguros no segmento da aviação geral, como foi provado com alguns valores obtidos pelos voos do piloto 3.

Perspetivas de Investigação Futuras

Durante o desenvolvimento desta dissertação, alguns tópicos foram reconhecidos como úteis para serem implementados em trabalhos futuros para que seja possível entender melhor a evolução da fadiga cognitiva e o impacto de fatores sobre ela. Com isso, acredita-se que os próximos passos deste trabalho devem cruzar as seguintes linhas de investigação:

- Adição de mais fatores ao estudo - como carga de trabalho, tempo de refeição e composição da mesma - uma vez que estes podem ter grandes impactos no nível de fadiga;
- Adição de mais voos ao teste, para que se possa obter resultados mais conclusivos;
- Usar indivíduos com mais variedade de género e idade;
- Incorporar outros métodos de medição de fadiga eventualmente com um menor erro associado.

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANAC	Agência Nacional de Aviação Civil
APAU	Associação Portuguesa de Aviação Ultraleve
FMG	Fatigue Management Guide for Airline Operators
GPIAAF	Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários
HF	Human Factors
HFACS	Human Factors Analysis and Classification System
IAS	Instrument Air Speed
ICAO	International Civil Aviation Organization
IEA	International Ergonomics Association
ILS	Instrument Landing System
Non-REM	Non-Rapid Eye Movement
PIC	Pilot In Command
PF	Pilot Flying
PM	Pilot Monitoring
PVT	Psychomotor Vigilance Test
REM	Rapid Eye Movement
SOP	Standardized Operations Manual
SPO	Specialized Operations
SPS	Samn-Perelli Seven-point fatigue Scale
SWS	Slow Wave Sleep
TIB	Time In Bed
TRT	Transportation Research Team
VAS	Visual Analog Scales
VFR	Visual Flight Rules
WOCL	Window Of Circadian Low

Nomenclature

V_{APP}	Approach speed	[kt]
V_{GA}	Go Around speed	[kt]
V_{MCA}	Minimum aerodynamic Control speed with critical engine failure	[kt]
RTI	Reaction Time	[ms]
SAFTE™	Sleep, Activity, Fatigue, and Task Effectiveness	[%]

Chapter 1

Introduction

1.1. Motivation

In the early days of aviation, one believed that approximately 80% of accidents were caused by mechanical failures, and the other 20% by human error. Today due to the development of technology and the implementation of better and more rigorous maintenance on aircraft, mechanical failures only cause 20% of accidents and human error takes the other 80% [1],[2].

In national territory, and after an analysis of all final reports of accidents and incidents from 2010 up until 2017, it was easily verifiable that most accidents occur in the domain of general aviation as shown in Figure 1.

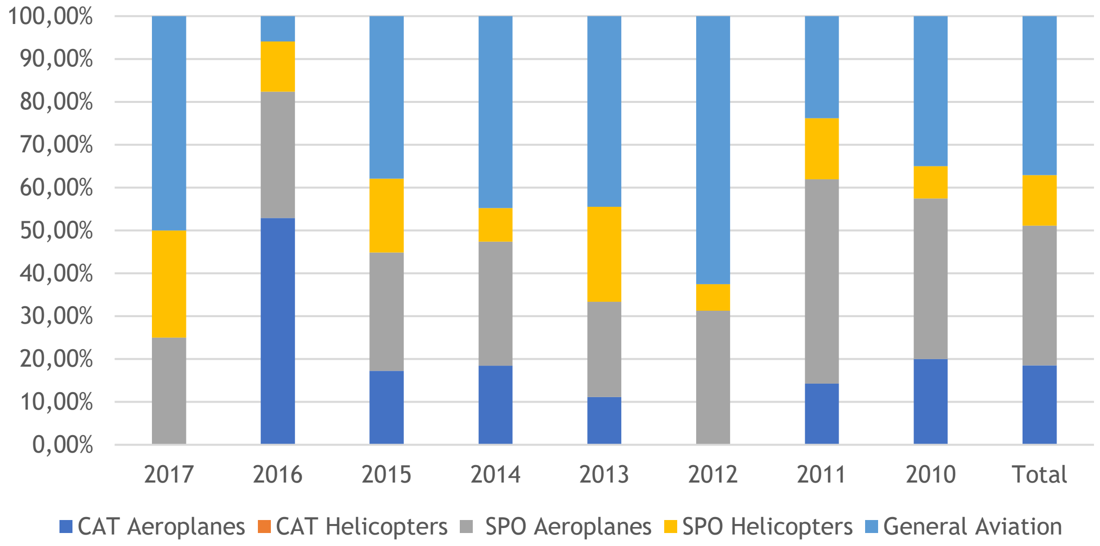

Figure 1 – Percentage of accidents and incidents on the various domain from 2010 to 2017 - Source: own elaboration based on [3]

An in-depth analysis on the data of 66 final reports related to the domain of general aviation and using The Human Factors Analysis and Classification System (HFACS) we obtained the results provided in Table 1 and Figure 2. From this analysis, it’s concluded that 81.82% of the final reports had indices of Human Factors (HF).

Table 1 – Number of reports with HF on the domain of general aviation - Source: own elaboration based on [3]

Year	Total of final reports	Total of final reports with HF	Total of HF	Final reports with HF [%]	Average of HF per final report
2017	1	1	5	100.00	5.00
2016	3	2	3	66.67	1.00
2015	6	3	9	50.00	1.50
2014	7	6	19	85.71	2.71
2013	1	1	2	100.00	2.00
2012	11	6	18	54.55	1.64
2011	8	8	19	100.00	2.38
2010	29	27	77	93.10	2.66
Total	66	54	152	81.82	2.30

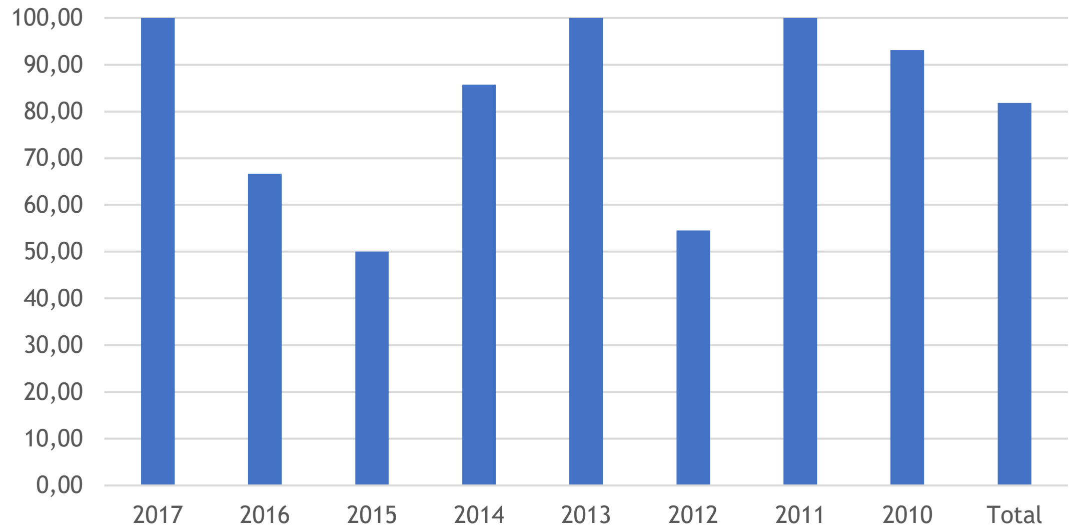

Figure 2 - Percentage of final reports of accidents and incidents with HF per year – Source: own elaboration based on [3]

On the premises of the results obtained and displayed above, came to our attention that HF on general aviation is a subject where there is a lack of studies and regulations.

Thus, one main objective of this study is to discover the main human causes of accidents and incidents in Portugal and how these HF have an impact during operation on non-pressurized airplanes that are normally used in general aviation.

1.2. Object and Objectives

In this study, the object under evaluation will be the performance of the pilots in non-pressurized aircraft, more specifically the case of cognitive fatigue and flight safety.

The objective of this dissertation is to understand the impact of cognitive fatigue as a contributory factor on the occurrence of incidents and accidents, by using the science principles present in the Fatigue Management Guide for Airline Operators (FMG) [6]. It will also be interpreted the evolution of cognitive fatigue, and its impact in the pilot performance throughout the operation of the aircraft; simultaneously it will be drawn a comparison of the fatigue experienced by the individuals that took part in this study and the real deterioration of their alertness measured by the equipment utilized.

Conclusions will also be drawn from: the study of final reports of occurrences from Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários (GPIAAF), using HFACS; data acquired experimentally during and outside the operation of the aircraft; and the results obtained on a survey launched to pilots, on the subject of cognitive fatigue.

1.3. Previous Work

In the theme of flight performance in unpressurized aircraft, there has already been done some studies by researchers from University of Beira Interior (UBI) Transportation Research Team (TRT) on the subjects of:

- “Psychophysiological Factors Analysis in Unpressurized Aircraft Cabins” by Ana Catarina Casaleiro Coelho, 2014, MSc Aeronautical Engineering. University of Beira Interior [8].
- “Pilots Performance and Flight Safety. Flight Physiology in Unpressurized Aircraft Cabins” by Sara Zorro, 2012, MSc Aeronautical Engineering. University of Beira Interior [9].
- “Unpressurized Light Aviation Aircrafts. Flight and Physiological Data Acquisition System” by André Marques, 2012, MSc Aeronautical Engineering. University of Beira Interior [10].
- “Desempenho de Pilotos e Segurança de Voo. O Caso da Hipóxia em Aviação Desportiva” by Leandro Rocha, 2011, MSc Aeronautical Engineering. University of Beira Interior [11].

This dissertation acts as a follow up to these studies in unpressurized aircraft and general aviation.

1.4. Methodology

The development of this dissertation began with a literature review of HF and final reports of occurrences from GPIAAF. From the review of the final reports from 2010 to 2017 it was taken the HF that had indices of being present during the accidents and incidents using HFACS. Then, from this Review of final reports it was concluded that the HF with more frequency was at the level of unsafe acts that is linked with cognitive fatigue. With this an exhaustive research was made on fatigue, its impact on the operation of aircraft, existing legislation and methods for measuring it (Figure 3).

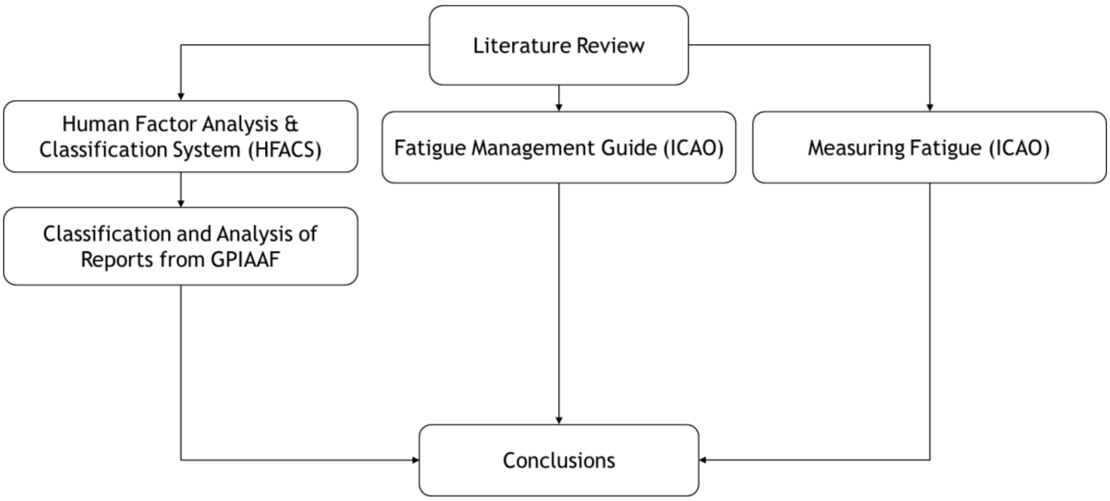

Figure 3 – Methodology schematics from literature review - Source: own elaboration

After gathering all information, a case study was established with an experimental work where were used 4 methods to measure fatigue, 2 objective measures (PVT and Actiwatch) and 2 subjective measures (SPS and Sleep diaries). Meanwhile, it was also launched an online survey to international and national pilots to understand what it is the common knowledge on the topic of cognitive fatigue. An analysis was made to the results of the online survey and experimental work, from this analysis conclusions were withdrawn to respond to the objectives of this dissertation (Figure 4).

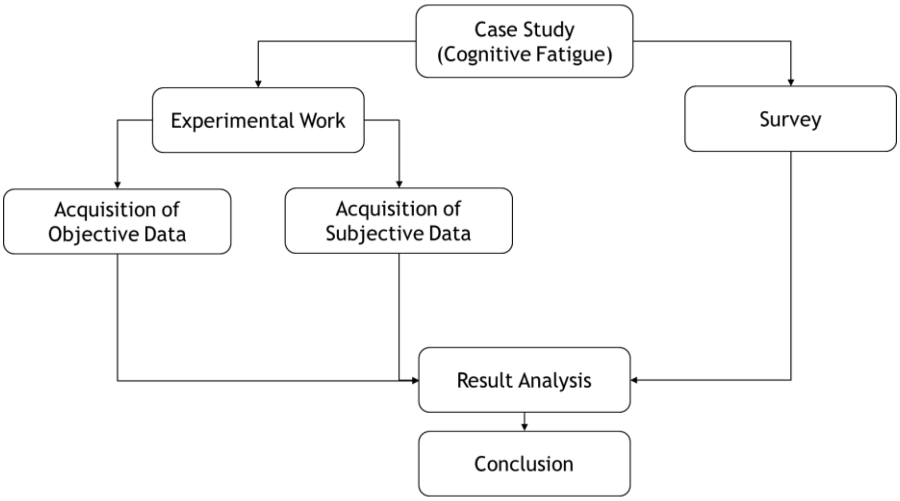

Figure 4 - Methodology schematics from case study - Source: own elaboration

1.5. Dissertation Structure

This dissertation has a six chapters structure.

Chapter 1 is the study introduction, and is composed of three sub-chapters: motivation, object and objective, and the structure of the dissertation, respectively.

Chapter 2 consists of the literature review and contains the information that contextualizes and emphasizes the relevance of this study. It entails seven sub-chapters being them: introduction, the definition of HF, accident and incident, HFACS, fatigue and biologic rhythms, statistics, accident and incident with fatigue, and conclusions.

Chapter 3 consists of the methods used in this study to measure and determinate the levels of fatigue and alertness, as well as a description of how they are used. It contains six sub-chapters: introduction, Samn-Perelli 7 Point Fatigue Scale (SPS), sleep diaries, actiwatch (Readiband 5), Psychomotor Vigilance Test (PVT), and conclusion. These methods can be divided into two types of data acquisition: objective data and subjective data.

Chapter 4 consists of the case study exposed on this dissertation and it is divided into four sub-chapters: an introduction, the questions and results of the online survey launched to the national pilots, the experimental work implemented in this study, and conclusion.

Chapter 5 contemplates an analysis of the results from the survey from the previous chapter and the results and analysis of the experimental work. It is divided into four sub-chapters being them: an introduction, survey analysis, experimental work results and analysis, and conclusion.

Chapter 6 (and last) is the dissertation conclusion and future work. Contains three sub-chapters: the dissertation conclusions taken from this study, concluding remarks and prospects for future work in this subject.

Chapter 2

The Human Factor in Aviation

2.1. Introduction

The main objective of most aeronautical organizations, such as GPIAAF, the Agência Nacional de Aviação Civil (ANAC), and the International Civil Aviation Organization (ICAO), is the safety of civil aviation. The HF are one of the major cause of accidents/incidents since the beginning of aviation history.

The HF began to be recognized and institutionalized by various organizations such as the Ergonomics Research Society in 1949, the Human Factors Society in 1957, and the International Ergonomics Association (IEA). As early as 1986, ICAO adopted the Resolution A26-9 on Flight Safety and HF. These measures were taken with the aim of: "To improve safety in aviation by making States more aware and responsive to the importance of human factors in civil aviation operations through the provision of practical human factors material and measures developed on the basis of experience in States" [12], pp.i.

The human element is indeed the most versatile and valuable factor in the aviation system, but it is also the most vulnerable to influences that affect its performance. When the pilot has these lower performances, it is often classified in several documents as "pilot error", which indicate where there was a failure, but does not indicate why it occurred or why did the performance of the pilot was not on the optimal level for operation.

2.2. Definition of Human Factor, Accident and Incident

The HF refers to the individuals daily work situations, relationships with machines, processes, and the surrounding environment. In a more concrete way, it is a science applied to the ergonomics that we normally consider to cover the adaptation to the work or the work conditions, in order to improve the performance of a worker [13].

The definition of accident and incident is expressed in ICAO Annex 13 - Aircraft Accident and Incident Investigation [14], which contains the international standards and recommendations of practices for the investigation of aircraft accidents and incidents. Accordingly, accident is an occurrence associated with the operation of an aircraft, which occurs between the time of embarkation and disembarkation, in which:

1) A person is fatally or seriously injured, resulting in:
   - Being on the aircraft;
   - Some type of contact with the aircraft or subsystems;
   - Direct exposure to engine jet.
2) The aircraft sustains damage or structural failure that:
   - Adversely affects the structural strength, performance and characteristics of the aircraft;
   - They require further repair or replacement of affected components, except for engine failure or damage, when it is limited to the engine, or its components;
   - They cause limited damage to the propeller, wing tip, antennae, tires, brakes, small roughness or holes in the outer layer of the aircraft.
3) The aircraft is lost or inaccessible.

An incident is an occurrence which is not an accident, in other words, it does not satisfy the description above, it is associated with the operation of an aircraft with effects that may affect the safety of operations.

2.3. Human Factor Analysis and Classification System (HFACS)

Although HF are connected to most accidents, the reporting systems are not developed based on them. As a result, most accident databases are not compatible with a traditional analysis of human error, making it difficult to establish an intervention strategy to attenuate the occurred human error.

To solve this problem, a human factor analysis and classification system (HFACS) [15] has been developed, in order to detect the occurrence of HF, therefore allowing an improvement in the investigation of accidents.

Based on the concept of active and latent failures [16], HFACS has four levels of failure:

- Level 1 - Unsafe acts;
- Level 2 - Preconditions for unsafe acts;
- Level 3 - Unsafe supervision;
- Level 4 - Organizational influences.

Now before the description of each level of failure, it is essential to mention that in this dissertation the level regarding organizational influences will not be used, because this study only refers the cases of general aviation and SPO of helicopters and airplanes where organizations are not always involved.

2.3.1. Unsafe Acts

Unsafe acts occur every time a subject fails to obey the rules of safety or protocols. This level is subdivided into two categories: errors and violations. Mistakes generally represent the mental or physical activities performed by an individual who failed to achieve the expected result. On the other hand, the violations refer to voluntary acts of non-compliance with the rules and regulations governing the safety of operations (Figure 5).

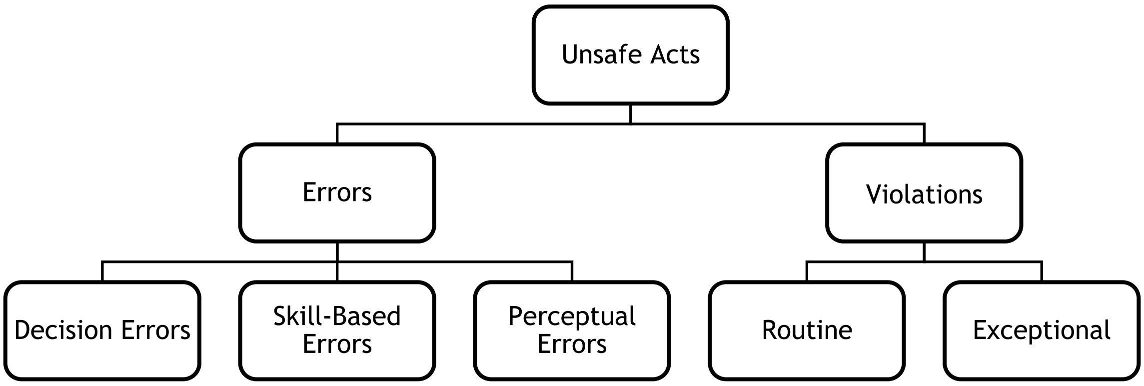

Figure 5 – Unsafe acts - Source: own elaboration

2.3.2. Preconditions to Unsafe Acts

Preconditions are essential to deepen the "why" of the occurrence of unsafe acts and to eliminate factors that cause accidents and incidents. The researchers [15] divided the unsafe acts into two preconditions: the conditions of the operator and the practices committed by the operator, as observed in Figure 6.

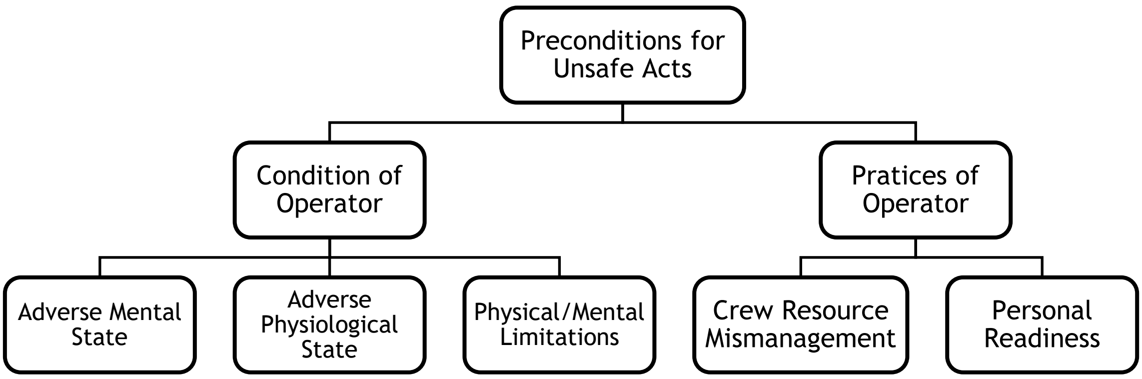

Figure 6 – Preconditions for unsafe acts - Source: own elaboration

2.3.3. Unsafe Supervision

In addition to the causal factors associated with the pilot/operator, Reason [16] traced the chain of events to supervisors. As such, four categories of unsafe supervision were identified:

inadequate supervision, improperly planned operations, failure to correct a known problem, and supervision infractions (Figure 7).

