Pilots performance and flight safety: the case of cognitive fatigue in un-pressurized aircraft cabins

João Artur de Freitas Rocha - joaoarturfr@hotmail.com
University of Beira Interior
Jorge Miguel dos Reis Silva - jmrs@ubi.pt
University of Beira Interior; CERIS/IST, Universidade de Lisboa

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 use the science principles present in the Fatigue Management Guide for Airline Operators (FMG) [1] to evaluate data obtained by four methods of measuring cognitive fatigue [2] 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 are 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 [3]. 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
Cognitive Fatigue; Human Factors; Accidents Investigation and Prevention; Pilots Performance

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I. Introduction

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 aircrafts, mechanical failures only cause 20% of accidents and human error takes the other 80% [1],[2].

In national territory (Portugal), 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. An in-depth analysis on the data of 66 final reports related to non-pressurized aircrafts and using The Human Factors Analysis and Classification System (HFACS) concluded that 81.82% of the final reports had indices of Human Factors (HF). 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.

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 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) [3]. 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.

II. Methodology

The development of this study 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 1).

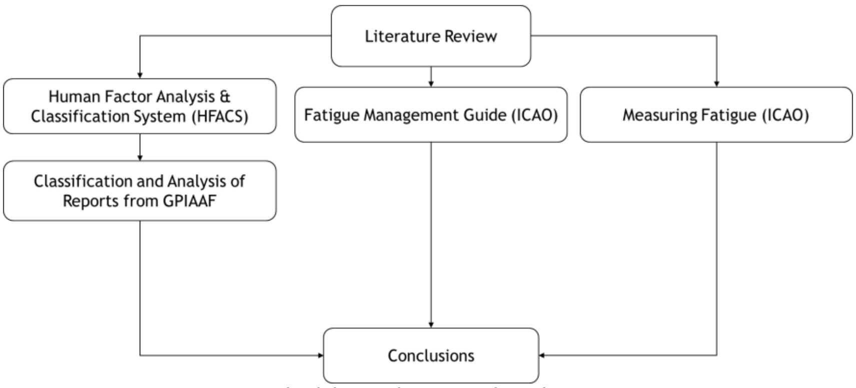

Figure 1 – Methodology schematics from literature review
Source: own elaboration

After gathering all information, a case study was established with an experimental work where were we used 4 methods to measure fatigue: 2 objective measures (Psychomotor Vigilance Task (PVT) and

Actiwatch) and 2 subjective measures (Samn-Perelli 7-point fatigue scale (SPS) and Sleep diaries). An analysis was made to the experimental work results, and from this analysis conclusions were withdrawn to respond to the objectives of this study (Figure 2).

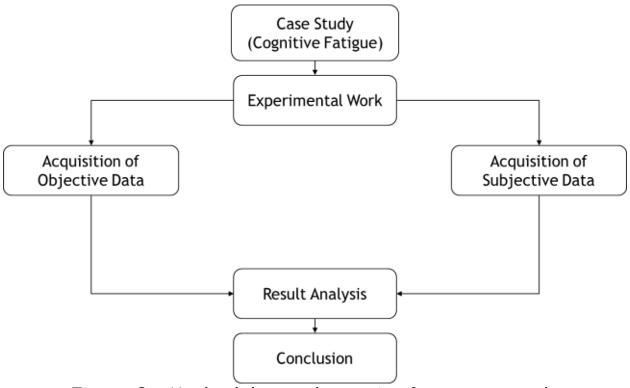

Figure 2 - Methodology schematics from case study
Source: own elaboration

III. The Human Factor in aviation

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. 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 [4].

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 resolve this problem, a human factor analysis and classification system (HFACS) [5] 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 [6], HFACS has four levels of failure, Figure 3. In this study 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.