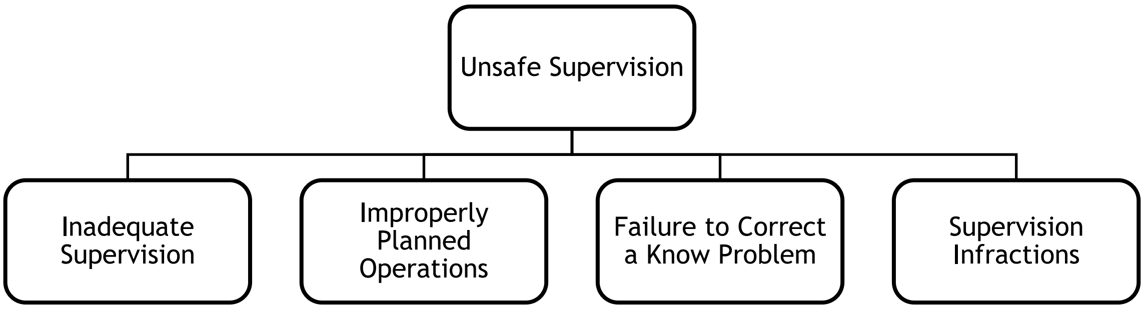

Figure 7 – Unsafe supervision - Source: own elaboration

2.4. Statistics of HF in Portugal

The implementation of the HFACS, mentioned above on the sub-chapter 2.3, to the final reports of incidents and accidents of the GPIAAF from 2010 to 2017 [3], allowed the acquisition of the data presented in the following table (Table 2). As the case studies are only for general aviation and SPO of helicopters and airplanes, where the use of aircraft with non-pressurized cabins predominates and where there is not always an influence of an organization, the factors regarding organizational influences were not applied as already stated on the Sub-chapter 2.3.

Table 2 – Classification of final reports using HFACS - Source: own elaboration

Ano	Unsafe acts	Preconditions for unsafe acts	Unsafe supervision	Total
2017	5	0	0	5
2016	2	0	1	3
2015	8	0	1	9
2014	15	1	3	19
2013	1	1	0	2
2012	15	3	0	18
2011	9	8	2	19
2010	67	5	5	77
Total	122	18	12	152

Using the data from the previous Table 2, the graph of Figure 8 was drawn with the percentage of each level of HF per year.

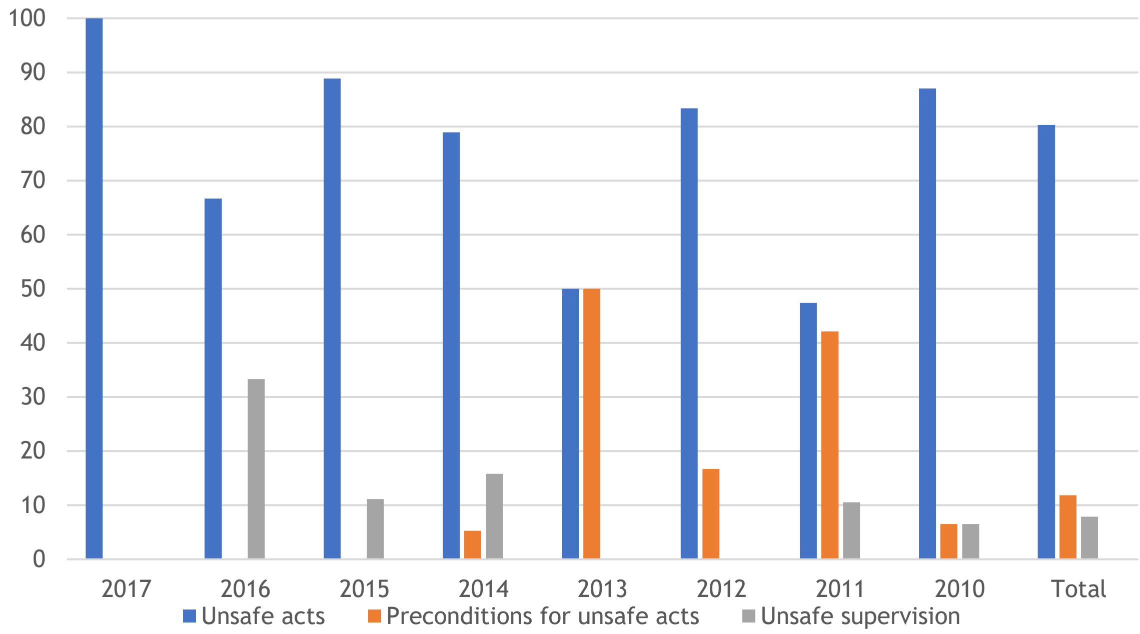

Figure 8 - Percentage of HFACS levels on final reports of accident and incident from 2010 to 2017 - Source: own elaboration based on Table 2

From Figure 8 is perceivable that the cause of most accidents/incidents in Portugal is at the level of unsafe acts that are related to cognitive fatigue as shown on Sub-chapter 2.5.3.

2.5. Fatigue and Types of Fatigue

2.5.1. Fatigue Definition

According to ICAO, fatigue is characterized as a physiological state of reduced mental or physical performance capacity, result of the lack of sleep, prolonged wakefulness, circadian phase or workload (mental and/or physical activity), and may impair the level and the ability of a crew member to operate an aircraft or perform safety-related tasks [5].

So fatigue can be described as a reduced ability to perform operational tasks and can be considered as an imbalance between [6]:

- Physical and mental effort of all wake activities (not only those of operation); and
- Recovery from this effort, which requires sleep (except recovery from muscle fatigue).

Physical fatigue is defined as an inability to exert force with one's muscles to the degree that is normally expected. It can be specific to a part of the body or overall tiredness. Physical fatigue is a result of physical exercise or a loss of sleep; this fatigue often leads to mental/cognitive fatigue [4].

Mental fatigue, which may include sleepiness, is related to the decrease of attention and ability to perform complex or simple tasks when compared with the regular efficiency of an individual [4].

The fatigue that is studied in this dissertation is that caused by the lack of sleep or inadequate sleep. This type of fatigue is known as "cognitive fatigue" or mental fatigue and is directly linked to reduced alertness, reaction time (RTI), thus impairing the decision making of the operator [7].

2.5.2. Types of Fatigue

Fatigue can be divided into three categories [4], being them:

- Transient fatigue is an acute type of fatigue caused by extreme sleep restriction or long periods of wakefulness within 1 or 2 days;
- Cumulative fatigue is brought on by a repeated slight sleep restriction or extended hours awake for a sequence of days;
- Circadian fatigue is a fatigue that is connected to the reduced performance during nighttime, and it is particularly linked to one's "Window Of Circadian Low" (WOCL), (as referred in Subchapter 2.6.2).

2.5.3. Hazards

Fatigue results in an impairment of an individual normal performance that increases the risk of failure during operation as, for example [4]:

- Increased RTI;
- Reduced attention;
- Impaired memory;
- Withdrawn mood;
- Inaccurate flying;
- Inadequate decision making;
- Loss of situational awareness.

2.5.4. Accident with Fatigue

After analyzing reports of accidents an incident from the GPIAAF is verifiable that fatigue is present in some of the occurrences. Due to limitations in methods that evaluate the condition of individuals during the occurrences, it is not easy to determine if the cause is related (or not) to HF.

The accident report "Hard landing during a porpoise landing", from GPIAAF, with document identification number 15/ACCID/2016_RF [17], is a case were fatigue is evident.

Figure 9- ATR 72-212 in is final Position on the runway [17]

An ATR 72-212A with registration CS-DJF (Figure 9) operated by White Airways on behalf of TAP Express performed a regular commercial passenger transport flight in nightly environment, between Porto airport (ICAO code: LPPR) and Lisbon airport (ICAO code: LPPT) with 20 passengers and 4 crew members on board. During the final approach to the runway 21 at LPPT pilots found conditions of rain and wind 240/09 with gusts up to 20kt.

At 21:34 UTC, the aircraft made the first touch on the runway, bounced, and touched hard again with the nose landing gear. Still, with too much kinetic energy, the aircraft bounced again and came to touch for the third time on the runway, continuing the phenomenon of porpoise landing, causing the separation of the wheels and respective axles of the nose landing gear.

Finally, after the fourth touch, the aircraft stabilized and completed the landing, with the nose landing gear leg structure in contact with the runway surface, stopping after crossing the runway 17/35.

On this flight TP1971, the pilot in command (PIC) was the pilot flying (PF) and the co-pilot, second in command (SIC) was the pilot monitoring (PM). The crew performed their sixth journey of the day between Lisbon and Porto in adverse weather conditions. During the preparations for this last flight of the day, the departure briefing procedure was only partial performed and summarized. The crew maintained conversations that were not relevant to the conduct of the flight in the restricted phases of the operational activity, not complying with the sterile cockpit procedure, foreseen in the operator's standardized operations manual (SOP). The approach to LPPT runway 21 was performed with the aid of ILS (Instrument Landing System) and under category I instrument conditions, with rain and moderate turbulence.

The calculated speeds by PM and recorded on the landing card refer to an estimated landing weight of 17.118kg and the following speeds: V_{APP} (Approach speed) 101kt, V_{MCA} (Minimum aerodynamic Control speed with critical engine failure) 107kt and V_{GA} (Go Around speed) 110kt. The considered estimated wind in LPPT was 210/13kt. The PM made a speed callout above the calculated "speed" (116 KIAS) according to the operator's SOP procedure, since the IAS (Indicated Air Speed) was above the VAPP that was calculated at 101 KIAS, and already corrected for the expected wind on the runway. There was no answer and confirmation from the PIC/PF to the speed warning.

Using the Human Factors Analysis and Classification System (HFACS) as a framework to provide useful means for a summarized evaluation, the incident analysis can be divided into four levels:

Level 1: Unsafe acts: (Crew)

- Skill-based errors: omitted steps in the procedures and poor pilot technique;
- Decision Errors: with an improper procedure and poor decision.

Level 2: Precondition for unsafe acts: (Crew)

- Adverse mental and physiological state: mental and physical fatigue;
- Crew resource management: with communication failures.

Level 3: Unsafe supervision: (Air Operator)

- Inadequate supervision: Operator failed to provide the crew with guidance, training, and track of performance.

Level 4: Organizational Influences: (Air Operator and/or Regulator)

- Operational process: Lack of oversight with effective risk management and safety programs implementation.

The investigation team concluded that probable causes were the decision made by the PIC/PF to proceed and force the landing not complying with the un-stabilized approach criteria, with IAS well above the reference VAPP. The contributing factors were fatigue that may have contributed to the accident by directly affecting pilot (PIC/PF) performance.

It is unfortunate that we can not present a case related to non-pressurized aircraft. This is a case where HF is present at various levels, including the one we are interested in within this dissertation “cognitive fatigue”. In this occurrence with a pressurized aircraft, which has several technical resources at their disposal to avoid / reduce this type of HF. It is therefore expected that in a non-pressurized aircraft the occurrence of this type of HF could have far more serious consequences for the aircraft, pilot(s) and passengers.

2.6. Scientific Principles for Fatigue Management

Following the Fatigue Management Guide for Airline Operators, second edition [6], there are four focal points on managing fatigue:

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

An ideal amount of sleep per night may vary between individuals, but most adults require between 7 and 9 hours, and it is clear that sleep cannot be sacrificed without consequences. Sleep has a vital role in memory and learning, maintaining alertness, performance, mood, general health, and well-being. So, sleep is one of the crucial points of this study.

2.6.1. Types of Sleep

Currently, the study and analysis of sleep use electrical patterns in brainwave activity, eye movements, and muscle tone in order to understand the effects of sleep in one’s performance. It was through these that two very different types of sleep were detected:

- Sleep with non-Rapid Eye Movement (non-REM); and
- Sleep with Rapid Eye Movement (REM).

During the non-REM sleep, brain wave activities gradually decrease when compared to waking brainwave activity; most adults spend around 55% of sleep in this type of sleep (Figure 10). According to the characteristics of brainwaves, this type of sleep is divided into three stages:

- Stages 1 and 2 is where our brain enters sleep and it represents a lighter sleep
- Stage 3 is known as Slow Wave Sleep (SWS) or deep sleep, at this phase brain cells (neurons) start firing in synchrony, generating large and slow electrical waves, thus the name slow wave sleep. During stage 3 the stimuli from the outside world are mostly

blocked. The SWS stage is necessary for learning since it is at this stage that the consolidation of certain types of memory occurs.

In REM sleep the body cannot move in response to brain signals so that dreams are not displayed by physical movements. In this type of sleep, the brain is restoring itself and sorting the information from the previous day to related memories already stored. Most adults typically spend about a quarter (25%) of their sleep in this type (Figure 10).

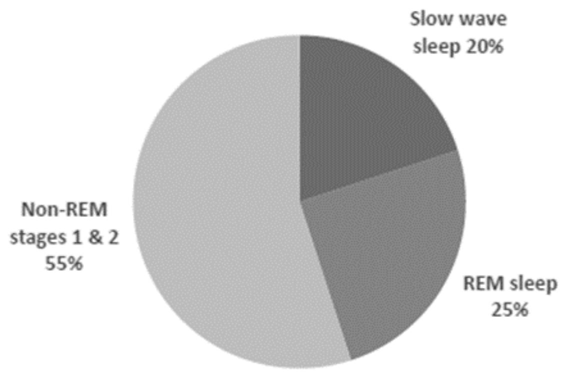

Figure 10 – Proportion of the night spent in each type of sleep, for a young adult [6]

Figure 11 depicts a hypnogram of an adult sleeping between 7-8 hours and the phases it goes through that time, respectively. As seen on Figure 11 the individual enters sleep in stage 1 and stage 2 then moves one to medium to deep sleep where he spends most of his cycle returning to stage 1 and stage 2 and going into rem phase, after which he starts a new cycle.

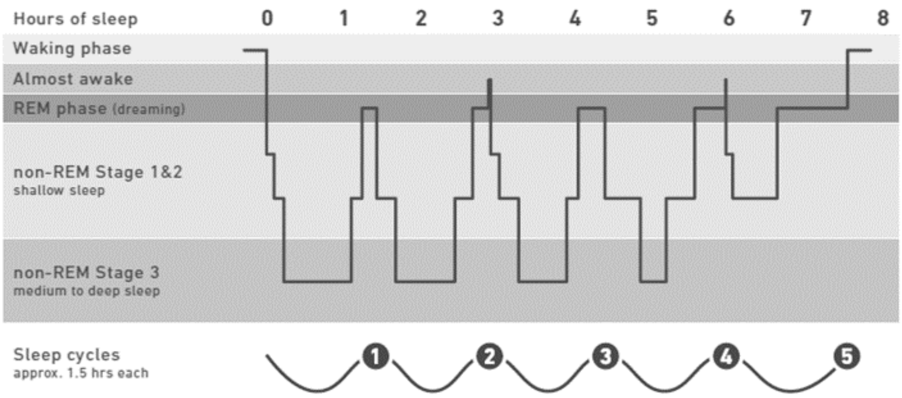

Figure 11 – Sleep Hypnogram for a healthy adult sleeping 7-8 hours [7]

2.6.2. Circadian Cycles and Effects on Sleep and Performance

Cognitive fatigue is mostly linked to the temporal organization of the human biological system, which is one of the most remarkable features of living organisms. The field of knowledge that studies this temporal organization is Chronobiology which examines periodic (cyclic) phenomena characterized by a wide spectrum of rhythms with different frequencies and amplitudes in living organisms. According to their periodicity (τ), the biological rhythm [18] directly linked to this type of fatigue is the circadian rhythms (Latin: circa diem = about one day), due to their great influence in daily life. These rhythms have a periodicity of between 20 h and 28 h.

Circadian rhythms include [6]:

- Rhythms in the subjective sensations of fatigue and sleepiness;
- Rhythms in the ability to perform mental and physical work; and
- Rhythms in the ability to fall asleep and remain asleep (sleep propensity).

Most of these fluctuations in appetite, blood pressure, body temperature and levels of fatigue change with daylight through a specialized entry pathway of the eyes over which we have little control and are slow to adjust. The morning light shortens the circadian cycle and the light at dusk prolongs the cycle of this biological clock (jet lag).

With consistent and adequate sleep these circadian rhythms, with their ups and downs, are fairly regular and predictable [7].

Circadian cycles schedule the human being for daytime wakefulness and nighttime drowsiness, affecting all aspects of human functioning, resulting in high performance and low-performance cycles (Figure 12). This exerts a strong influence on sleep, creating windows where sleep is promoted and windows where sleep is denied.

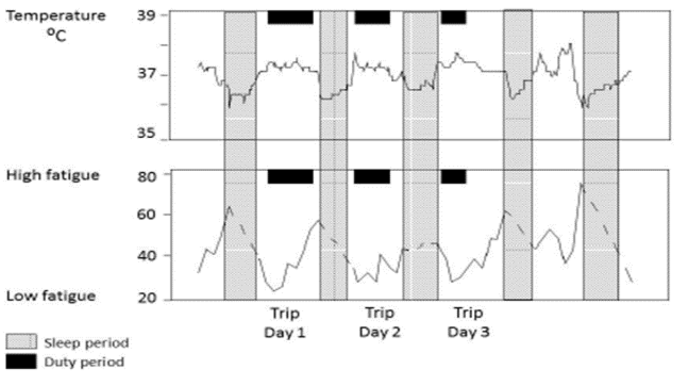

Figure 12 – Circadian rhythms of a short-haul pilot [6]

As can be seen in Figure 12, the Window of Circadian Low (WOCL) occurs at the minimum daily core body temperature that corresponds to the time of day when people feel sleepier and are less able to perform tasks.

2.6.3. Sleep-Wake Homeostasis and the Sleep Drive

Homeostasis [7] is the control mechanisms that keep the body's various systems in check and in balance. It controls sleep, body temperature, blood and tissue metabolism, and blood pressure. The homeostasis sleep drive works similar to an hourglass, it controls de time since our last sleep until when the sand runs out, and the body is reminded that it needs to sleep again (Figure 13).

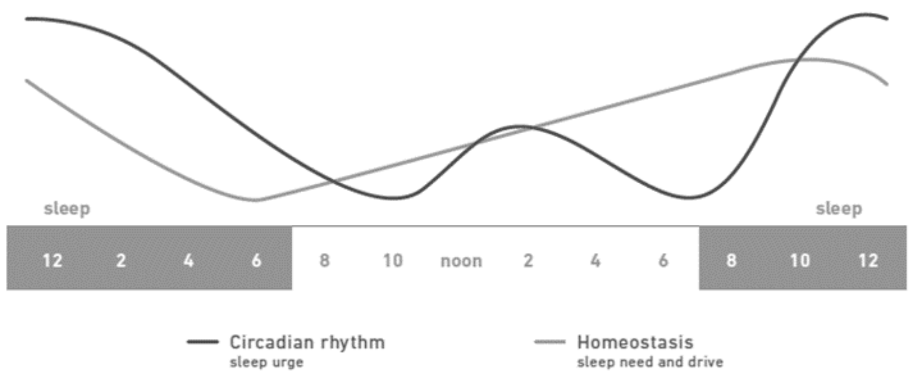

Figure 13 – Relation between circadian rhythm and homeostatic sleep drive [7]

2.6.4. Factors that Affect Sleep Quality

To have a night of fully restorative sleep, the brain needs unbroken cycles of non-REM and REM phases. There are several factors that influence the occurrence of these interruptions, which consequently affect the quality and quantity of sleep in general. These factors are [6],[19]:

- Sleep quality and age;

  Throughout adult life, the portion of sleep time spent on SWS decreases, particularly among men. In addition, sleep usually becomes more fragmented after the age of 50-60 years. Even so from a practical and scientific point of view, age is not considered a specific factor to be addressed in the management of fatigue, because it is not yet clear whether these sleep changes that occur with age reduce the effectiveness for restoring waking function.

- Sleep disturbances;

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

- Caffeine, nicotine, and alcohol;

  Caffeine (in coffee, tea, energy drinks, etc.) stimulates the brain, making difficult to fall asleep and disrupting sleep quality. The consumption of caffeine within 4 hours of sleep is likely to disrupt the sleep we get, but it can assist nap recovery [19]. The nicotine contained in cigarettes affects sleep in a manner similar to that of caffeine. Alcohol, which promotes drowsiness, also disturbs sleep because while the body is processing this substance, the brain cannot obtain REM sleep. So, drinking alcohol before sleep is a bad idea since it may help you to fall asleep, but worsens its quality.

- Environment;

  Environmental factors also influence sleep quality, from the bright light that increases the alertness, the sudden sounds, and the ideal temperature. Falling asleep requires the ability to reduce body temperature (losing heat through the extremities) so that it is easier to fall asleep. For most people, the ideal sleeping temperature is between 18-20ºC.

- Food and diet;

  What and when we ingest has a big impact on fatigue management and sleep. Food is a powerful element since different meals have a variety of different impact on our biological system. For example [19]:

  a) Meals made up largely of carbohydrates assists sleep;
  b) Meals which consists largely of protein promotes wakefulness and activity;
  c) Regular meal timings help to regulate the circadian body clock;
  d) On night shifts, main meals should be taken before 01:00 am;
  e) After night duty, a light snack of carbohydrates should be taken no later than two hours before expected sleep time.

Scientific evidence shows that the longer we are awake, the worse it is the state of alertness and performance. This occurs due to increasing homeostatic pressure for sleep associated with long waking periods. Sleeping is the only way to reverse such effects. It is also supported that naps can be used as mitigation of fatigue, justifying that a short nap can improve alertness and performance. Restricting sleep night after night makes individuals less alert and less functional each subsequent day (Figure 14). This is sometimes described as "sleep debt".

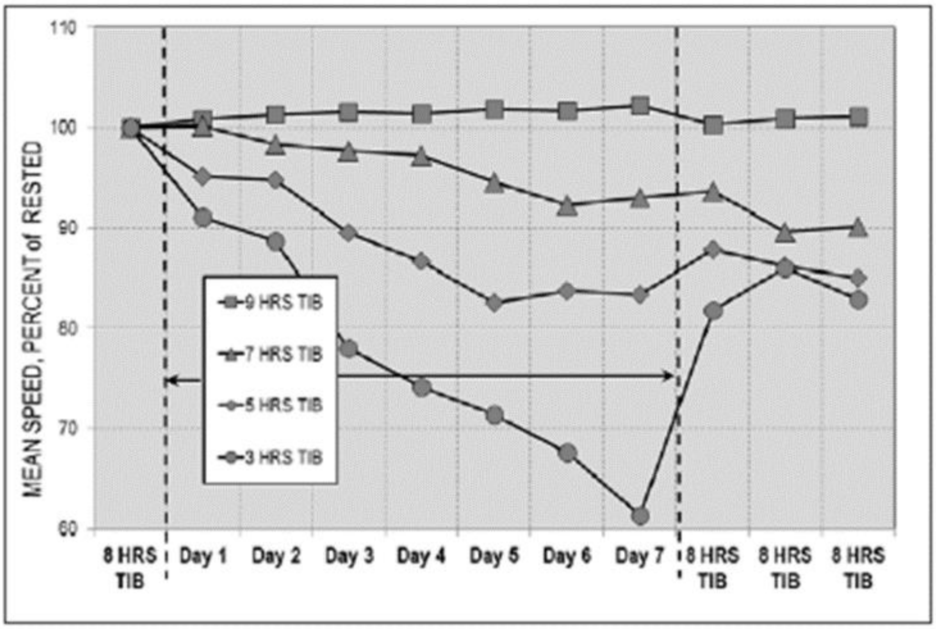

Figure 14 – Impact of different nightly times in bed (TIB) on daytime performance [6]

In the first days of severe restriction of sleep, for example, with 3 hours in bed, individuals can get a sense of drowsiness. However, after several days, they fail to notice the differences although their attention and performance continue to decrease. In summary, as sleep restriction continues, people become less and less able to assess their own functional status.

In general, more complex mental tasks, such as decision making and communication, seem to be more severely affected by the loss of sleep than simpler tasks. Objective and subjective tests are useful in fatigue management considered to be reliable to measure the impairment related to the sensation of fatigue and performance.

The ability to tolerate sleep loss is largely variable in an individual. But drowsiness eventually becomes oppressive and results in uncontrollable micro-sleeps (momentary lapses in consciousness). In a typical 3 to 4 second micro-sleep, while operating, a lot can happen. Even more alarming is the fact that they may occur before someone feels drowsy or shows any signs of fatigue.

To recover from an accumulation of sleep debt, it takes at least two nights of unrestricted sleep [6]. Already the recovery of alertness and performance can take more than two nights of sleep without restrictions.

2.6.5. Influence of Workload on Fatigue

The ICAO defines workload as "mental and/or physical activity" that is taken as a potential cause of fatigue in general [6]. There is a broad acceptance of the idea that intermediate levels of workload may contribute to a less impaired performance, since low workloads may have no stimulus, leading to monotony and boredom and high workload situations can exceed an individual's ability, resulting in worse performance.

The workload can have three dimensions:

1. The nature and amount of work to be done (including time on task, difficulty and complexity of task, and intensity of work);
2. Time constraints (including the time that task demands, external factors or by team member);
3. Factors related to the performance capacity of the individual (level of experience and ability, sleep history, and circadian phase).

The cognitive demand for tasks is also an important factor since physical and mental activity require perceptual actions, cognitive actions, and motor skills. This can be understood by looking to the Cognitive Demand model [20], (Figure 15); this model takes in consideration five basic cognitive tasks when performing an activity: Perception, Comprehension, Strategic Thinking, Decision Making, and Execution. These tasks are what permits a person to make the acquisition of situational awareness or the performance of decision-making.

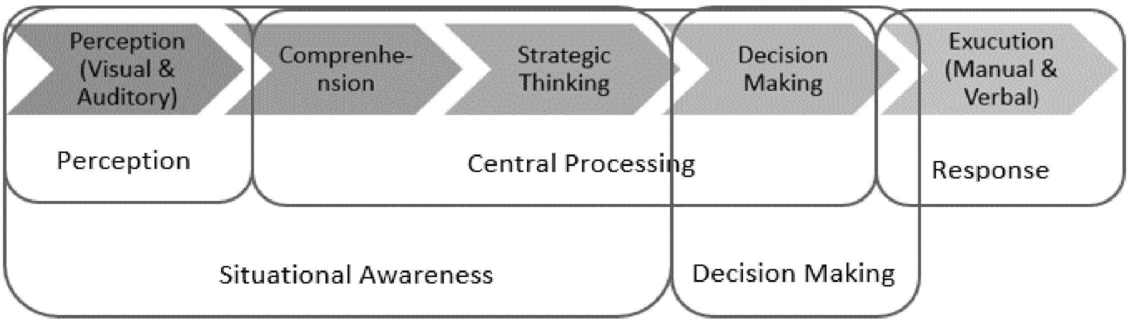

Figure 15 – The Cognitive Demand model - Source: own elaboration based on [20]

The bottom line is a person’s experience of workload in combination of both the actual external demands of the job, and the individual characteristics and expertise of the person doing the work.

2.7. Conclusion

Based on the data presented in the previous sub-chapters is easily concluded that the HF most present in incidents and accidents in Portugal is at the level of unsafe acts, but due to limitations on the investigation of incidents and accidents is difficult to affirm that fatigue is the cause of these unsafe acts. However, these acts can be caused by fatigue being that fatigued people often experience difficulty in increased RTI, reduced attention, impaired memory, withdrawn mood, inaccurate flying, inadequate decision making, and loss of situational awareness.

The cycle of work\fatigue\sleep is a normal part of a healthy human life. This fatigue appears due to changes in the circadian body clock, being that most of these changes are associated with sleep. For a normal adult is expected to sleep normally between seven to eight hours a day; moreover, this sleep should be uninterrupted and include both Rem and non-Rem phases. So, is easily understandable that the issue “fatigue” is a matter of sleep regularity and in/with quantity/quality. Not forgetting that workload is also an important factor and has its impact on fatigue.

The fact is that fatigated individuals are often very poor judges at accessing their own state of alertness.

Chapter 3

Fatigue Measurements

3.1. Introduction

To conduct this study, it was used two types of output data, being them subjective data and objective data. These two types of data acquisition give the possibility of having a perception of which is the impairment between the feeling of fatigue and the actual state of the operator.

It is used two methods of data acquisition for each type of data, being them:

1. Subjective data
   a. Samn-Perelli 7-point fatigue scale (SPS);
   b. Sleep diaries.
2. Objective data
   a. Actiwatch (Readiband 5);
   b. Psychomotor Vigilance Task (PVT).

These methods for measuring fatigue were taken from the ICAO, Measuring Fatigue by Dr. Michelle Millar, Technical Officer (Human Performance) [21].

3.2. Samn-Perelli 7-Point Fatigue Scale (SPS)

There are several subjective ways of measuring fatigue such as Visual Analog Scales (VAS), but the one being used within the scope of this work is the SPS (Figure 16). The related scale is easy and quick to fill and causes minimal disruption during aircraft operation. It is used in many studies, which gives a possible benchmark for comparing results [21]. But because it is a subjective scale, it has some disadvantages, such as easily presenting errors and not always reflecting reliable results, since the human error of wrongfully perceiving fatigue is always a contributing factor [22].

The scale is described from points, one to seven, as a function of the operating time, the points being marked by predefined periods of time, having the following classification:

1. Completely alert, wide awake;
2. Very alert, but not at peak;
3. Slightly alert, somewhat fresh;
4. Some feeling of tiredness, less than fresh;

5. Moderately tired;
6. Extremely tired, very difficult to concentrate;
7. Completely exhausted, unable to react and operate effectively.

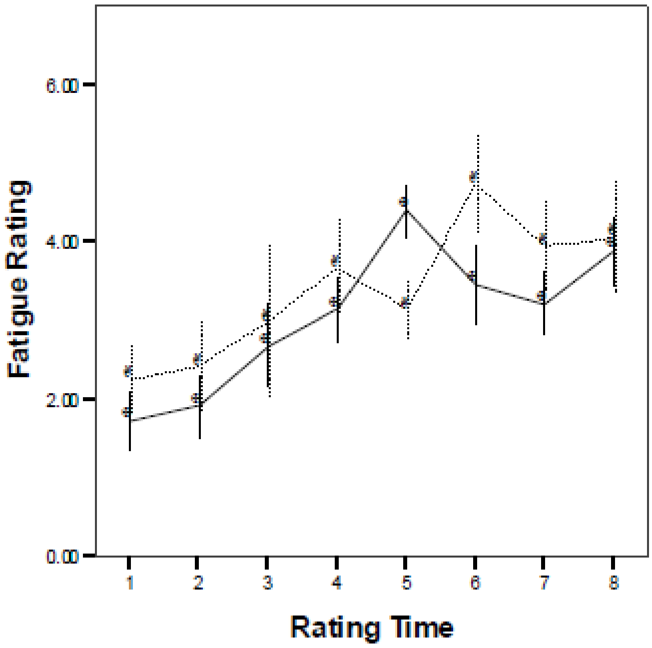

Figure 16 – Samn-Perelli 7-point fatigue scale [21]

In this case study, the SPS fatigue scale is implemented using the table presented in Figure 17. This table is to be filled during flight with the classification system presented above and also taking into consideration the type of flight as shown in Table 3. These rates are given in pre-determined time periods in accordance with the duration of the flight (Table 4). In the table to be filled is also present spaces for the input of PVT test results (Subchapter 3.4).

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Figure 17 - SPS fatigue scale table - Source: own elaboration

Table 3 – Fulfilment of SPS table according to the type of flight - Source: own elaboration

Type of flight	**Procedure**	
Long	(To fill according to the time periods present in Table 4)	
Circuit	Stop and go, Full-stop and taxi back	(To fill after landing, in the phase of preparation for a new take-off)
	Touch and go	(To fill before and after the flight)

Table 4 – Time periods according to the time of flight - Source: own elaboration

Time of flight	**<2 hours**	**>2 hours**
Time period	15 minutes	30 minutes

3.3. Sleep Diaries

The sleep diaries, observed in Figure 16, are a useful tool to be used along with other measures to perceive the sensations had by an individual in relation to the quantity and quality of sleep.

These diaries often ask an individual:

- Where they sleep;
- What time they go to bed and get up;
- How much sleep they think they get;
- How well they think they sleep.

This type of data permits a comparison between objective periods and quality of sleep, measured by polysomnography or an equal method, and the perceived time and quality of sleep. The diary to be used in this study (Figure 19) was constructed based on the sleep diaries of the National Sleep Foundation [23], (Figure 18), and contains a section for the input of results from the PVT test (Subchapter 3.4).

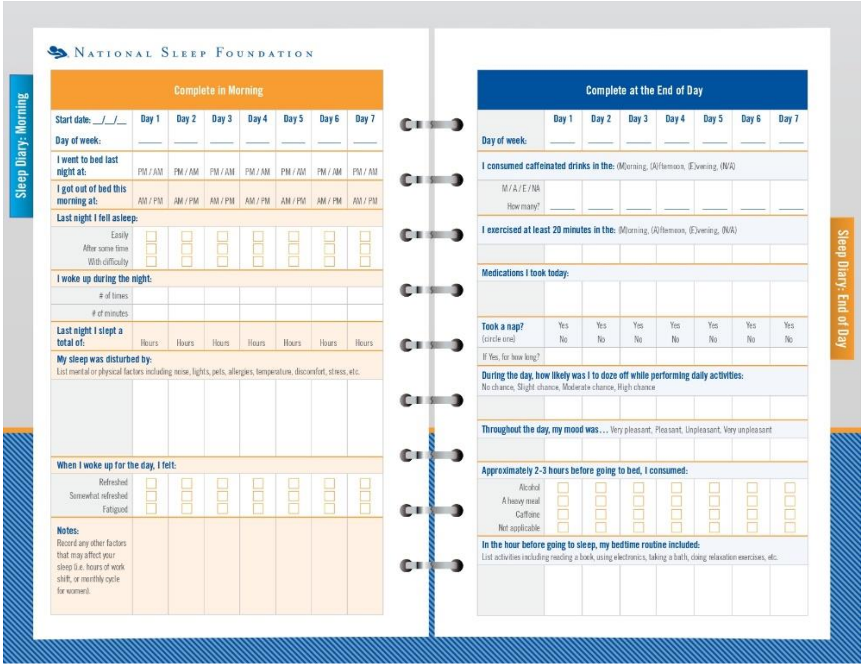

Figure 18 – Sleep diaries from National Sleep Foundation [23]

	Day	1	2	3	4	5
Fill in the morning after waking up	What hours did you lay down?					
	What hours did you woke up?					
	Number of times you woke up during the night?					
	How long did it take to fall asleep?					
	Did you take any medication the night before?					
	From 1 to 7 what does it feel like to wake up?					
	Results from PVT test (ms)					
Fill in the evening before going to sleep	Number of drinks with caffeine?					
	Number of drinks with alcohol?					
	Naps duration and hour?					
	Time doing exercise and at what hour?					
	From 1 to 7 what did you feel at the end of the day?					
	Results from PVT test (ms)					

Figure 19 – Sleep diary used in this study - Source: own elaboration

3.4. Psychomotor Vigilance Task (PVT)

The psychomotor abilities of an individual, correlate the cognitive functions with the physical movements. In the PVT test, it is measured the psychomotor speed by looking at an individual’s ability to detect and respond to rapid changes in the environment, such as the presence of a stimulus. The PVT is an important tool in determining an individual's alertness by assessing RTI, movement time and vigilance, thus giving a level of impairment.

In this study, it is used a smartphone application called Sleep-2-Peak (Figure 20) as an evaluation tool of the operator response time.

Figure 20 – Smartphone application Sleep-2-Peak [24]

This application will allow a later comparison of RTI when alert or in the context of prolonged wakefulness, to identify which are the changes related to cognitive fatigue. This test has a duration of 3-minutes, as opposed to the 10-minutes gold standard PVT test, making it easier to apply in studies with short evaluation times. It was already validated that this choice of shorter duration has a low effect on final results since on the longer 10-minute test even severely sleep-deprived individuals will be able to compensate by increasing effort, which will result in inadequate performance. Thus, a valid and sensitive alertness test will capture subtle changes in fatigue-related behaviour, even in a very brief period on a task [25].

This application of this test using, sleep-2-Peak, is performed in the following way:

- Seated, with a straight back;
- Both feet on the ground;
- Back and arms not supported;
- With the smartphone at the level of the abdomen;
- With the index finger at approximately 1cm from the screen.

To start the test, it is only necessary to open smartphone application, click on “Do Test” (Figure 21) and after its conclusion the result was written on the referred space of the provided sleep diaries and Samn-Perelli 7-point fatigue scale table.

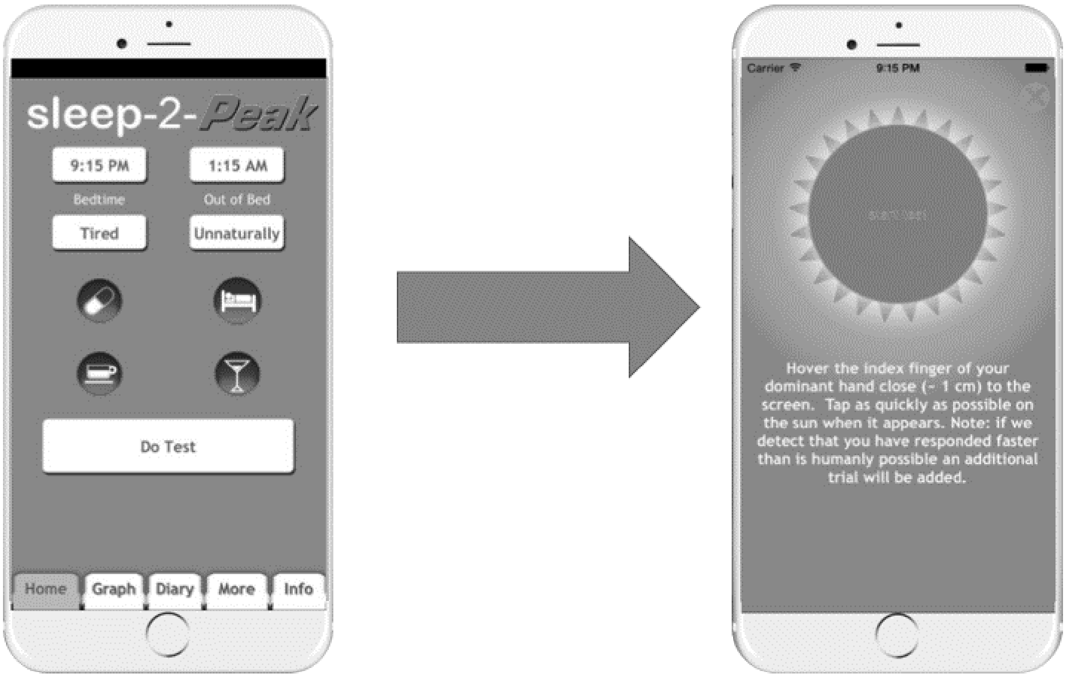

Figure 21 – Use of Sleep-2-Peak - Source: own elaboration based of [24]

3.5. Actiwatch (Readiband™ 5)

Actiwatches are devices capable of monitoring activity, estimating sleep periods and their quality, and various other parameters depending on the device type. These have advantageous characteristics, such as the fact that they are not intrusive to the operation and are easy to administer. As in the case of this study, they are used in conjunction with the subjective measures, SPS and sleep diaries in order to cross data and make conclusions.

Figure 22 – Readiband™ 5 [26]

In this study, the device used is the Readiband™ 5 (Figure 22), from Fatigue Science [27], which combines scientific accuracy and reliability. The Readiband™ 5 captures sleep data with high resolution, using an algorithm that scored as "Sleep" when is detect a minimal activity over a period of time (Figure 23) and was validated with an accuracy of 93% when compared to clinical polysomnography [28]. However, since it is difficult to differentiate lying quietly in bed from lying in bed asleep, the algorithm occasionally may slightly overestimate sleep time [29].

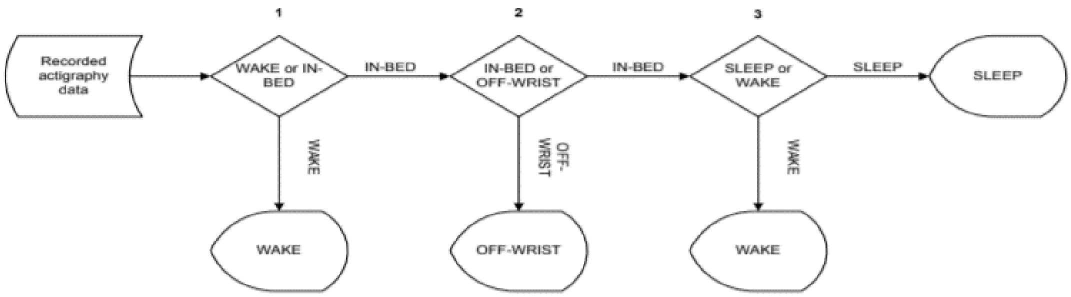

Figure 23 – High level overview of the three step state determination logic [28]

This device has a low power touch screen optimized for variable light conditions, displaying:

- Reminder to charge the battery level;
- Clock for user convenience;
- User name to facilitate identification.

It has a soft, flexible band that fits a wide range of wrist sizes and has a quick release clasp. The battery is rechargeable via USB to any computer or wall charger and requires no accessories. It can be synchronized via Bluetooth ™ to the Readiband Mobile application or the base station in order to collect the data over which a biomathematical model and computer algorithms, SAFTE™ (Sleep, Activity, Fatigue, and Task Effectiveness), are used to analyze the various sleep factors that may lead to sleep de-synchronization or sleep deprivation.

The data acquired by the Readiband, before being analyzed by the SAFTE™ algorithms, is represented as a graph from midnight to midnight (Figure 24). This figure shows vertical black lines that represent motion or activity, the darker segments represent sleep periods, and the segments marked with a lighter color represent the periods of wakefulness estimated from the motion detected.

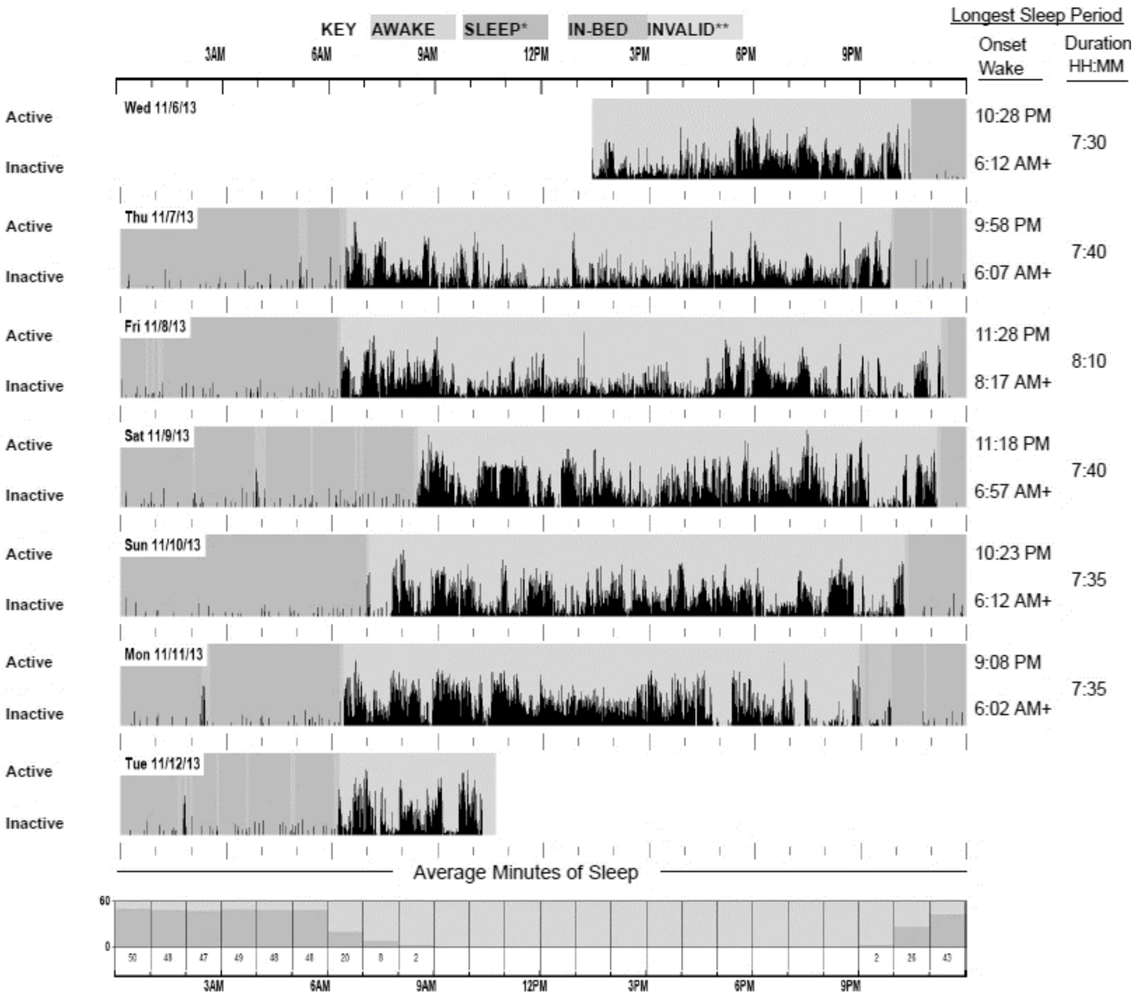

Figure 24 – Actigraphy obtained from the motion or activity detected by the actiwatch and estimated sleep/awake periods [29]

3.5.1. SAFTE™

SAFTE™ fatigue model was developed by the US Army Research Laboratory over a period of 25 years and USD 37 million in research and has been extensively tested and validated by the US Army, US Department of Transportation, FAA, and industry organizations among others. It is one of the most applied biomathematical models in this area of knowledge.