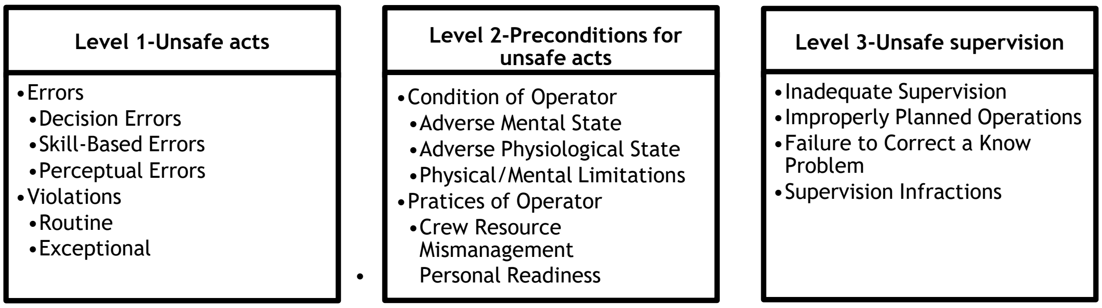

Figure 3 – HFACS levels
Source: own elaboration based on [5]

Statistics of HF in Portugal

The implementation of the HFACS, to the final reports of incidents and accidents of the GPIAAF from 2010 to 2017 [7], allowed the acquisition of the data presented in Table 1. The case studies are only for general aviation and SPO of helicopters and airplanes, where the use of aircraft with non-pressurized cabs predominates.

Table 1 - 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, the following graph (Figure 4) was drawn with the percentage of each level of HF per year. From this figure is perceivable that the cause of most accidents/incidents in Portugal is at the level of unsafe acts that are related to cognitive fatigue.

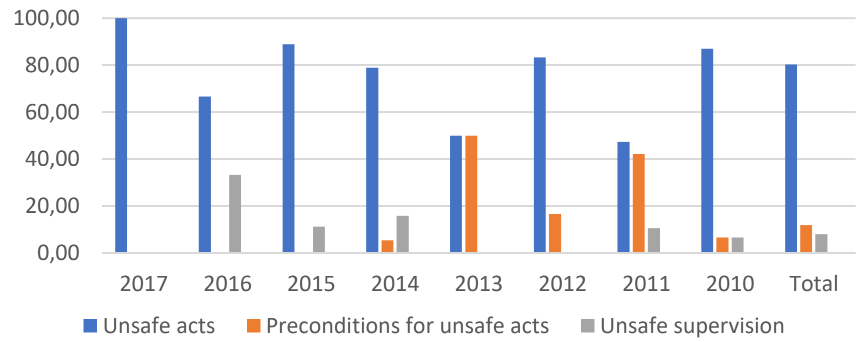

Figure 4 - Percentage of HFACS levels on final reports of accident and incident from 2010 to 2017
Source: own elaboration based on Table 1

This relation to cognitive fatigue is associated to the fact that fatigued people often experience increased Reaction times (RTI), reduced attention, impaired memory, withdrawn mood, inaccurate flying, poor decision making and loss of situational awareness. 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 [8].

So fatigue can be described as a reduced ability to perform operational tasks and can be considered as an imbalance between 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) [3]. 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 [9]. The fatigue that is studied in this work 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 [10]. Fatigue can be divided into three

categories [9], but for this study it is taken in consideration circadian fatigue that is directly related to the circadian body clock [3].

IV.Scientific Principles and Measurements for Fatigue Management

Following the Fatigue Management Guide for Airline Operators [3], there are four focal points on managing fatigue that can be seen on Figure 5.

1-Circadian Cycles and Effects on Sleep and Performance	**2-Sleep-Wake Homeostasis and the Sleep Drive**	**3-Factors that Affect Sleep Quality**	**4-Influence of Workload on Fatigue**
• The circadian body clock affects the timing and quality of sleep and produces daily highs and lows in performance capacity on various tasks.	• 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.	• Reducing the amount or the quality of sleep, even for a single night, decreases the ability to function and increases sleepiness the next day.	• 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.

Figure 5 - Points on managing fatigue from the Fatigue Management Guide for Airline Operators – Source: own elaboration based on [3]

An ideal amount of sleep per night may vary between individuals, but 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.

Based on the data presented in Figure 4 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. The cycle of work\fatigue\sleep is a normal part of a healthy human life, due to changes in the circadian body clock; fatigue appears since most of these changes are associated with sleep. A normal adult is expected to sleep between seven to nine hours uninterruptible a day that should include both Rem (Rapid eye movement) and non-Rem (non-Rapid eye movement) phases. So, is easily understandable that the issue with fatigue is a matter of sleep regularity and quantity/quality; not forgetting that workload is also an important factor and has its weight on fatigue. The fact is that fatigated individuals are often very poor judges at accessing their own state of alertness.