The SAFTE™ fatigue model uses a person's sleep data acquired by the Readiband™ 5 and analyzes them within the context that is scientifically known about human sleep and fatigue. It is one of the few biomathematical models available to analyze human sleep and fatigue; this biomathematical model produces results after acquiring sleep data from three consecutive days. When a person's accurate sleep data is acquired over a period of days, the SAFTE™ fatigue model applies complex algorithms to analyze it and produce a SAFTE Alertness Score (Figure 25).

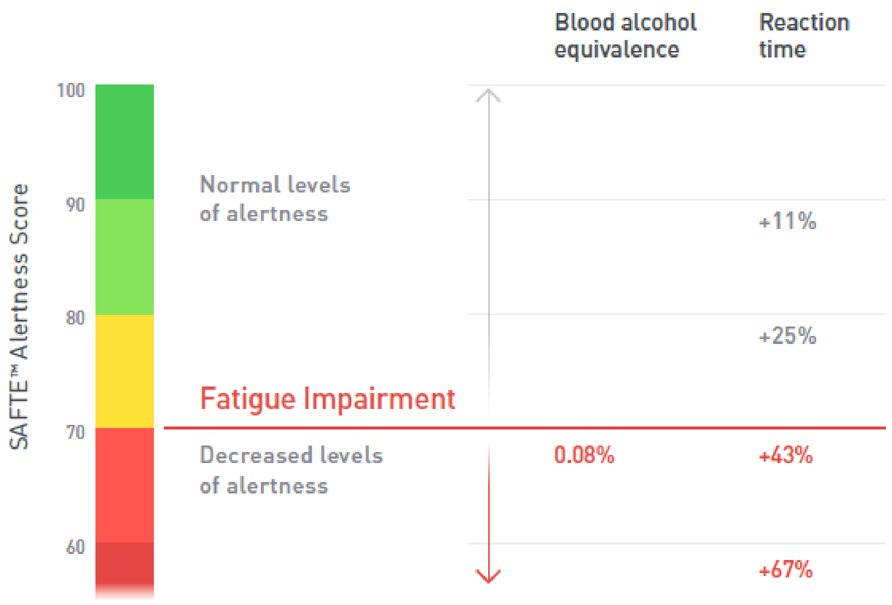

Figure 25 – SAFTE^{TM} alertness score [7]

The alert state is the quantification of fatigue impairment, on a scale ranging from 0 to 100 (Figure 25). With this data, we can reliably compare effects of fatigue in operational situations as shown in the FAA report, Flight Attendant Work / Rest Patterns, Alertness, and Performance Assessment: Field Validation of Biomathematical Fatigue Modeling [30]. Figure 26 represents an easier way of pinpoint the day-to-day fatigue pattern of an individual over a period of six days; this is obtained from the data of an actigraphy and an analysis made by SAFTE^{TM}. In Figure 27 is depicted a table that compares the risk of accident or serious error by the reduction of reaction time or SAFTE level of alertness.

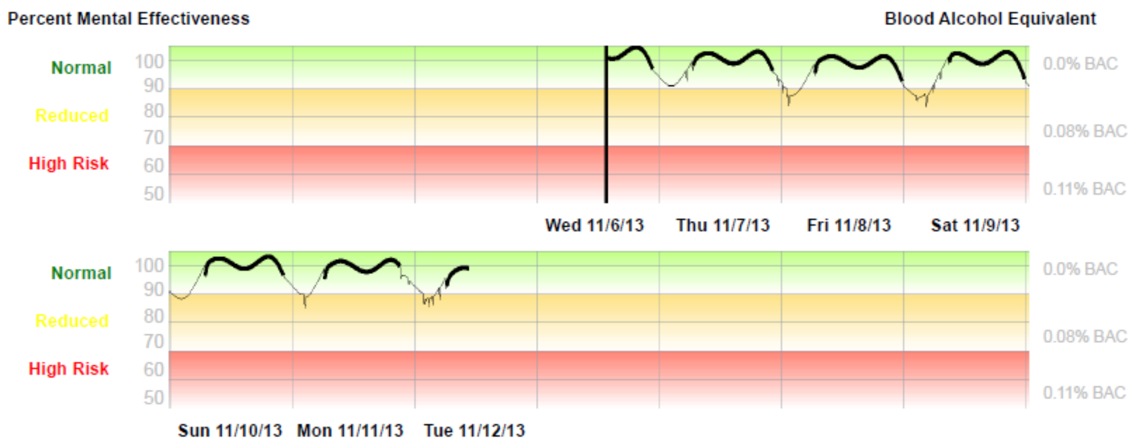

Figure 26 - SAFTE^{TM} model results over a period of six days [29]

	SAFTE™ Alertness zone	Percentage of time spent in each	Reaction time slowed by	Blood Alcohol Concentration (BAC)	Risk of accident or serious error
High	90 - 100	54.6	5%	0%	Very Low
Reduced	80 - 90	38.1	18%	0%	Low
	70 - 80	7.2	34%	0.05%	Elevated
Low	60 - 70	0.0	55%	> 0.08%	High
	0 - 60	0.0	100%	> 0.11%	Very High

Figure 27 - Risk of accident [7]

3.6. Conclusion

In this chapter were presented the methods used for this study to measure fatigue in a subjective and objective way, why where chosen these ones and their use for obtaining measurements of fatigue. These were chosen because they obtain results that are an indicator of not just a global fatigue (physical and mental) but also, they are more suitable for measuring or predict cognitive fatigue in the operational situation where the study occurs.

It was also presented validation studies for these methods and how they are implemented in this case study. It is also important to know that the Samn-Perelli 7-point fatigue scale and the sleep diaries are subjected to human error of auto-evaluation. The Readiband, in conjunction with the SAFTE™, gives predictions of cognitive fatigue based on the data from the actigraphy which has a 93% accuracy for determining sleep scoring.

Chapter 4

Case Study

4.1. Introduction

In this chapter it is introduced the case study of this dissertation; this study is also a sequence of an experimental work made in 2011 on the University of Beira Interior in a master's degree dissertation in Aeronautic Engineering with the title "Desempenho de Pilotos e Segurança de Voo: O Caso da Hypoxia em Aviação Desportiva" [11]. Following the same theme of human performance for the case study, this dissertation is also made with the objective of evaluating the performance of pilots in general aviation in the case of cognitive fatigue.

This chapter described how is made the implementation of the methods referred in the previous chapter on a day-to-day basis. It is also presented the survey launched online released in parallel with the experimental study. This survey has the objective of understanding what is the idea that pilots, in general, have about the mitigation of cognitive fatigue as way to improve operational safety.

4.2. Survey

The survey launched to the pilots had the title "Cognitive fatigue in aviation" (Annexe 1) and it was constructed based on the scientific principles for fatigue management of FMG for operators [6] from ICAO. This survey has 25 questions in Portuguese and it was launched on 25 of September 2018, and we obtained 41 responses. In this subchapter, it will be presented only the questions in the scope of this dissertation and the results obtained. The analyses of these results will be presented in the next chapter.

4.2.1. Question 1

This question is referred to the age of the individual since age is an important factor in the quality of sleep and has a direct impact on cognitive fatigue. The results obtained are represented in Table 5 and Figure 28.

Table 5 – Results from question 1 - Source: own elaboration

Age	[24,29]	]29,34]	]34,39]	]39,44]	]44,49]	]49,54]	]54,59]	]59,64]	]64,69]	]69,74]
Answers	1	1	4	3	5	1	3	9	4	4
Answers [%]	2.86	2.86	11.43	8.57	14.29	2.86	8.57	25.71	11.43	11.43

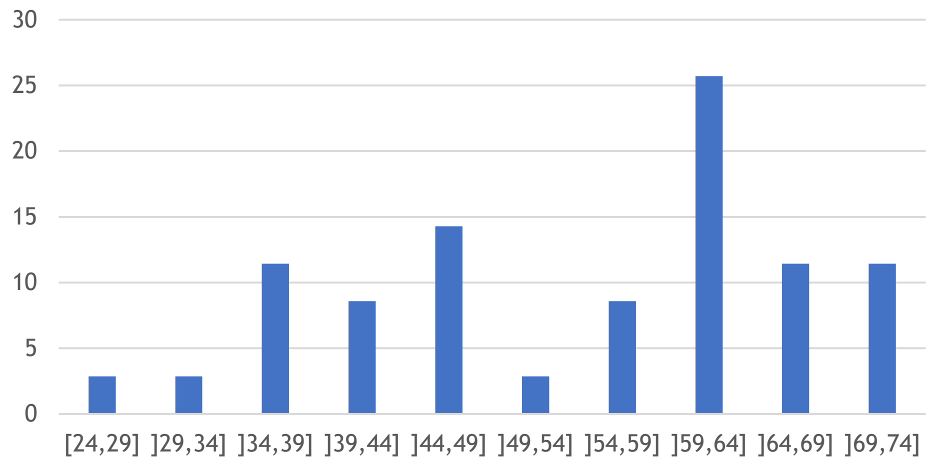

Figure 28 – Age [%], results from question 1 - Source: own elaboration

4.2.2. Question 2

Question 2 asks the gender of the individual. The results are shown in Table 6 and Figure 29.

Table 6 - Results from question 2 - Source: own elaboration

Gender	Female	Male
Answers	3	38
Answers [%]	7.3	92.7

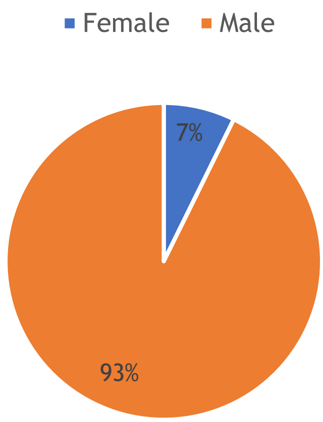

Figure 29 – Gender [%], results from question 2 - Source: own elaboration

4.2.3. Question 3

This question asks an individual if his/her line of work is associated with aviation. This question is made in order to distinguish from general aviation from aviation associated with operations that normally has implemented legislation that mitigates fatigue. The obtained results are presented in Table 7 and Figure 30.

Table 7 - Results from question 3 - Source: own elaboration

	Yes	No
Answers	14	27
Answers [%]	34.1	65.9

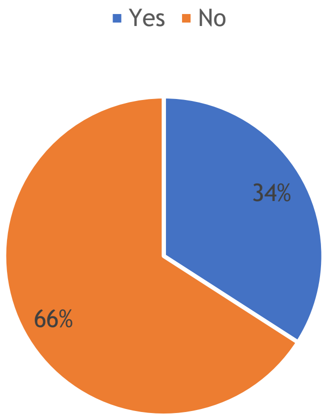

Figure 30 - Aviation as a professional activity [%], results from question 3 - Source: own elaboration

4.2.4. Question 4

In question 4 is asked what is the category or categories in which the individuals fly. The answers are presented in Table 8 and Figure 31, where is shown the number of selections in each category from the total of answers.

Table 8 – Results from question 4 - Source: own elaboration

Flight category	General aviation	Military aviation	International air transport	Air-taxi	Corporate
Answers	33	1	6	1	4
Answers [%]	84.6	2.6	15.4	2.6	10.3

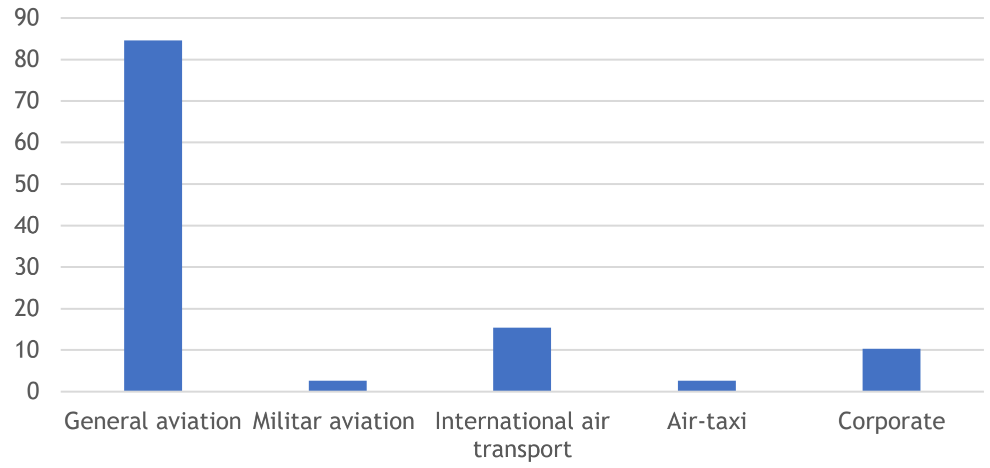

Figure 31 - Number of selections by category of flight from a total of answer [%], results from question 4 - Source: own elaboration

4.2.5. Question 5

This question is related with the type of flight license obtained by the individuals. The results for this question are represented in Table 9 and Figure 32, following the notation:

a) Ultralight pilot;
b) Glider pilot;
c) Private aircraft pilot;
d) Private helicopter pilot;
e) Private motor glider pilot;
f) Private balloon pilot;
g) Commercial aircraft pilot;
h) Commercial helicopter pilot;
i) Commercial balloon pilot;
j) Airline aircraft pilot;
k) Airline helicopter pilot;
l) Ultralight flight instructor;
m) Flight instructor of light aviation;
n) Airline flight instructor;
o) Instrument flight instructor.

The results show the number of selections in each category from the total answers.

Table 9 - Results from question 5 - Source: own elaboration

License type	a)	b)	c)	g)	j)	k)	l)	m)	n)	o)
Answers	32	3	10	3	6	1	3	3	3	1
Answers [%]	78	7.3	24.4	7.3	14.6	2.4	7.3	7.3	7.3	2.4

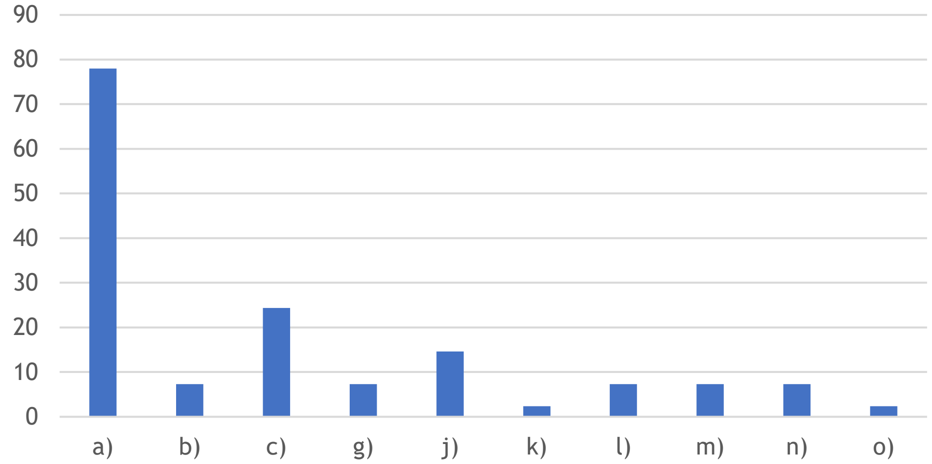

Figure 32 - Number of selections by type of flight license from a total of answer [%], results from question 5 - Source: own elaboration

4.2.6. Question 6

In this question is asked which medical license is detained by the individuals. The results are presented in Table 10 and Figure 33.

Table 10 - Results from question 6 - Source: own elaboration

	Class 1	Class 2	Class 3
Answers	10	28	2
Answers [%]	25	70	5

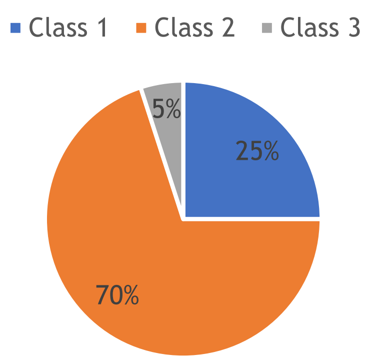

Figure 33 - Medical class license [%], results from question 6 - Source: own elaboration

4.2.7. Question 7

For this question is asked which of the provided factors can negatively influence the performance of one individual alert state. The provided options are as followed:

a) Nicotine;
b) Meal hour;
c) Medication;
d) Alcohol;
e) Caffeine;
f) Sleep time;

Being that the surveyed individuals can choose more than one option. The results are presented in Table 11 and represented in Figure 34.

Table 11 - Results from question 7 - Source: own elaboration

Factors	**a)**	**b)**	**c)**	**d)**	**e)**	**f)**
Answers	5	20	27	31	7	38
Answers [%]	12.2	48.8	65.9	75.6	17.1	92.7

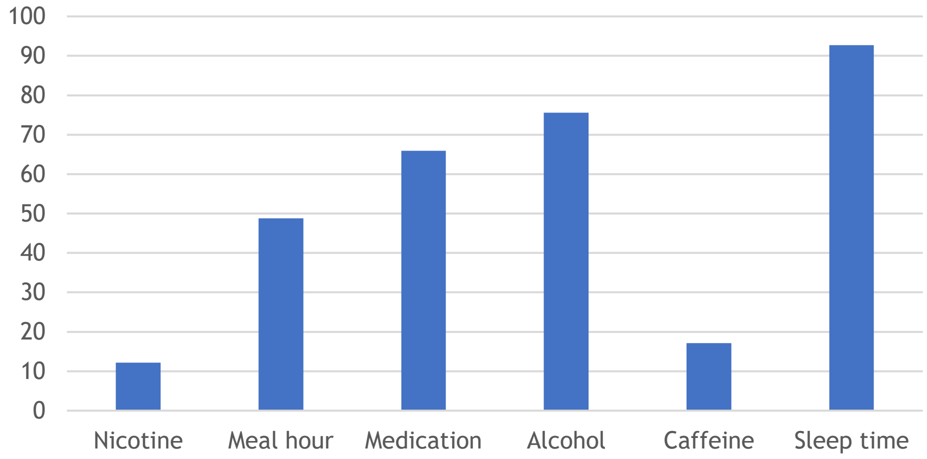

Figure 34 - Number of selections by factors from a total of answer [%], results from question 8 - Source: own elaboration

4.2.8. Question 9

In this question it is asked if during the flight hours that the pilots have done, they had noticed some degree of loss of performance derived from cognitive fatigue, having in consideration that the definition of cognitive fatigue promotes the reduction of alertness, RTI and decision making. The results are shown in Table 12 and Figure 35.

Table 12 - Results from question 9 - Source: own elaboration

	Yes	No
Answers	24	17
Answers [%]	58.5	41.5

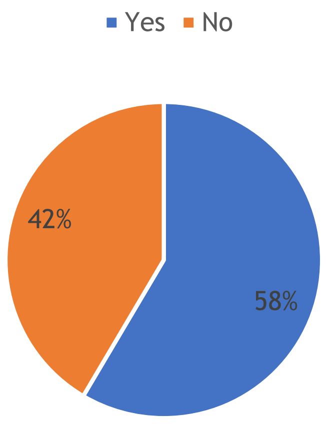

Figure 35 – Error due to cognitive fatigue [%], results from question 9 - Source: own elaboration

4.2.9. Question 10

This question asks the surveyed individuals if they would have in consideration their feeling of tiredness as a factor for the forfeit of a planned flight. The results obtained are presented in Table 13 and Figure 36.

Table 13 - Results from question 10 - Source: own elaboration

	Yes	No
Answers	37	3
Answers [%]	92.5	7.5

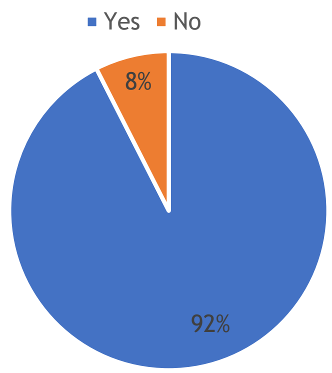

Figure 36 - Withdraw from a planned flight due to tiredness [%], results from question 10 - Source: own elaboration

4.2.10. Question 11

In this question is asked if the pilots' flight were performed in days in which they have their normal labor activity, or if their labor activity involves piloting. The presented options are as follows:

a) Yes;
b) No;
c) Sometimes;
d) "My labor activities include to flight".

The obtained results are presented in Table 14 and Figure 37.

Table 14 - Results from question 11 - Source: own elaboration

	a)	b)	c)	d)
Answers	8	17	8	8
Answers [%]	19.5	41.5	19.5	19.5

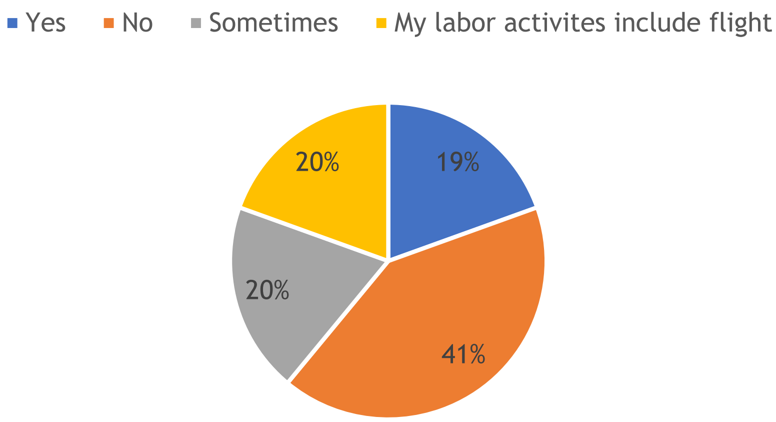

Figure 37 - Labor activities before flight [%], results from question 11 - Source: own elaboration

4.2.11. Question 12

Question 12 inquires the individuals about the time of day where they normally perform their flights. The results are presented in Table 15 and Figure 38.

Table 15 - Results from question 12 - Source: own elaboration

Time	[06:00,07:00[	[07:00,08:00[	[08:00,09:00[	[09:00,10:00[	[10:00,11:00[
Answers	2	2	3	3	12
Answers [%]	5.56	5.56	8.33	8.33	33.33

[11:00,12:00[	[14:00,15:00[	[15:00,16:00[	[16:00,17:00[	[18:00,19:00[	[19:00,20:00]
2	2	5	3	1	1
5.56	5.56	13.89	8.33	2.78	2.78

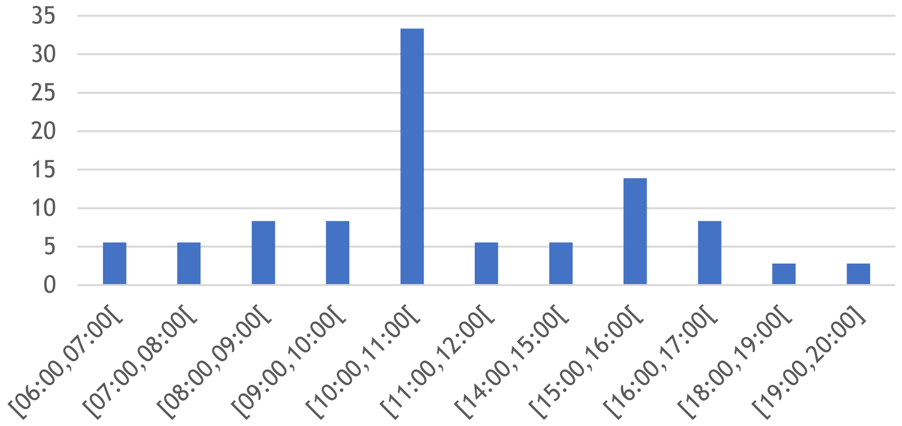

Figure 38 - Time of flight [%], results from question 12 - Source: own elaboration

4.2.12. Question 14

Using the SPS fatigue scale, described on the Subchapter 3.2, the inquired pilots describe the feeling of tiredness which they normally experience **before** initiating the flying operation. The obtained results are as shown in Table 14 and Figure 39.

Table 16 - Results from question 14 - Source: own elaboration

SPS	1	2	3	4	5	6	7
Answers	28	11	1	0	0	0	0
Answers [%]	70	27.5	2.5	0	0	0	0

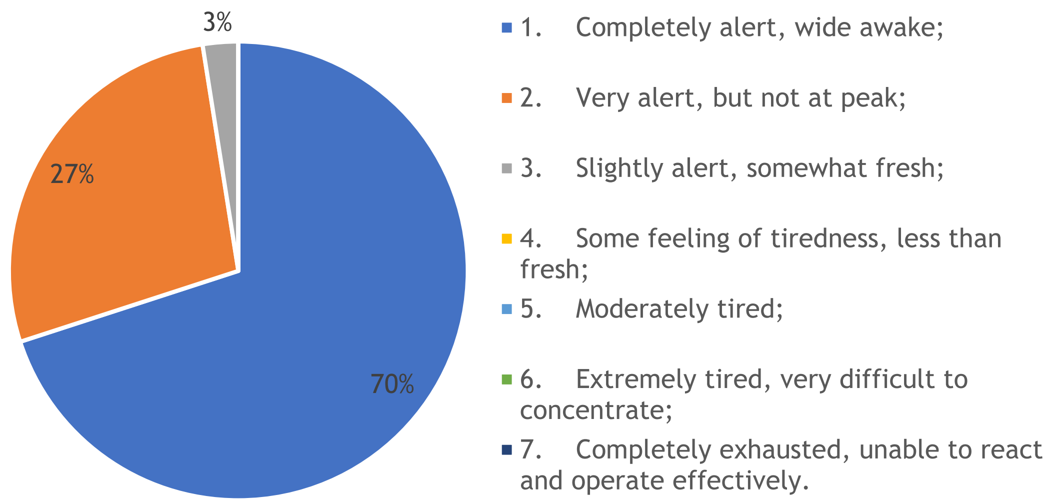

Figure 39 - SPS fatigue level before flight [%], results from question 14 - Source: own elaboration

4.2.13. Question 15

In question 15 is asked to the pilots to use the SPS fatigue scale, as in question 14, to describe their normal feeling of tiredness **after** the flight operation. The results of this question are presented in Table 17 and Figure 40.

Table 17 - Results from question 15 - Source: own elaboration

SPS	1	2	3	4	5	6	7
Answers	17	11	2	5	5	0	0
Answers [%]	42.5	27.5	5	12.5	12.5	0	0

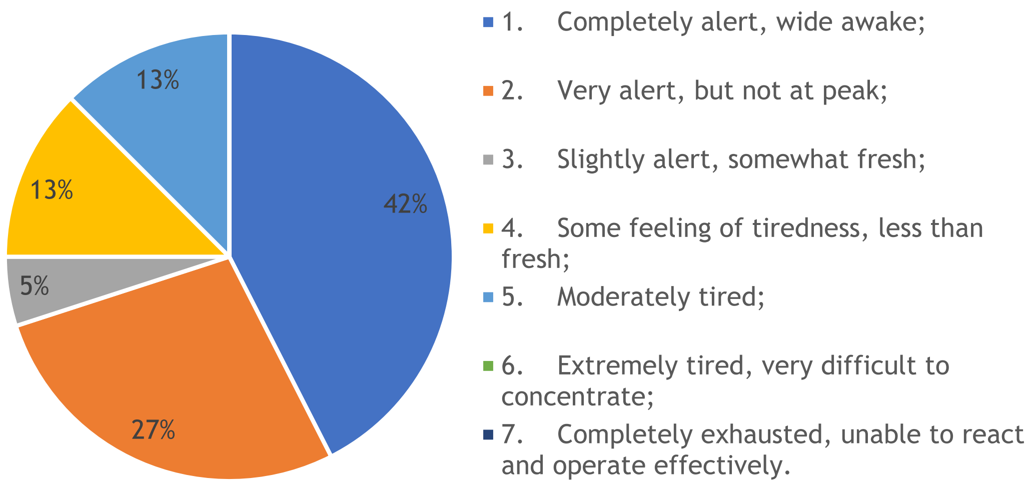

Figure 40 - SPS fatigue level after flight [%], results from question 15 - Source: own elaboration

4.2.14. Question 16

In this question, it is asked the average quantity (in hours) of sleep that each pilot as per night. This is a good indicator of the cognitive state in which the pilot starts the day. The results are shown in Table 18 and Figure 41.

Table 18 - Results from question 16 - Source: own elaboration

Hours of sleep	<4	4-5	5-6	6-7	7-8	>8
Answers	0	0	5	21	15	0
Answers [%]	-	-	12.20	51.22	36.59	-

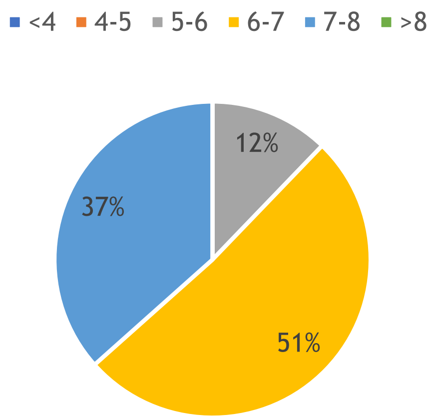

Figure 41 - Hours of sleep [%], results from question 16 - Source: own elaboration

4.2.15. Question 17

For this question, and following the same theme of sleep, is asked the average number of awakes per night experienced by the pilots. This is one of the ways of perceiving the quality of sleep of one individual. The results obtained are presented in Table 19 and Figure 42.

Table 19 - Results from question 17 - Source: own elaboration

Number of awakes	Non	1	2	3	4	>4
Answers	6	22	10	2	0	1
Answers [%]	14.63	53.66	24.39	4.88	-	2.44

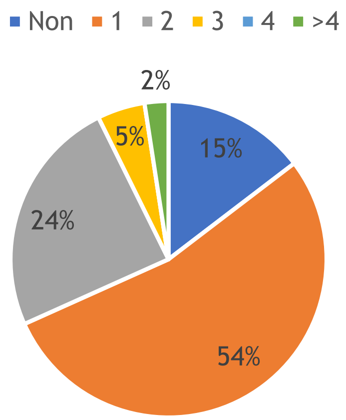

Figure 42 - Number of awakes [%], results from question 17 - Source: own elaboration

4.2.16. Question 18

This question intends to know if the pilots normally experience a feeling of tiredness after waking, because this is also a good indicator of the quality of sleep. The results are presented in Table 20 and Figure 43.

Table 20 - Results from question 18 - Source: own elaboration

	Yes	No
Answers	6	35
Answers [%]	14.6	85.4

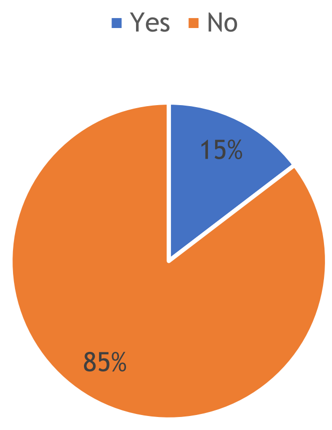

Figure 43 - Difficulty initiating routine [%], results from question 18 - Source: own elaboration

4.2.17. Question 19

In question 19 is asked about the feeling of having or not enough rest during sleep. The results are presented in Table 21 and Figure 44.

Table 21 - Results from question 19 - Source: own elaboration

	Yes	No
Answers	13	28
Answers [%]	31.7	68.3

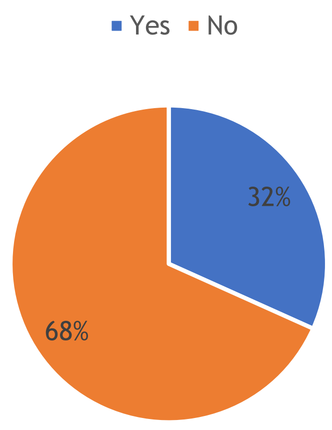

Figure 44 - Tiredness after waking up [%], results from question 19 - Source: own elaboration

4.2.18. Question 20

In this question is asked if the individuals usually experience drowsiness during the course of the day. The results are shown in Table 22 and Figure 45.

Table 22 - Results from question 20 - Source: own elaboration

	Yes	No
Answers	15	26
Answers [%]	36.6	63.4

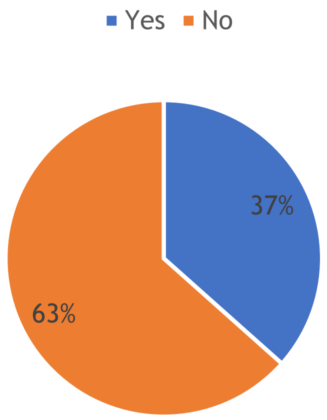

Figure 45 - Drowsiness during the day [%], results from question 20 - Source: own elaboration

4.2.19. Question 21

This question intends to know if enquired individuals practice some type of sport or physical activity regularly. The results of this question are presented in Table 23 and Figure 46.

Table 23 - Results from question 21 - Source: own elaboration

	Yes	No
Answers	23	18
Answers [%]	56.1	43.9

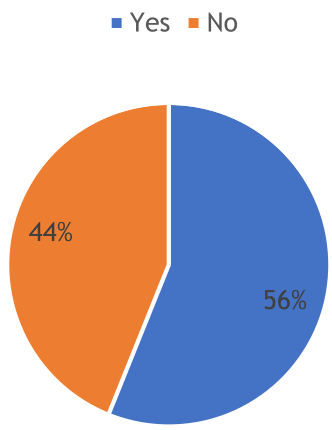

Figure 46 - Practice exercise with regularity [%], results from question 21 - Source: own elaboration

4.2.20. Question 22

The question 22 asks if individuals normally experience difficulty of concentration on a day to day bases, because this can be a symptom of cognitive fatigue. The results obtained are presented in Table 24 and Figure 47.

Table 24 - Results from question 22 - Source: own elaboration

	Yes	No
Answers	4	37
Answers [%]	9.8	90.2

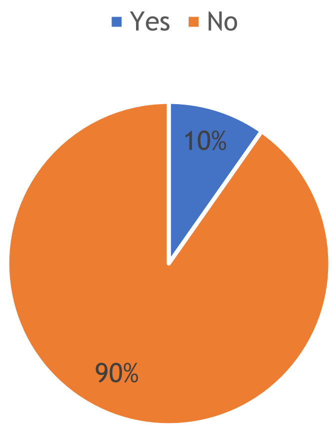

Figure 47 - Difficulty concentrating [%], results from question 22 - Source: own elaboration

4.2.21. Question 23

The question 23 asks the surveyed individuals about having trouble in expressing the right words during a conversation, as this can also be a sign of cognitive fatigue. The results are presented in Table 25 and Figure 48.

Table 25 - Results from question 23 - Source: own elaboration

	Yes	No
Answers	8	33
Answers [%]	19.5	80.5

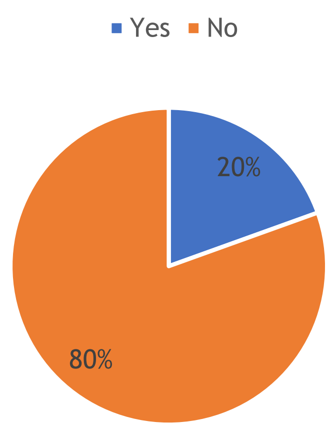

Figure 48 - Difficulty finding the right words [%], results from question 23 - Source: own elaboration

4.2.22. Question 24

In this question is asked if the pilots have had some experiences of loss of memory. As the questions above this can also be a consequence of cognitive fatigue. The results obtained are shown in Table 26 and Figure 49.

Table 26 - Results from question 24 - Source: own elaboration

	Yes	No
Answers	11	30
Answers [%]	26.8	73.2

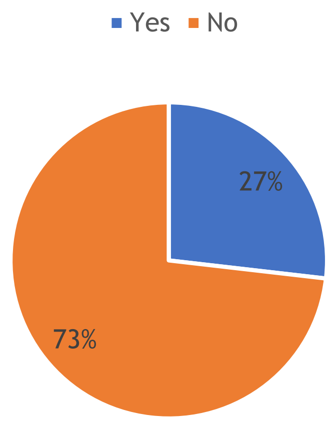

Figure 49 - Memory problems [%], results from question 24 - Source: own elaboration

4.2.23. Question 25

The last question addresses if the inquired individuals easily lose interest in the activities that they perform. The results are presented in Table 27 and Figure 50.

Table 27 - Results from question 25 - Source: own elaboration

	Yes	No
Answers	4	37
Answers [%]	9.8	90.2

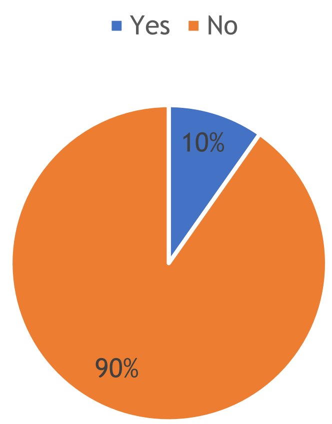

Figure 50 - Easily loses interest in activities [%], results from question 25 - Source: own elaboration

4.3. Experimental Work

4.3.1. Preparation

The material necessary to carry out this experimental study was almost all provided, except the application needed to realize the PVT test. This application will have to be installed on the smartphone through the Play Store or App Store.

During the whole period of this study, the individual always kept the watch on the wrist from the beginning, except during the bath or activities that may cause the watch to be in direct contact with water.

4.3.2. Study Implementation

After three days of sleep data obtained by the actiwatch the SAFTE™ fatigue model can produce alertness score results, after which the period of data collection inherent to this study began. This data was obtained by following a daily procedure repeated from the 4th day of the study until the last one.

This daily procedure began with the completion of the sleep diary part described as “Fill in the morning after waking up”, and the realization of the PVT in which the result is noted in the same sleep diary part. When performing PVT tests, it is only needed to open the application and select the button “start test”, Figure 18 from Subchapter 3.4, following the method as described in the same subchapter.

Before the operation of the aircraft a PVT test is performed and also as soon as the activity ends. The results from these PVT tests were noted in a designated space on the Samn-Perelli 7-point scale table, Figure 14 on Subchapter 3.2. During the operation of the aircraft, the Samn-Perelli 7-point scale table was filled according to Table 3 and Table 4, from the same subchapter.

This process ends at bedtime with the PVT test and fulfilment of the sleep diary on the part described with “Fill in the evening before going to sleep”, with the result from PVT test and answering to the remaining questions.

Figure 49 is a schematic to demonstrate the daily processes realized by our pilots involved in this study.

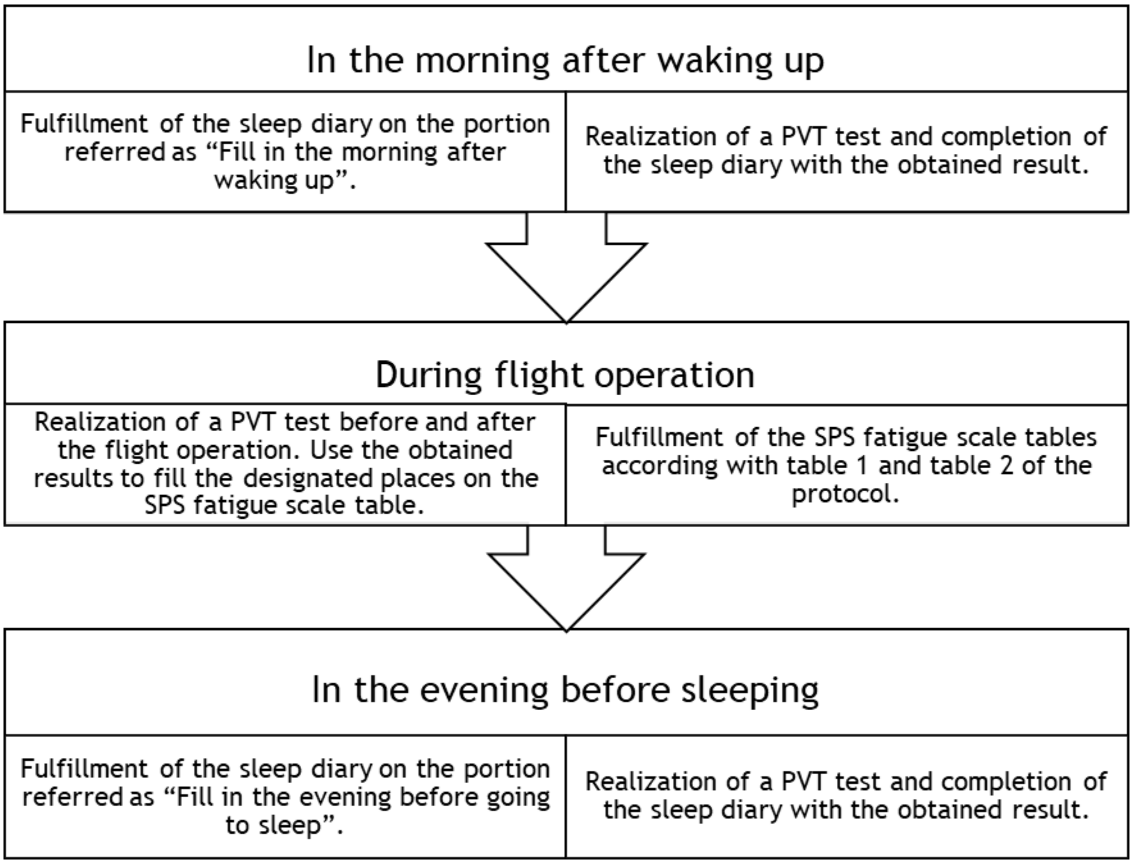

Figure 51 - Daily procedure for each individual - Source: own elaboration

In Annexe 2 is presented the documents used in the experimental study.

4.4. Conclusion

With the answer from the online survey it is possible to make conclusions on the universe of 41 responses that shows if the inquiries present symptoms of fatigue, if this is a theme known to the subjects, if they understand the hazards that can be caused by fatigue, if they know how to attenuate or control their levels of fatigue and if they have in consideration this factor before flying. With the implementation of the procedures in Figure 51 and using the documents in Annexe 2 it was possible to obtain the objective and subjective results that will be presented and discussed in the next chapter.

Chapter 5

Result Analysis

5.1. Introduction

The results from the online survey, displayed in Chapter 4, are analyzed and discussed in this chapter and from the implementation of the documents on Annexe 2, and using the procedure presented on Figure 51 were withdraw results that are presented and discussed in this chapter.

5.2. Survey Analysis

The applied survey obtained a universe of 41 inquiries where the results showed that 25.71% between]59,64], 14.29% between]44,49], 11.43% between]34,39], 11.43% between]64,69] and 11.43% between]69,74]. From all inquiries, 7.3% were female, 92.7% were male and 34.1% had aviation associated with his/her line of work where the other 65.9% had aviation as a hobby or leisure activity.

The individuals' responses to what categories or category of flight they perform shown that 84.6% flight in general aviation, 15.4% in international air transport, and 10.3% in corporates. From this question, it is also perceivable that the category in which the inquiries most fly is the one in study in this dissertation.

The license or licenses detained by the pilots obtained from the survey indicates that 78% had ultralight pilot license, 24.4% had private aircraft pilot license and 14.6% had airline aircraft pilot license.

From the pilots that responded to this survey 70% had class 2 medical license, 25% had class 1 and 5% had class 3. When asked about which factors, from those presented in the question, the pilots had as negative to the normal performance of an individual, it was withdrawn that 92.7% had sleep time, 75.6% had alcohol, 65.9% had medication, 48.8% had the meal hour, 17.1% had caffeine and 12.2% had nicotine as a negative factor. Although all the answers were acceptable the factor that has more influence on performance is sleep time, as shown. It is also important to take in consideration that the other factors have an influence on sleep time, so they can have direct or indirect repercussions on the performance of the pilot.

When inquired on the subject of cognitive fatigue it was verified that 58.5% had experienced a loss of performance due to this factor and 41.5% never had noticed this type of fatigue.

Cognitive fatigue is a common occurrence in aviation bearing in mind that most of incidents/accidents that occur due to human factors like decision error and perceptual error have as root this type of fatigue. Also significant to these obtained results is the fact that normally, in general aviation, when times/periods of flight are smaller, this type of fatigue can pass undetected.

In this survey, 92.5% of the individuals responded that tiredness would be a factor had in consideration to an eventual forfeit of a planned flight, where 7.5% responded that would not have in consideration their tiredness.

Most of the pilots (41.5%) answered that they would not fly in days where they have their normal labour activities, where 19.5% (each of the following options) would flight, or would sometimes flight, or have to flight as a labor activity. These answers are in accordance with what is expected, as after a day of work the tendency is for the individuals to feel tired and without optimal performance to be conducting a safe flight operation.

When asked the time of day where normally they would perform their flights it would be possible to observe that 33.33% between [10:00,11:00[, 13.89% between [15:00,16:00[, 8.33% between [08:00,09:00[, 8.33% between [09:00,10:00[, and 8.33% between [16:00,17:00[. The timetable of answers is somewhat what is expected from pilots with licenses for general aviation, taking into account that most pilots have licenses for VFR flight, and so can only flight during day time.