To conduct this study, it was used two types of output data, being them subjective data and objective data. These two types of 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 – as depicted in Figure 6, taken from the ICAO, Measuring Fatigue, by Dr. Michelle Millar, Technical Officer (Human Performance) [11].

Subjective data	**Objective data**
• Samn-Perelli 7-point fatigue scale (SPS) • Sleep diaries	• Actiwatch (Readiband 5) • Psychomotor Vigilance Task (PVT)

Figure 6 – Types of data and methods utilized in this study
Source: own elaboration

A. Samn-Perelli 7-point Fatigue Scale (SPS)

This 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 [11]. 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 [12]. 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 classification as shown in Figure 7.

Samn-Perelli 7-point Fatigue Scale 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 7 - Samn-Perelli 7-point Fatigue Scale Classification
Source: own elaboration

In this case study, the SPS fatigue scale is implemented using the table presented in Figure 8. This table is to be filled during flight with the classification system presented above and taking into consideration the type of flight as shown in Table 2. These rates are given in pre-determined time periods in accordance with the duration of the flight, as depicted in Table 3. In the table to be filled there are spaces too for the input of PVT test results.

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 8 - SPS fatigue scale table
Source: own elaboration

Table 2 – Fulfilment of SPS table according to the type of flight
Source: own elaboration

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

Table 3 – Time periods according to the time of flight
Source: own elaboration

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

B. Sleep Diaries

The sleep diaries 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. 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 was constructed based on the sleep diaries of the National Sleep Foundation [13], and contains a section for the input of results from the PVT test.

C. Actiwatch (Readiband™ 5)

Actiwatches are devices capable of monitoring activity, estimating sleep periods and their quality, and various other parameters depending on the device in question. 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 the present study, they are used in conjunction with the subjective measures, SPS and sleep diaries to cross data and make conclusions. 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 and was validated with an accuracy of 93% when compared to clinical polysomnography [14]. However, since it is difficult to differentiate lying quietly in bed from lying in bed asleep, the algorithm occasionally may slightly overestimate sleep time [15]. The data acquired by the Readiband, is analyzed by the SAFTE™ (Sleep, Activity, Fatigue, and Task Effectiveness) algorithms that 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. 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, as in Figure 9. The alert state is the quantification of fatigue impairment, on a scale ranging from 0% to 100%. With this, 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 [16].

	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 9 – Example of a SAFTE™ alertness score
Source:[10]

D. Psychomotor Vigilance Task (PVT)

The psychomotor abilities of an individual, relate 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 as an evaluation tool of the operator response time.

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 as a low effect on 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 [17].

To start the test, it is only necessary to open smartphone application, click on "Do Test". After its conclusion the result is written on the referred space of the provided sleep diaries and Samn-Perelli 7-point fatigue scale table.

V. Study Implementation

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. After three days of sleep data obtained by the actiwatch the SAFTE^{TM} 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". Before the operation of the aircraft a PVT test is performed and 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, as in Figure 5. During the operation of the aircraft, the Samn-Perelli 7-point scale table was filled according to Table 2 and Table 3. 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 10 is a schematic to demonstrate the daily processes realized by our pilots involved in the study.

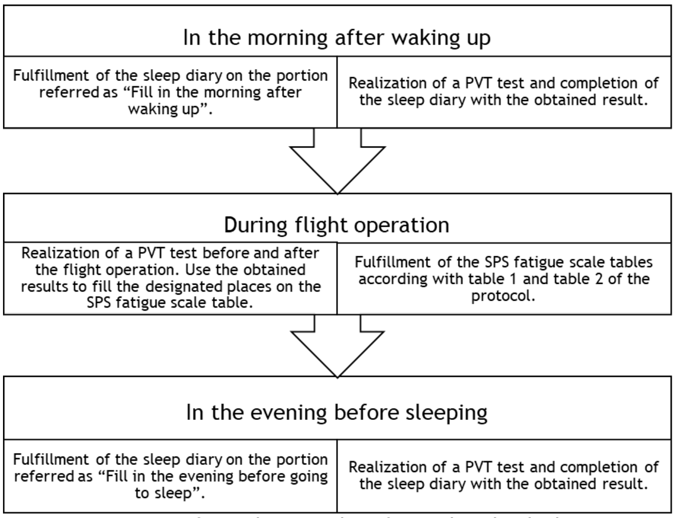

Figure 10 - Daily procedure for each individual
Source: own elaboration

VI. Results and Analysis

Using the methods and their implementation as described above we obtained the results for the study time period, from the three pilots evaluated. With these values and the theoretical information gathered, 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 4.