Using SPS fatigue scale, from Subchapter 3.2, 70% of the inquired pilots evaluated themselves as completely alert and wide awake before flight operation, 27.5% felt very alert but not at peak and 2.5% were slightly alert, somewhat fresh. After the flight operation, 42.5% of the pilots felt completely alert and wide awake, 27.5% were very alert but not at peak and 12.5% had some feeling of tiredness. From these answers is perceptible that most pilots do not feel any discrepancy on the feeling of fatigue from before and after the flight; this can be explained with the time of the flights that these pilots execute, being this an unknown information.

In the inquired individuals 51.22% between 6-7, 36.59% between 7-8 hours and 12.20% sleep between 5-6 hours. These answers are amongst the expected results, as a normal adult should sleep 7 -9 hours to have fully restorative sleep. Also, 53.66% awake 1 time per night, 24.39% awakes 2 times per night and 14.63% of the pilots don't awake amidst sleep. The number of awakes per night is a good indicator of the quality of the sleep, as a person that sleeps 8 hours is normal that awake 2-3 times but to awake more than 5-6 times indicates poor sleep quality. Following the theme of the quality of sleep 36.6% of the pilots answered that they fell drowsiness during the day which indicates that they can have accumulated fatigue or that they do not have a good sleep culture. In a group of inquiries 56.1% of the pilots practice some type of sport which can explain some level of fatigue during the day.

In a day-to-day basis, 26.8% have memory problems, 19.5% have difficulty finding the right words to express themselves, 9.8% easily loses interest in activities and 9.2% of the pilots experienced difficulty of concentration. So, the minority of the pilots inquired have signs of cognitive fatigue and the majority have fatigue in control and have normal sleep in terms of quality and quantity.

5.3. Experimental Work Results and Analysis

Using the methods and their implementation as described above we obtained the results for the study time period, 19 of May to 2 of June, from the three pilots evaluated. With these values and the information gathered in Chapter 2 and Chapter 3, it was made an analysis of the results. It is used colours to differentiate between good and not so good (bad) values; this set of colours is presented in Table 28.

Table 28 – Set of colours and classification - Source: own elaboration

Colours	**Red**	**Yellow**	**Green**
Classification	Bad	Intermediate	Good

- **Pilot 1:**

The pilot 1 is 33 years old and has 240 flight hours; he does not have caffeine, alcohol or exercise habits. The sleep quantity and quality are presented in Table 30, Figure 52 and Figure 53. The data related to the pilot's performance, that is, alertness (SAFTE), reaction time and self-evaluation using SPS, are presented in Table 31, Figure 54 and Figure 55. The results from flight days are presented in Table 32, Table 33 and Table 34.

Using the best RTi (223 ms) measured on the PVT tests and assuming it is the fastest RTi of this individual, Table 29 - in advance in the text, was made in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 29 – Risk of accident or serious error classification by RTi (Pilot 1) - Source: own elaboration

Reaction time slowed [%]	**RTi [ms]**	**Risk of accident or serious error**
5%	234.15	Very low
18%	263.14	Low
34%	298.82	Elevated
55%	345.65	High
100%	446.00	Very high

Table 30 – Pilot 1 sleep quality and quantity - Source: own elaboration

	Sleep quantity (actiwatch)	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]
19/05/2019	7	3	0.43	242
20/05/2019	5.8	4	0.69	242
21/05/2019	7.6	4	0.53	255
22/05/2019	3.8	3	0.79	259
23/05/2019	7.2	2	0.28	261
24/05/2019	6.4	0	0.00	241
25/05/2019	8.8	5	0.57	239
26/05/2019	7.3	0	0.00	291
27/05/2019	7.4	7	0.95	223
28/05/2019	5.2	5	0.96	315
29/05/2019	8.3	4	0.48	304
30/05/2019	7.5	5	0.67	265
31/05/2019	6	5	0.83	279
01/06/2019	6.7	8	1.19	283
02/06/2019	5.8	2	0.34	307

As can be seen in Chapter 2 the quantity and quality of sleep are two variables that are directly related to the type of fatigue in the study. Also, as is common knowledge that quantity and quality (awakenings per hour) are not always related, as seen in Table 30, in days were there are good quantity and poor quality (high awakenings per hour) the RTi from the PVT test increases, but the opposite is also true. So, it is needed a good portion of both so the level of fatigue and RTi raises. In the case of this pilot, when looking at Figure 52 and Figure 53 (the red area showed on the figures represents the zones where the quantity or quality have bad values) it is perceivable that his RTi changes more frequently with the quality of sleep than the quantity. In average his RTi after waking is 267.07 ms that is 19.76% slower than the fastest morning PVT (223 ms), and before going to sleep his RTi has an average value of 264.64 ms that is 18.67% slower. His awakenings per hour (quality) is 0.58/hour that is well above the normal value of 0.37/hour for a good quality sleep and almost reaching the value of a poor quality sleep that is set above 0.68/hour. His sleep quantity has a average value of 6.72 hours that is almost at the recommend values that range between 7 and 9 hours. The average value of SAFTE^{TM} alertness is at 90 % which is right between the high and reduced level of alertness and means very low to low risk of accident or serious error.

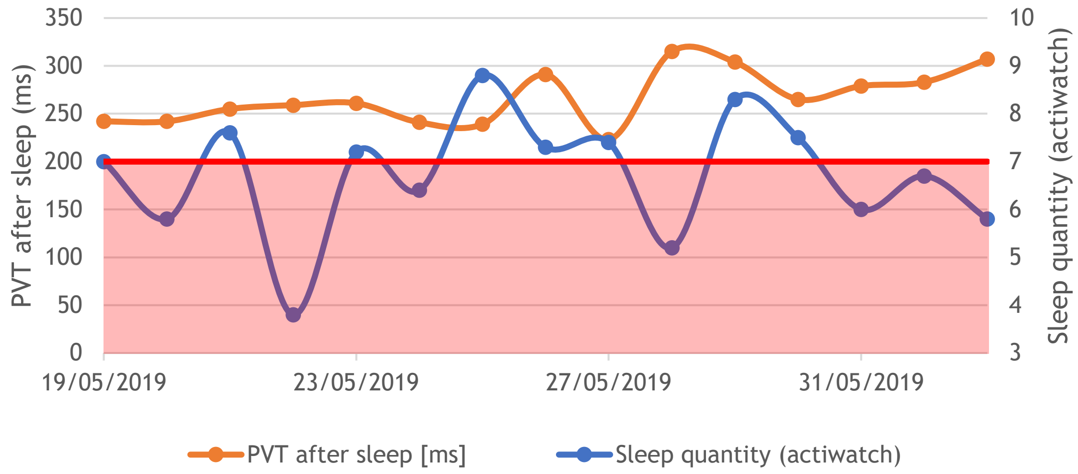

Figure 52 – Sleep quantity and PVT after sleep (Pilot 1) - Source: own elaboration

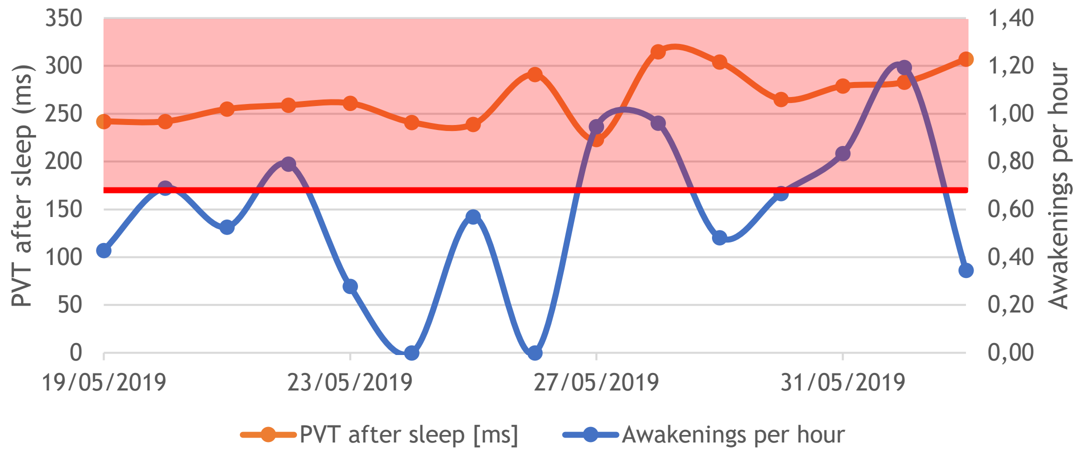

Figure 53 – Awakenings per hour and PVT after sleep (Pilot 1) - Source: own elaboration

Now looking to the results of the fatigue scale SPS and comparing it with the values of RTi from the PVT tests and SAFTE from the actiwatch it is possible to distinguish the difference from self-evaluation to objective data and see if the pilot is a poor judge of is performance. On Table 31 (where in blue are marked the days in which the pilot flew) and Figure 54 and Figure 55 sometimes is possible to notice correspondence on the rise of RTi follow up by the rise of the SPS level but, at the days of the highest RTi (315 ms and 307 ms, respectively) he classified himself as 4 (from 1 to 7) and in another day as 2, so he is a poor judge of himself.

Table 31 - Pilots performance measured by SAFTE™, SPS and PVT (Pilot 1) - Source: own elaboration

	SAFTE [%]	SPS after sleep	PVT after sleep [ms]	Reaction time slowed [%]	SPS before sleep	PVT before sleep [ms]	Reaction time slowed [%]
19/05/2019	91	1	242	-8.52	3	248	-11.21
20/05/2019	89	1	242	-8.52	2	227	-1.79
21/05/2019	90	2	255	-14.35	5		
22/05/2019	83	3	259	-16.14	3	240	-7.62
23/05/2019	89	2	261	-17.04	2	257	-15.25
24/05/2019	90	3	241	-8.07	3	253	-13.45
25/05/2019	94	2	239	-7.17	2	281	-26.01
26/05/2019	94	1	291	-30.49	2	275	-23.32
27/05/2019	92	1	223	0.00	2	233	-4.48
28/05/2019	88	4	315	-41.26	2	283	-26.91
29/05/2019	91	2	304	-36.32	2	288	-29.15
30/05/2019	93	2	265	-18.83	2	251	-12.56
31/05/2019	90	2	279	-25.11	2	318	-42.60
01/06/2019	88	2	283	-26.91	2	261	-17.04
02/06/2019	88	2	307	-37.67	2	290	-30.04

The difference between the best RTi value and the worse result of RTi from the morning PVT was 41.26% slower, and for the evening PVT was 42.60% slower. So, there were days where the risk of accident or serious error was elevated for this individual during his evaluation.

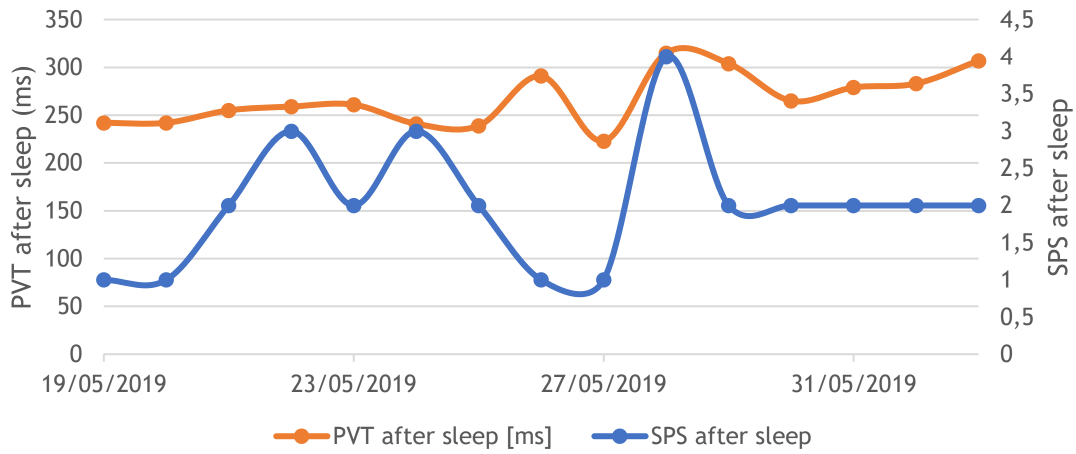

Figure 54 - PVT after sleep and SPS after sleep (Pilot 1) - Source: own elaboration

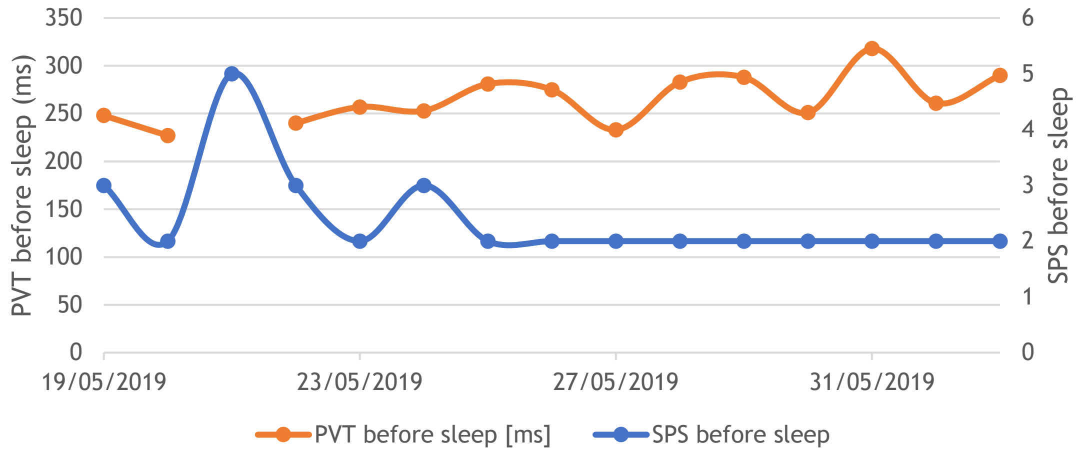

Figure 55 - PVT before sleep and SPS before sleep (Pilot 1) - Source: own elaboration

By comparing the data from the SPS before during and after the flight, with the SFATE alertness values and the PVT test before and after, it is possible to obtain an evolution of the pilot's fatigue level and its risk. Table 32 shows the condition of the pilot on the days in which he flew.

Table 32 – Data from flight days (Pilot 1) - Source: own elaboration

Flight (n°)	Date	Hour of flight	Duration [min]	Time slept [hours]	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	PVT before sleep [ms]
1	26/May	15:00	30	7.3	0	0.00	291	275
2	1/June	17:00	30	6.7	8	1.19	283	261

In the day of the first flight, the pilot had a good quantity and quality sleep but his RTi after sleep was 30.49% worse than the fastest PVT test. From the data of Table 33, there are no variations on the SPS level and the variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed a 10.75% increase in RTi. The pilot started and finished the flight with a level of low risk of accident or serious error since is RTi did not pass an 18% increase in RTi. There were no significant changes in the performance of the pilot due to cognitive fatigue.

Table 33 – Data from pilot 1 flight n°1 - Source: own elaboration

Flight n° 1	Before flight	During flight	After flight
Time [min]	0	15	30
SPS	1	1	1
SAFTE [%]	92.2	92.1	92
PVT [ms]	251		278

In the day of the second flight, the pilot had an almost good quantity, a poor-quality sleep and his RTi after sleep was 26.91% worse than the fastest PVT test. From the data of Table 34, there are no variations on the SPS level and the variations on the SAFTE are negligible but in an alertness zone with low risk. The RTi values of before and after flight showed a 5.57% improvement. The pilot started and finished the flight with a level of low risk of accident or serious error, since his RTi did not pass the 18% increase, and by the end of the flight was near de 5% of increase in RTi getting close to the level of very low risk of accident or serious error. There were no significant changes on the performance of the pilot due to cognitive fatigue but, it is noticeable that even with worse values of SAFTE score, the quantity of sleep and quality of sleep the RTi values were better than in the last (first) flight.

Table 34 - Data from pilot 1 flight nº2 - Source: own elaboration

Flight nº 2	Before flight	During flight	After flight
Time [min]	0	15	30
SPS	1	1	1
SAFTE [%]	88.4	88.7	89
PVT [ms]	251		237

- **Pilot 2:**

The pilot 2 has 48 years old and has 400 flight hours; he has exercise habits with an average of 37 min of exercise per day but, the caffeine and alcohol intake are not relevant. The sleep quantity and quality are presented in Table 36, Figure 56 and Figure 57. The data related to the pilot's performance, that is, alertness (SAFTE), reaction time and self-evaluation using SPS are presented in Table 37, Figure 58 and Figure 59. The results from flight days are presented in Table 38, Table 39, Table 40, Table 41 and Table 42.

Using the best RTi measured (236 ms) on the PVT tests and assuming it is the fastest RTi of this individual Table 35 - in advance in the text, was made in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 35 - Risk of accident or serious error classification by RTi (Pilot 2) - Source: own elaboration

Reaction time slowed [%]	RTi [ms]	Risk of accident or serious error
5%	247.80	Very low
18%	278.48	Low
34%	316.24	Elevated
55%	365.80	High
100%	472	Very high

Table 36 - Pilot 2 sleep quality, quantity and habits - Source: own elaboration

	Sleep quantity (actiwatch)	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	Exercise [hour]	Exercise time [min]
19/05/2019	5.4	3	0.56	236	0	0
20/05/2019	7.6	0	0.00	257	20:00	45
21/05/2019	8.3	0	0.00	262	20:00	60
22/05/2019	7.8	1	0.13	256	0	0
23/05/2019	7.2	1	0.14	255	18:30	60
24/05/2019	6.9	2	0.29	247	0	0
25/05/2019	6.3	2	0.32	259	0	0
26/05/2019	7.8	8	1.03	246	0	0
27/05/2019	6.5	3	0.46	257	19:00	45
28/05/2019	6.8	2	0.29	269	0	0
29/05/2019	6.6	2	0.30	320	18:00	60
30/05/2019	7.5	3	0.40	249	19:00	30
31/05/2019	5.8	1	0.17	287	0	0
01/06/2019	6.9	7	1.01			

As seen in Table 36, Figure 56 and Figure 57 (where the red area shown on the figures represent the zones where the sleep quantity or quality have bad values), the RTi of pilot 2 changes more frequently with the quantity of sleep than the quality. In average his RTi after waking is 261.54 ms that is 10.82% slower than the fastest morning PVT (236 ms) and before going to sleep his RTi has an average value of 258.15 ms that is 9.38% slower. His average awakenings per hour (quality) is 0.36/hour that is below the normal value of 0.37/hour for a good quality sleep. His sleep quantity has an average value of 6.96 hours that is almost at the recommend values that range between 7 and 9 hours. The average value of SAFTE^{TM} alertness is at 93 % which is a high level of alertness and translates a very low risk of accident or serious error.

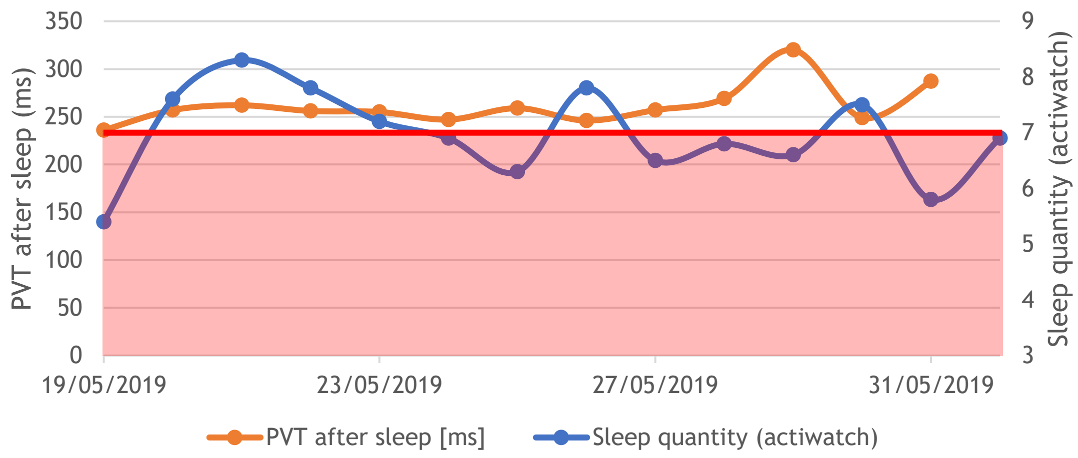

Figure 56 - Sleep quantity and PVT after sleep (Pilot 2) - Source: own elaboration

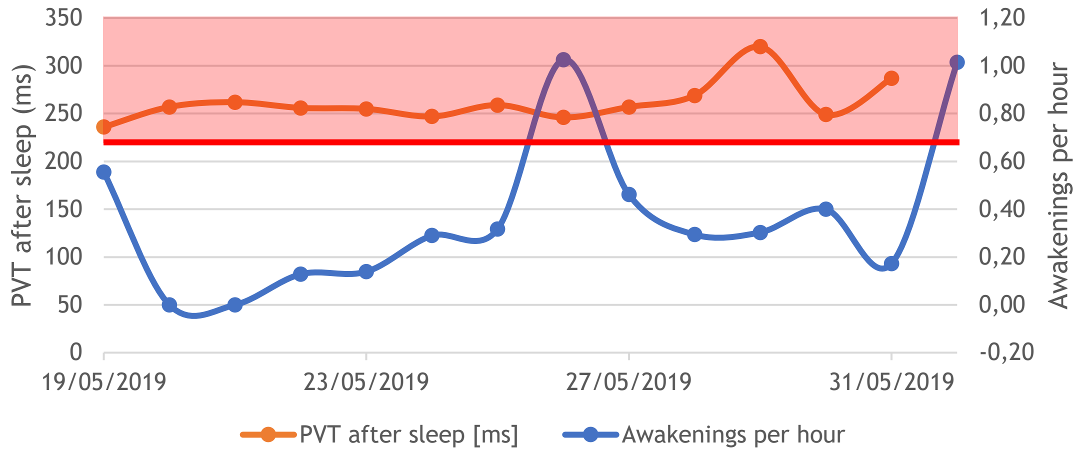

Figure 57 - Awakenings per hour and PVT after sleep (Pilot 2) - Source: own elaboration

On Table 37 (where in blue are marked the days in which the pilot flew) and Figure 58 and Figure 59 is possible to notice that the changes in the values of RTi do not have any effect on the individual self-evaluation so, it can be concluded that the individual is a poor judge of is state of fatigue.

Table 37 - Pilots performance measured by SAFTE^{TM}, SPS and PVT (Pilot 2) - Source: own elaboration

	SAFTE [%]	SPS after sleep	PVT after sleep [ms]	Reaction time slowed [%]	SPS before sleep	PVT before sleep [ms]	Reaction time slowed [%]
19/05/2019	94	2	236	0.00	1	242	-2.54
20/05/2019	95	2	257	-8.90	1	239	-1.27
21/05/2019	96	2	262	-11.02	1	243	-2.97
22/05/2019	96	2	256	-8.47	2	246	-4.24
23/05/2019	95	2	255	-8.05	2	314	-33.05
24/05/2019	94	2	247	-4.66	2	244	-3.39
25/05/2019	92	2	259	-9.75	2	256	-8.47
26/05/2019	93	2	246	-4.24	2	288	-22.03
27/05/2019	92	2	257	-8.90	2	247	-4.66
28/05/2019	92	2	269	-13.98	2	256	-8.47
29/05/2019	91	2	320	-35.59	2	239	-1.27
30/05/2019	92	2	249	-5.51	2	276	-16.95
31/05/2019	90	2	287	-21.61	2	266	-12.71
01/06/2019	90						

The difference between the best RTi value and the worse result of RTi from the morning PVT was 35.59% slower and for the before sleep PVT was 33.05% slower. So, there were days where the risk of accident or serious error was elevated for this individual during his evaluation, but with a lower risk that the pilot 1.

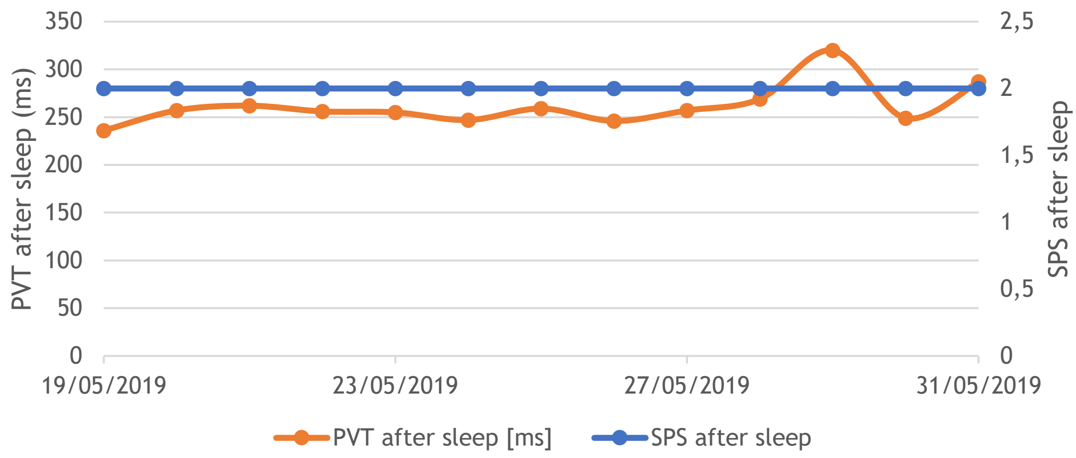

Figure 58 - PVT after sleep and SPS after sleep (Pilot 2) - Source: own elaboration

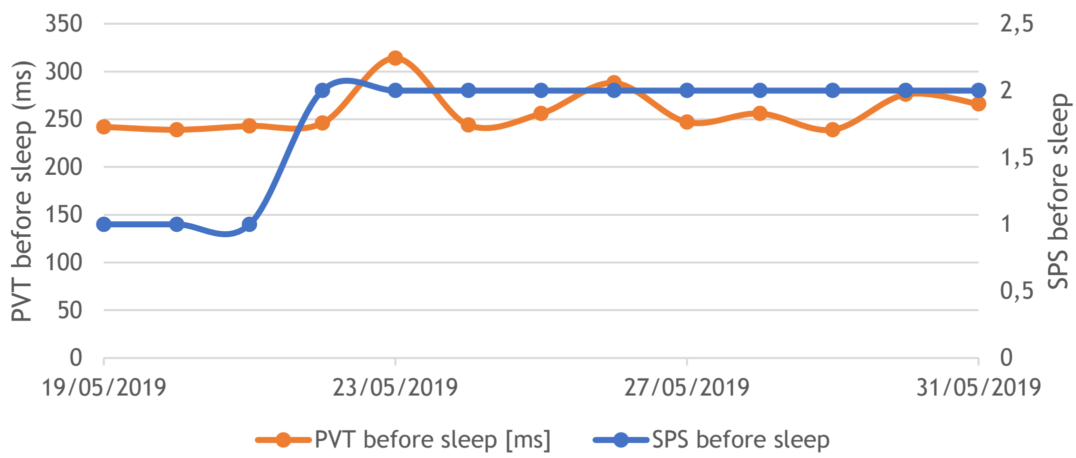

Figure 59 - PVT before sleep and SPS before sleep (Pilot 2) - Source: own elaboration

Table 38 shows the condition of the pilot 2 on the days in which he flew.

Table 38 - Data from flight days (Pilot 2) - Source: own elaboration

Flight (n°)	Date	Hour of flight	Duration [min]	Time slept [hours]	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	PVT before sleep [ms]
1	22/May	11:00	60	7.8	1	0.13	256	246
2	25/May	17:00	30	6.3	2	0.32	259	256

3	31/May	18:00	30	5.8	1	0.17	287	266
4	1/June	18:00	30	6.9	7	1.01		

In the day of the first flight, the pilot had a good sleep quantity and quality and his RTi after sleep was 8.47% worse than the fastest PVT test. From the data of Table 39, there are no variations on the SPS level but, he evaluated himself with some level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed a 1.19% decrease in RTi. The pilot started and finished the flight with a level of low risk of accident or serious error since is RTi did not pass an 18% increase in RTi and his final value was really near the 5% mark that is as very low risk of accident or serious error. There were no significant changes in the performance of the pilot due to cognitive fatigue.

Table 39 - Data from pilot 2 flight n°1 - Source: own elaboration

Flight n° 1	Before flight	During flight			After flight
Time [min]	0	15	30	45	60
SPS	2	2	2	2	2
SAFTE [%]	98.2	98.2	98.1	98	97.8
PVT [ms]	251				248

The second day of the flight the pilot had a good sleep quantity and quality and his RTi after sleep was 9.75% worse than the fastest PVT test. From the data of Table 40, there are no variations on the SPS level but he evaluated himself with some level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed 2.59% increase in RTi. The pilot started and finished the flight with a level of low risk of accident or serious error since is RTi did not pass an 18% increase, but his final value was really near that mark that would increase the risk of accident or serious error to “elevated”. There were no significant changes on the performance of the pilot due to cognitive fatigue but, the pilot was already fatigated on the beginning of the flight and after the flight, as he almost presented an elevated risk of accident or serious error.

Table 40 - Data from pilot 2 flight n°2 - Source: own elaboration

Flight n° 2	Before flight	During flight	After flight
Time [min]	0		30
SPS	2		2
SAFTE [%]	92		92.4
PVT [ms]	270		277

The third day of flight the pilot had a poor quantity but a good quality of sleep and his RTi after sleep was 21.61% worse than the fastest PVT test. From the data of Table 41, there are no variations on the SPS level but, he evaluated himself with some level of fatigue. The variations on the SAFTE are from a reduced alertness zone to a high alertness zone but in low to very low risk. The RTi values of the before and after flight showed 1.10% increase in RTi; however, his values end near the point of passing from a low level of risk to an elevated level of risk. There were no significant changes on the performance of the pilot due to cognitive fatigue but, the pilot was already fatigated on the beginning of the flight, more than the last (second) flight, and after this flight he almost presented an elevated risk of accident or serious error just like the previous (second) flight.

Table 41 - Data from pilot 2 flight nº3 - Source: own elaboration

Flight nº 3	Before flight	During flight	After flight
Time [min]	0		30
SPS	2		2
SAFTE [%]	89.8		90.4
PVT [ms]	272		275

On the fourth flight, the pilot had a poor quantity but almost good and a poor-quality of sleep and there are no values for the PVT test. From the data of Table 42, there are no variations on the SPS level but he evaluated himself with some level of fatigue. The are no values on the SAFTE alertness score. The RTi values of the before and after flight showed 1.49% increase in RTi; his values were better than the last two flights (second and third) but worse than the first one. The level of risk from RTi values had a low level of risk. There were no significant changes on the performance of the pilot due to cognitive fatigue but, the pilot was already fatigated on the beginning of the flight and his risk level remained the same, with a low level of risk.

Table 42 - Data from pilot 2 flight nº4 - Source: own elaboration

Flight nº 4	Before flight	During flight	After flight
Time [min]	0		30
SPS	2		2
SAFTE [%]			
PVT [ms]	268		272

- **Pilot 3:**

The pilot 3 has 32 years old and has 180 flight hours; he has a high caffeine intake of 4.08 (average) coffees per day but no alcohol or exercise habits. The sleep quantity and quality are presented in Table 44, Figure 60 and Figure 61. The data related to the pilot’s performance, that is, alertness (SAFTE), reaction time and self-evaluation using SPS are presented in Table 45, Figure 62 and Figure 63. The results from flight days are presented in Table 46, Table 47, Table 48, Table 49 and Table 50.

Using the best RTi measured (240 ms) on the PVT tests and assuming it is the fastest RTi of this individual Table 43 – in advance in the text, was made in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 43 - Risk of accident or serious error classification by RTi (Pilot 3) - Source: own elaboration

Reaction time slowed [%]	RTi [ms]	Risk of accident or serious error
5%	252.0	Very low
18%	283.2	Low
34%	321.6	Elevated
55%	372.0	High
100%	480	Very high

Table 44 - Pilot 3 sleep quality, quantity and habits - Source: own elaboration

	Sleep quantity (actiwatch)	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	Caffeine
19/05/2019	5.8	3	0.52	292	3
20/05/2019	7.8	5	0.64	281	4
21/05/2019	7.4	3	0.41	327	4
22/05/2019	7.8	3	0.38	291	5
23/05/2019	5.6	4	0.71	325	3
24/05/2019	5.6	3	0.54	301	5
25/05/2019	4.4	2	0.45	242	4
26/05/2019	7.3	4	0.55	260	4
27/05/2019	7.3	2	0.27	302	5
28/05/2019	6.4	1	0.16	306	3
29/05/2019	6.4	4	0.63	292	4
30/05/2019	3.6	0	0.00	260	4
31/05/2019	6	7	1.17	242	5
01/06/2019	7.3	3	0.41		

On Table 44, Figure 60 and Figure 61 (where the red area shown on the figures represent the zones where the sleep quantity or quality have bad values), the RTi of pilot 3 in morning suffer changes more frequently with the quantity of sleep than the quality. In the 30 of May, he had 3.6 hours (bad quality) of sleep but 0 awakenings (good quality) and still had a recovery of 28.27% from the PVT test on the night before to the PVT test in the morning. In average his RTi after waking is 286.23 ms that is 19.26% slower than the fastest morning PVT (240 ms) and before going to sleep his RTi has an average value of 318.54 ms that is 32.72% slower. His average awakenings per hour (quality) is 0.49/hour that is over the normal value of 0.37/hour for a good quality sleep but, under the value of 0.68 that is the reference point where the bad quality starts. His sleep quantity has an average value of 6.34 hours that is not far from the recommended values that range between 7 to 9 hours. The average value of SAFTE™ alertness is at 88.5 % which is a reduced level of alertness and has a low risk of accident or serious error.

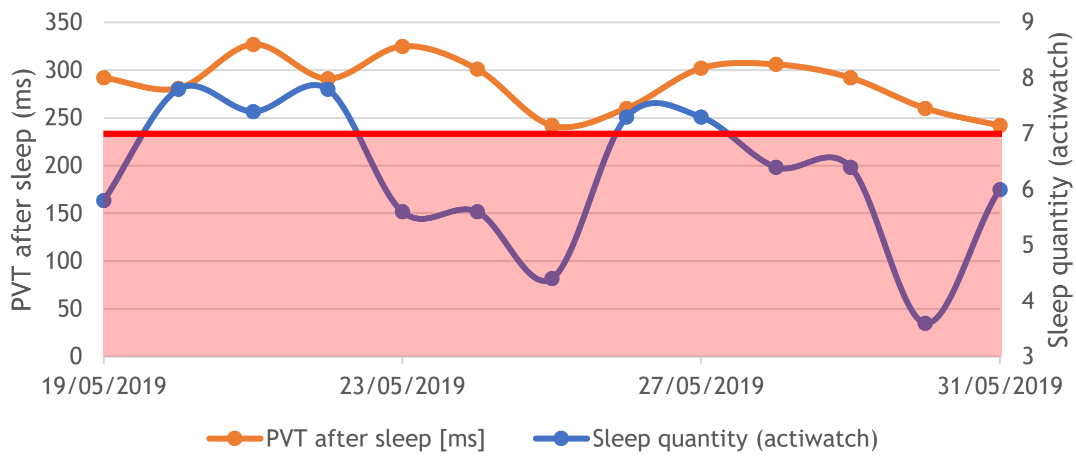

Figure 60 - Sleep quantity and PVT after sleep (Pilot 3) - Source: own elaboration

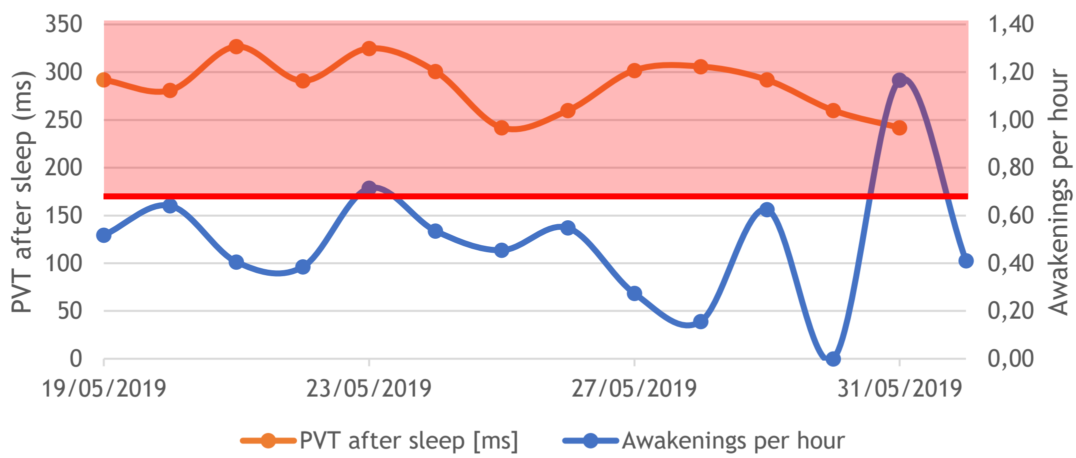

Figure 61 - Awakenings per hour and PVT after sleep (Pilot 3) - Source: own elaboration

On Table 45 (where in blue are marked the days in which the pilot flew) and Figure 62 and Figure 63 is possible to notice that the changes on the values of RTi have a small to no effect on the individual self-evaluation, so it can be concluded that the individual is a poor judge of his state of fatigue; however is an individual with high levels of cumulative fatigue.

Table 45 - Pilots performance measured by SAFTE™, SPS and PVT (Pilot 3) - Source: own elaboration

	SAFTE [%]	SPS after sleep	PVT after sleep [ms]	Reaction time slowed [%]	SPS before sleep	PVT before sleep [ms]	Reaction time slowed [%]
19/05/2019	92	3	292	-21.67	4	327	-36.25
20/05/2019	91	2	281	-17.08	2	291	-21.25
21/05/2019	93	2	327	-36.25	3	342	-42.50
22/05/2019	94	2	291	-21.25	3	327	-36.25
23/05/2019	89	3	325	-35.42	6	374	-55.83
24/05/2019	87	4	301	-25.42	6	388	-61.67
25/05/2019	83	2	242	-0.83	4	325	-35.42
26/05/2019	88	2	260	-8.33	3	288	-20.00
27/05/2019	90	2	302	-25.83	2	301	-25.42
28/05/2019	90	5	306	-27.50	6	314	-30.83
29/05/2019	89	6	292	-21.67	6	327	-36.25
30/05/2019	82	3	260	-8.33	4	287	-19.58
31/05/2019	83	2	242	-0.83	2	250	-4.17
01/06/2019	88						

The difference between the best RTi value and the worse result of RTi from the morning PVT was 36.25% slower and for the before sleep PVT was 61.67% slower. So, there were days where the risk of accident or serious error was very high and with the highest risk comparing with the other 2 (previous analyzed) pilots.

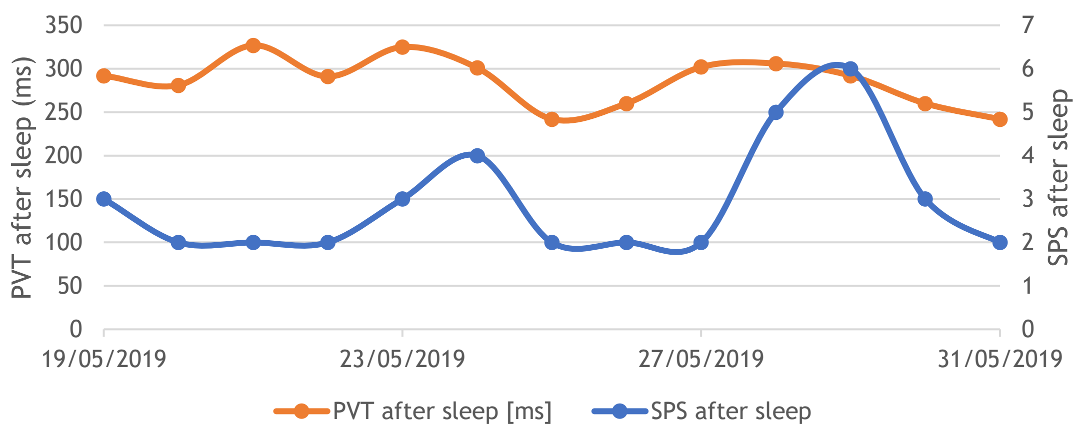

Figure 62 - PVT after sleep and SPS after sleep (Pilot 3) - Source: own elaboration

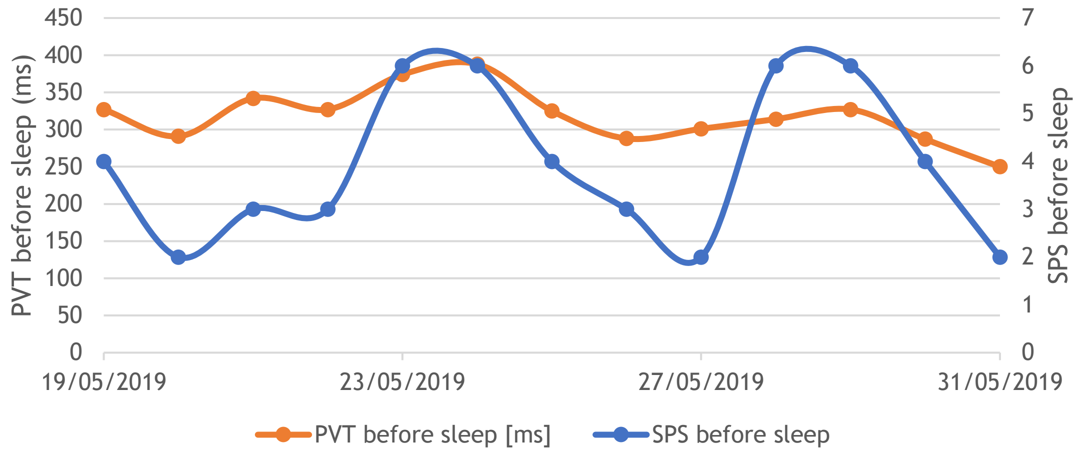

Figure 63 - PVT after sleep and SPS after sleep (Pilot 3) - Source: own elaboration

In Table 46 are presented the condition of the pilot on the days in which he flew.

Table 46 - Data from flight days (Pilot 3) - Source: own elaboration

Flight (nº)	Date	Hour of flight	Duration [min]	Time slept [hours]	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	PVT before sleep [ms]	Caffeine
1	21/May	09:00	50	7.4	3	0.41	327	342	4
2	30/May	19:00	55	3.6	0	0.00	260	287	4
3	1/June	17:30	40	7.3	3	0.41			
4	1/June	20:00	20						

In the first flight, the pilot had a good quantity and an intermediate quality sleep. His RTi after sleep was 36.25% worse than the fastest PVT test. From the data of Table 47, there are no variations on the SPS level but, he evaluated himself with some to no level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed a 29.07% decrease in RTi. The pilot started with a high risk of accident or serious error and finished the flight with a very low, since is RTi pass an 34% increase in RTi and his final value was below the 5% mark that means a very low risk of accident or serious error. The pilot started the flight with a high level of risk but during the flight was able to recover to a very low risk; it is very likely that his caffeine intake was a mitigating factor in the recovery from his high level of fatigue.

Table 47 - Data from pilot 3 flight n°1 - Source: own elaboration

Flight n° 1	**Before flight**	**During flight**		**After flight**
Time [min]	0	15	30	50
SPS	2	1	1	1
SAFTE [%]	92.3	93.2	94.1	94.7
PVT [ms]	344			244

In flight number 2 the pilot had a bad quantity and a good quality of sleep that, as referred before, had a great recovery from his last (previous) day. His RTi after sleep was 8.33% worse than the fastest PVT test. From the data of Table 48, there are no variations on the SPS level but, he evaluated himself with some to no level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with low risk of accident or serious error. The RTi values of the before and after flight showed a 4% decrease in RTi. The pilot started and finished with a very low risk of accident or serious error since his RTi did not pass the 5% increase in RTi. There were no significant changes in the performance of the pilot due to cognitive fatigue but, the pilot was with a very low level of risk during his flight; so, cognitive fatigue did not have an effect in this flight but, as in the last (previous) flight the caffeine must have been a mitigating factor in regulation of fatigue.

Table 48 - Data from pilot 3 flight n°2 - Source: own elaboration

Flight n° 2	**Before flight**	**During flight**		**After flight**
Time [min]	0	15	30	55
SPS	2	1	1	1
SAFTE [%]	82.7	83	83.4	84
PVT [ms]	250			240

In flight number three the pilot had a good quantity and an intermediate quality sleep. There were no values for his RTi after and before sleep. From the data of Table 49, there are no variations on the SPS level but, he evaluated himself with no level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with low risk. The RTi values of the before and after flight showed a 3.78% increase in RTi. The pilot started and finished with a low risk of accident or serious error since his RTi did not pass an 34% increase in RTi but was above the 18% increase mark. There were no significant changes on the performance of the pilot due to cognitive fatigue but, the pilot was with a low level of risk during his flight; there were no data on the caffeine consumption, so it is not possible to know if it was used as a mitigating factor.