Table 4 – 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. Using the best RTi (223 ms) measured on the PVT tests and assuming it is the fastest RTi of this individual, Table 5 was constructed in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 5 - 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

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 6 shows the condition of the pilot on the days in which he flew.

Table 6 - Data from flight days (Pilot 1)
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]
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 frist day of 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 7, 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 changes in the performance of the pilot due to cognitive fatigue.

Table 6 - Data from pilot 1 flight nº1 and flight nº2
Source: own elaboration

	Flight nº1			Flight nº2		
	Before flight	During flight	After flight	Before flight	During flight	After flight
Time [min]	0	15	30	0	15	30
SPS	1	1	1	1	1	1
SAFTE [%]	92.2	92.1	92	88.4	88.7	89
PVT [ms]	251		278	251		237

In the day of the second flight, the pilot had an almost good quantity and a poor-quality sleep and his RTi after sleep was 26.91% worse than the fastest PVT test. From the data of Table 7 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 and quality of sleep, the RTi values were better than in first flight.

- **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, and the caffeine and alcohol intake are not relevant. Using the best RTi measured

(236 ms) on the PVT tests and assuming it is the fastest RTi of this individual, Table 8 was constructed in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 7 - 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 8 - Data from flight days (Pilot 2)
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]
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 (Table 9). From the data of Table 10, 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 9 - Data from pilot 2 flight nº1 and flight nº2
Source: own elaboration

	Flight nº 1					Flight nº 2		
	Before flight	During flight			After flight	Before flight	During flight	After flight
Time [min]	0	15	30	45	60	0		30
SPS	2	2	2	2	2	2		2
SAFTE [%]	98.2	98.2	98.1	98	97.8	92		92.4
PVT [ms]	251				248	270		277

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 10, 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.

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 11 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 10 - Data from pilot 2 flight n°3 and flight n°4
Source: own elaboration

	Flight n° 3			Flight n° 4		
	Before flight	During flight	After flight	Before flight	During flight	After flight
Time [min]	0		30	0		30
SPS	2		2	2		2
SAFTE [%]	89.8		90.4			
PVT [ms]	272		275	268		272

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 11 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 - a low level of risk.

- **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. Using the best RTi measured (240 ms) on the PVT tests and assuming it is the fastest RTi of this individual, Table 12 was constructed in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 11 - 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 12 - Data from flight days (Pilot 3)
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]	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 of sleep. His RTi after sleep was 36.25% worse than the fastest PVT test (Table 13). From the data of Table 14, 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 13 - Data from pilot 3 flight nº1 and flight nº2
Source: own elaboration

	Flight nº 1				Flight nº 2			
	Before flight	During flight		After flight	Before flight	During flight		After flight
Time [min]	0	15	30	50	0	15	30	55
SPS	2	1	1	1	2	1	1	1
SAFTE [%]	92.3	93.2	94.1	94.7	82.7	83	83.4	84
PVT [ms]	344			244	250			240

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 14 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.

In flight number 3 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 15 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 14 - Data from pilot 3 flight nº3 and flight nº4
Source: own elaboration

	Flight nº 3			Flight nº 4		
	Before flight	During flight	After flight	Before flight	During flight	After flight
Time [min]	0	15	40	0		20
SPS	1	1	1	1		1
SAFTE [%]	87.3	87.5	87.9	90.3		90.7
PVT [ms]	264		274	240		246

The fourth flight was executed in the same day 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 15 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.

VII. Conclusion

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 and is by conducting studies in the fields of human performance that we can find ways to mitigate the probabilities of "human error".

The pilots that participated in this study had normal lives during the test period, and so it was possible to observe the fatigue accumulated by these individuals. 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 had an impact 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 be considered 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 study 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. 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, more diversified group of subjects and flights, it would be possible to make more conclusive affirmations.

VIII. References

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