Table 49 - Data from pilot 3 flight nº3 - Source: own elaboration

Flight nº 3	Before flight	During flight	After flight
Time [min]	0	15	40
SPS	1	1	1
SAFTE [%]	87.3	87.5	87.9
PVT [ms]	264		274

The fourth flight was executed in the same days as the third flight, so the conditions before flight were the same in terms of sleep quantity and quality. The RTi value to have in the mind is the one at the end of his last (third) flight, since it is the last available data of his performance. In the last (third) flight his performance in terms of RTi slowed, but from the data of Table 50 the RTi values of the before and after flight show a 2.5% increase RTI, but in an alertness zone with very low risk contrary to the last (third) flight. Between the last (third) and this flight, the pilot recovers his values of RTi but this time there are no data on caffeine consumption, so it is not possible to presume if this recover was made with caffeine as a mitigating factor or not. There were no variations on the SPS level and the variations on the SAFTE are negligible. There were no significant changes in the performance of the pilot due to cognitive fatigue since he remained with good values in all evaluated aspects during his flight.

Table 50 - Data from pilot 3 flight nº4 - Source: own elaboration

Flight nº 4	Before flight	During flight	After flight
Time [min]	0		20
SPS	1		1
SAFTE [%]	90.3		90.7
PVT [ms]	240		246

- **Pilot 1, Pilot 2, Pilot 3 - Comments:**

In Table 51 are depicted all average values of fatigue performance measurement for the three pilots.

Table 51 – Average values of all tested pilots - Source: own elaboration

	Pilot n° 1	Pilot n° 2	Pilot n° 3	Total average
Age	33	48	32	
Flight hours	240	400	180	
Mean flight time	30	37.5	41.25	36.25
Coffee intake (average per day)	0	0.23	4.08	
Physical Exercise time [min]	0	37	0	
PVT after waking up [ms]	267.07	261.54	286.23	
SPS after sleep	2	2	2.92	
PVT before going to sleep [ms]	264.64	258.15	318.54	
SPS before sleep	2.4	1.77	3.92	
PVT before flight [ms]	251	265.25	274.5	
PVT after flight [ms]	257.5	268	251	
Sleep Hours [hours]	6.72	6.96	6.34	6.67
Awakenings per hour	0.58	0.36	0.49	0.48
SAFTE [%]	90	93	88.5	90.50

Getting enough sleep (both quantity and quality) on a regular basis is essential for restoring the brain and body, but looking at the values on Table 51 the average sleep quantity is below what is aspect from a good quantity sleep (7-9 hours). Thus, in terms of quality of sleep, the Pilot 1 and Pilot 3 have an intermediate quality level and Pilot 2 has a good quality. Still, when looking at RTi values from the PVT tests the effects of the quality and quantity of sleep does not show direct impacts partly because of other factors like:

- the quantity of exercise in pilot 2 seems to influence is RTi, increasing his values on days that he practices exercise;
- the caffeine consumption on pilot 3 seems to hide his levels of fatigue showing better RTi values.

In Pilot 1 were no interferences in his performance due to the factors taken into consideration during the trial tests (caffeine, alcohol, naps and exercise time). The slowest in terms of RTi was Pilot 3 that is the one with worse sleep quantity and highest SPS scores; on average SAFTE level had a low risk of accident or serious error. The Pilot 1 and Pilot 2 had an average SAFTE level of very low risk of accident or serious error. We found any correspondence between their real fatigue and SPS scores nor were the pilots old enough to be observed an influence of age on the RTi values.

It is very perceptible that these pilots have problems of cumulative fatigue that sometimes are reduced with sleep of good quantity and quality but not enough to solve the problem. Only Pilot 3 showed values of RTi before the flight that were on the range of elevated risk of accident or serious error and could compromise his safety. The other two pilots only had levels of very low to low risk level of an accident or serious error. The workload of these pilots from their day-to-day labour activity had great impacts on their RTi and sleep but there was not enough data on this parameter to determine how great he impacted on their levels of fatigue.

5.4. Conclusion

The times/periods of flight were short and so was not possible to get big variations on the results, but it was possible to see the presence and evolution of fatigue and how it reflects on the values of RTi. The results of the survey were also very important because they show that the pilots are attentive to the factor of cognitive fatigue and that some of them seem to suffer from some of its effects.

Chapter 6

Conclusions

6.1. Dissertation Conclusions

The HF has always been a big concern in the aviation sector and even more for the sub-sectors that have almost none to none regulation to attenuate the problems associated with the “Human” element.

At the beginning of this dissertation, a study was made to understand the HF that had caused more accidents or incidents in Portugal. From this study we concluded that most occurrences had has one of their causes on the level 1 of HFACS “Unsafe Acts” that are related to cognitive fatigue as showed on Sub-Chapter 2.5.3. Then it was set that the objective of this dissertation would be to understand if cognitive fatigue can be the cause of occurrences on general aviation. It was also set that one of the objectives would be the understanding of the evolution of this fatigue and what factors had more impact on the performance of pilots, during the operation of an ultralight aircraft, as well as, what was the pilot’s perception of his own fatigue.

With these objectives set, contextualization of the theme was made, always trying to use information established by the ICAO from where we took the scientific principles for fatigue management. With the scientific base made, we chose the methods for the evaluation of pilots’ fatigue. Simultaneously a survey was applied to the Portuguese community of General Aviation pilots to understand the real importance on this subject.

From this survey we realize that most of the 41 participants had an almost good quantity sleep and a good quality sleep, they consider alcohol and sleep time to be the factors that most affect fatigue levels, and that most of them had already experienced cognitive fatigue during a flight. Most of the surveyed individuals did not fly on days where they had labour activities not related to the operation of aircrafts. From the survey it was also perceivable that some of the inquired individuals showed problems related with cognitive fatigue.

Our case study was conducted with 3 general aviation pilots, we called Pilot 1, 2 and 3, whose identification is not done in the dissertation but their main physical characteristics and habits. The case study evidences the influence of caffeine and physical exercise on the performance of pilots, and that caffeine disguised the performance of an individual and physical exercise worsens one’s levels of performance. It was also perceivable the effects of sleep quantity and quality on performance and recovery of fatigue.

The pilots that participated in this study had normal lives during the test period, and even so it was possible to observe the cumulative fatigue accumulated by these individuals. It was not possible to go deep in the theme of cumulative fatigue since there were no data related to the workload of the day-to-day labour activities executed by these pilots.

From the data collected was not possible to see any relations between the self-evaluation fatigue scale SPS and the objective data from the PVT test and the SAFTE alertness scores. Except the fact that on some of more extreme days of fatigue it impacted on the values of SPS.

Before, during and after the flights the levels of SAFTE score never passed the point of lower risk of accident or serious error, but this can be explained by the short periods of flight made in this type of aviation, particularly by our test pilots. On the PVT tests, some pilots had values that may consider them near or in the elevated risk of accident or serious error but in most cases, they remained on the spectrum of very low to low risk.

A very important conclusion of this dissertation is that most individuals that fly in this segment of aviation have normal lives and jobs that promotes some type of cumulative fatigue in their bodies, due to work schedules, restriction of sleep hours and workloads, so it is up to the pilot to understand his condition before operating an aircraft. And here is the biggest problem concerning safety because all our pilots were poor judges of their performance. So, cognitive fatigue can be a cause or one of the causes of occurrences related to unsafe acts on the segment of general aviation - as depicted, for example, from Pilot 3 data.

6.2. Concluding Remarks

The objectives of this dissertation were fulfilled since it was perceptible that the impact of cognitive fatigue can be a contributory factor on the occurrence of incidents and accidents. It was also interpreted the evolution of cognitive fatigue, and its impact in the pilot performance throughout the day and during the operation of the aircraft. If it was possible to have more factors under evaluation it would have been more perceptible how this type of fatigue evolves and with a greater number of subjects, it would be possible to make more conclusive affirmations. The comparison of the fatigue experienced by the individuals and the real deterioration of their alertness measured by the equipment utilized was not conclusive and it was not possible to see any correlation, but the use of a more diversified group of subjects and flights would have made possible new lines of conclusions.

From this work it prepared and submitted an abstract and future paper that has been accepted for presentation at the VII RIDITA – Air Transportation Sustainability: Technological, Operational, Economic, Social and Environmental Strategies, to be held in Covilhã, October 9-11, 2019 (Annexe 3).

6.3. Prospects for Future Work

During the development of this dissertation, some topics were recognized as useful to implement in future research works so that it is possible to better understand the evolution of cognitive fatigue and the impact of several factors on it. Thus, the next steps should cross the following research lines:

- To add more factors such as workload, and meal time and its composure, since both have considerable impacts on one's level of fatigue;
- To add more flights and test pilots so that it could be drawn more conclusive results;
- To use pilots from both genders, with a wider range of age;
- To Incorporate other methods for measuring fatigue with lower associated errors.

References

[1] W. Rankin, "MEDA Investigation Process," *AERO QTR_02*, pp. 14–21, 2007.

[2] D. A. Wiegmann and S. A. Shappell, "A Human Error Analysis of Commercial Aviation Accidents Using the Human Factors Analysis and Classification System (HFACS)," 2001.

[3] "SÍNTESE DOS ACIDENTES E INCIDENTES COM AERONAVES CIVIS," *GPIAAF – Unidade de Aviação Civil*. [Online]. Available: http://www.gpiaa.gov.pt/. [Accessed: 25-Jul-2018].

[4] SKYbrary, "Fatigue." [Online]. Available: https://www.skybrary.aero/index.php/Fatigue. [Accessed: 20-Sep-2018].

[5] ICAO, "Fatigue Management." 2013.

[6] International Civil Aviation Organization (ICAO), IFALPA, and IATA, *Fatigue Management Guide for Airline Operators*, 2nd ed. 2015.

[7] Fatigue Science, *The Science of Sleep and Workplace Fatigue Technology to Combat Fatigue at Work*. .

[8] A. C. Casaleiro Coelho, "Psychophysiological Factors Analysis in Unpressurized Aircraft Cabins," University of Beira interior, 2014.

[9] S. Zorro, "Pilots Performance and Flight Safety. Flight Physiology in Unpressurized Aircraft Cabins," University of Beira Interior, 2012.

[10] A. Marques, "Unpressurized Light Aviation Aircrafts. Flight and Physiological Data Acquisition System," University of Beira Interior, 2012.

[11] L. Rocha, "Desempenho de Pilotos e Segurança de Voo: O Caso da Hipoxia em Aviação Desportiva," University of Beira Interior, 2011.

[12] International Civil Aviation Organization, "Fundamental Human Factors concepts," *Circular 216-AN/131 Human Factors Digest No. 1*, no. 1. 1989.

[13] SKYbrary, "The Human Factors 'Dirty Dozen.'" [Online]. Available: https://www.skybrary.aero/index.php/The_Human_Factors_%22Dirty_Dozen%22. [Accessed: 20-Sep-2018].

[14] I. C. A. Organization, "Annex 13 Aircraft Accident and Incident Investigation," 2016.

[15] S. A. Shappell and D. A. Wiegmann, “The Human Factors Analysis and Classification System – HFACS,” 2000.

[16] J. Reason, *Human Error*. Cambridge University Press, 1990.

[17] GPIAAF, “Aterragem dura em sequência de porpoise landing || Hard landing during a porpoise landing,” 2016.

[18] J. A. Wise, V. D. Hopkin, and J. Garland, *Handbook of Aviation Human Factors. Second Edition*. 2010.

[19] A. Isaac, “Dying for a rest: how much of a problem is fatigue?,” *Hind Sight*, no. 13, 2011.

[20] P. Suarez and N. Suarez, “Where is my workload? Identifying hot spots,” *Hind Sight*, no. 21, pp. 58–61, 2015.

[21] M. Millar, “Measuring Fatigue,” in *Asia-Pacific FRMS Seminar*, 2012, vol. 1.

[22] V. J. Gawron, “Overview of Self-Reported Measures of Fatigue,” *Int. J. Aviat. Psychol.*, vol. 26, pp. 120–131, 2016.

[23] National Sleep Foundation, “Sleep Diary.” [Online]. Available: https://www.sleepfoundation.org/content/nsf-official-sleep-diary. [Accessed: 25-Oct-2018].

[24] “Sleep-2-Peak.” [Online]. Available: https://sleep-2-peak.com/. [Accessed: 30-Oct-2018].

[25] J. F. Brunet, D. Dagenais, M. Therrien, D. Gartenberg, and G. Forest, “Validation of sleep-2-Peak: A smartphone application that can detect fatigue-related changes in reaction times during sleep deprivation,” 2016.

[26] Fatigue Science, *Readiband 5 Research Specalog*. .

[27] “Fatigue Science.” [Online]. Available: https://www.fatiguescience.com/. [Accessed: 15-Aug-2018].

[28] P. Russell, C.A., Caldwell, J.A., Arand, D., Myers, L.J., Wubbels and H. Downs, “Validation of the Fatigue Science ReadiBand ™,” pp. 1–10.

[29] Fatigue Science, “INDIVIDUAL SLEEP AND EFFECTIVENESS ANALYSIS.”

[30] P. G. Roma, S. R. Hursh, A. M. Mead, and T. E. Nesthus, “Flight Attendant Work/Rest Patterns, Alertness, and Performance Assessment: Field Validation of Biomathematical Fatigue Modeling,” 2012.

Annexe 1- Survey

Fadiga cognitiva na aviação

Este inquérito é de preenchimento voluntário e destina-se a pilotos de aviação com licença válida, independente da classe ou tipo da mesma. Insere-se no âmbito da Dissertação de Mestrado em Engenharia Aeronáutica de João Artur de Freitas Rocha na Universidade da Beira Interior, sob orientação científica do Professor Doutor Jorge Miguel dos Reis Silva.
O objetivo do inquérito é a recolha de informação sobre o impacto da fadiga cognitiva nesses pilotos .
Caso surja alguma dúvida no preenchimento deste inquérito não hesite em enviar um e-mail para joao.rocha@ubi.pt.
Desde já agradecemos a sua colaboração.

Nota sobre privacidade:
Este inquérito é anónimo. O registo guardado das suas respostas ao inquérito não contém nenhuma informação indicativa do seu autor.

1. **Data de nascimento**

   Example: December 15, 2012

2. **Qual o seu género?**
   Mark only one oval.

   ◯ Feminino
   ◯ Masculino

3. **A sua atividade profissional principal relaciona-se com a aviação?**
   Mark only one oval.

   ◯ Sim
   ◯ Não

4. **A actividade que desempenha como piloto insere-se em qual ou quais destas categorias?**
   Check all that apply.

   ☐ Aviação Geral
   ☐ Aviação Militar
   ☐ Transporte aéreo internacional
   ☐ Transporte aéreo regional
   ☐ Taxi-aéreo
   ☐ Corporate

5. **Qual ou quais os tipos de licenças de voo que possui?**
Check all that apply.

- [ ] Piloto de ultraleve
- [ ] Piloto de planador
- [ ] Piloto particular de avião
- [ ] Piloto particular de helicóptero
- [ ] Piloto particular de motoplanador
- [ ] Piloto particular de balão
- [ ] Piloto comercial de avião
- [ ] Piloto comercial de helicóptero
- [ ] Piloto comercial de balão
- [ ] Piloto de linha aérea de avião
- [ ] Piloto de linha aérea de helicóptero
- [ ] Instrutor de voo de ultraleves
- [ ] Instrutor de voo de ligeiros
- [ ] Instrutor de voo de linha aérea
- [ ] Instrutor de voo com instrumentos

6. **Que classe de licença médica que detém actualmente?**
Mark only one oval.

- ( ) Classe 1
- ( ) Classe 2
- ( ) Classe 3

7. **Que fatores considera que poderiam influenciar negativamente o seu estado de alerta?**
Check all that apply.

- [ ] nicotina
- [ ] hora de refeição
- [ ] medicação
- [ ] álcool
- [ ] cafeína
- [ ] horas de sono

8. **A fadiga cognitiva é a fadiga que leva à redução do nível de alerta, do tempo de reação e de tomada de decisão, prejudicando o desempenho. Acha que o controlo da fadiga cognitiva é importante na prevenção de ocorrências?**
Mark only one oval.

- ( ) Sim
- ( ) Não

9. **Alguma vez sentiu uma falha no seu desempenho enquanto piloto devido a fadiga cognitiva?**
Mark only one oval.

- ( ) Sim
- ( ) Não

10. **Caso se sinta cansado antes de um voo, que planeou previamente, teria esse fator em consideração para uma eventual desistência de voar?**
Mark only one oval.

- Sim
- Não

11. **Costuma pilotar em dias em que exerce a sua atividade laboral habitual?**
Mark only one oval.

- Sim
- Não
- As vezes
- A minha atividade laboral inclui a pilotagem

12. **A que horas do dia costuma efetuar os seus voos?**

Example: 8:30 AM

13. **Quanto tempo em média costuma voar?**

Example: 8:30 AM

14. **De 1 a 7, antes de um voo, como caracteriza o seu nível de fadiga cognitiva?**
Mark only one oval.

- 1-completamente alerta e acordado
- 2-muito alerta mas não completamente
- 3-ligeiramente alerta
- 4-alguma sensação de cansaço, não muito alerta
- 5-moderadamente cansado
- 6-extremamente cansado
- 7-completamente exausto, incapaz de reagir e trabalhar eficientemente

15. **De 1 a 7, após um voo, como caracteriza o seu nível de fadiga cognitiva?**
Mark only one oval.

- 1-completamente alerta e acordado
- 2-muito alerta mas não completamente
- 3-ligeiramente alerta
- 4-alguma sensação de cansaço, não muito alerta
- 5-moderadamente cansado
- 6-extremamente cansado
- 7-completamente exausto, incapaz de reagir e trabalhar eficientemente

16. **Quantas horas costuma dormir por noite?**
Mark only one oval.

- <4
- 4-5
- 5-6
- 6-7
- 7-8
- >8

17. **Quantas vezes acorda em média por noite?**
Mark only one oval.

- nenhuma
- 1
- 2
- 3
- 4
- >4

18. **Ao acordar pela manhã sente dificuldade em iniciar a sua rotina diária?**
Mark only one oval.

- Sim
- Não

19. **Após uma noite de sono sente que não descansou o suficiente?**
Mark only one oval.

- Sim
- Não

20. **Costuma sentir sonolência durante o dia?**
Mark only one oval.

- Sim
- Não

21. **Pratica exercício físico com regularidade?**
Mark only one oval.

- Sim
- Não

22. **No dia a dia sente dificuldade em concentrar-se?**
Mark only one oval.

- Sim
- Não

23. **Durante uma conversa tem dificuldade em encontrar as palavras corretas?**
Mark only one oval.
- Sim
- Não

24. **Costuma ter problemas de memória?**
Mark only one oval.
- Sim
- Não

25. **Costuma perder facilmente o interesse pelas atividades que começa?**
Mark only one oval.
- Sim
- Não

Muito obrigado pela sua colaboração

Annexe 2- Documents Delivered to the Pilots

Name:

Age: **Gender:** ◯ Male ◯ Female

Flight hours: **Type of licence:**

e-mail:

	Day	1	2	3	4	5
Fill in the morning after waking up	What hours did you lay down?					
	What hours did you woke up?					
	Number of times you woke up during the night?					
	How long did it take to fall asleep?					
	Did you take any medication the night before?					
	From 1 to 7 what does it feel like to wake up?					
	Results from PVT test (ms)					
Fill in the evening before going to sleep	Number of drinks with caffeine?					
	Number of drinks with alcohol?					
	Naps duration and hour?					
	Time doing exercise and at what hour?					
	From 1 to 7 what did you feel at the end of the day?					
	Results from PVT test (ms)					

	Day	6	7	8	9	10
Fill in the morning after waking up	What hours did you lay down?					
	What hours did you woke up?					
	Number of times you woke up during the night?					
	How long did it take to fall asleep?					
	Did you take any medication the night before?					
	From 1 to 7 what does it feel like to wake up?					
	Results from PVT test (ms)					
Fill in the evening before going to sleep	Number of drinks with caffeine?					
	Number of drinks with alcohol?					
	Naps duration and hour?					
	Time doing exercise and at what hour?					
	From 1 to 7 what did you feel at the end of the day?					
	Results from PVT test (ms)					

	Day	11	12	13	14	15
Fill in the morning after waking up	What hours did you lay down?					
	What hours did you woke up?					
	Number of times you woke up during the night?					
	How long did it take to fall asleep?					
	Did you take any medication the night before?					
	From 1 to 7 what does it feel like to wake up?					
	Results from PVT test (ms)					
Fill in the evening before going to sleep	Number of drinks with caffeine?					
	Number of drinks with alcohol?					
	Naps duration and hour?					
	Time doing exercise and at what hour?					
	From 1 to 7 what did you feel at the end of the day?					
	Results from PVT test (ms)					

Tables to be filled during flight operations, based on Samn-Perelli 7-point fatigue scale, according to the type of flight performed:

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Annexe 3- Scientific Article Accepted for Presentation

VII RIDITA – Air Transportation Sustainability: Technological, Operational, Economic, Social and Environmental Strategies, Faculty of Engineering of the University of Beira Interior, Covilhã, Portugal, 9 - 11 October 2019

Pilots Performance and Flight Safety
The Case of Cognitive Fatigue in Unpressurized Aircraft Cabins

João Rocha, Jorge Silva

Abstract:

The purpose of this study is to understand the impact, evolution and perception of cognitive fatigue as a contributory factor on the occurrence of incidents and accidents, on unpressurized aircraft.

This study uses the science principles present in the Fatigue Management Guide for Airline Operators (FMG) to evaluate data obtained by four methods of measuring cognitive fatigue. These consist in two objective measures, Psychomotor Vigilance Test (PVT) and an actiwatch (Readiband 5), and two subjective measures Samn-Perelli 7-point fatigue Scale (SPS) and sleep diaries. It is also obtained results from a survey related to this theme.

From this research are draw conclusions of the influence and evolution of cognitive fatigue on the operations of unpressurized aircrafts and it is understood the difference between perceived cognitive fatigue and the real cognitive fatigue accumulated by the pilot. Is also drawn findings from a launched survey related to this theme.

In this case study the focus will fall upon general aviation where there is no way to control and monitor the fatigue element, the cause of most incidents and accidents that occur in Portugal as concluded by analyzing several GPIAAF final reports using HFACS. Normally this type of research is conducted within airline operators, that are already a very restricted and controlled domain of civil aviation, instead of within general aviation.

Keywords: Accidents Investigation and Prevention, Operational and Flight Safety, Pilots Performance, Human Factors, Cognitive Fatigue.