# HELICOPTER PILOT ROSTERING ON/OFF SCHEDULE SCHEME IN ANGOLA OIL AND GAS OFFSHORE INDUSTRY

## Fatigue in Offshore Helicopter Pilots

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Provas destinadas à obtenção do grau de Mestre em Operações de Transporte Aéreo

Outubro de 2020

**VERSÃO DEFINITIVA**

ISEC LISBOA | INSTITUTO SUPERIOR DE EDUCAÇÃO E CIENCIAS

Escola de Aeronáutica

Dissertation submitted as partial requirement for the conferral of Master of Air Transport Operations

Provas para obtenção do grau de Mestre em Operações de transporte Aéreo

# HELICOPTER PILOT ROSTERING ON/OFF SCHEDULE SCHEME IN ANGOLA OIL AND GAS OFFSHORE INDUSTRY – Fatigue in Offshore Helicopter Pilots

Escalas de Rotação ON/OFF de Pilotos de Helicóptero da Indústria de Óleo e Gás em Angola – Fadiga em Pilotos de Helicópteros Offshore

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Outubro de 2020

## Acknowledge

The author would like to acknowledge some parties involved in this study towards this Masters Dissertation in the field of Air Transport Operations program 2018 – 2020.

First and foremost, mention that is sincerely grateful to SonAir Serviços Aéreos for enthusiastically supporting this academic study with particular reference to SonAir CEO Eng. Ruben Monteiro da Costa, for the full support and official approval for the private information collection and practical use of its internal data.

A, heartily thank entirely the departments and staff of SonAir involved in the gathering and supplying of the data, significant reference to the Operational Safety Department (GSO), and its Safety Manager, Eng. Hélder Almeida, who supported the gathering of relevant information on the comprehensive survey. Rotor wing pilots (DOV/AR) who voluntarily invested their time and helped extrapolate the data from the survey. For providing their extensive expertise and experience towards this research.

The author would also like to thank the Executive Director of the Master's Degree program, the PhD António Rodrigues and to my Supervising Coordinator Professor of this project the Aviation Specialist Professor Rui Castro e Quadros from ISEC School of Aeronautics. Thankful for the individual support, guidance, expertise both at the project level as well as throughout the educational training acquired at this academic institution.

Especial thanks, to BP Angola Aviation Technical Advisor Captain Jorge Gambôa. Offshore helicopter pilots from Angola Captain Sergio Sousa AW139/H225/S76c++ and Instructor Captain Hélder Neto H225/S76C++, from France Instructor Captain Daniel Moulins AS332L2/S76C++, from England Instructor Captain Jonathan Drew S76C++, from Portugal Instructor Captain Paulo Galvão H225/S76C++ and from Brazil Instructor Captain Wallace Brasil AS332L2/S76C++/S92. Maintenance avionics specialist Elvis Alves AS332L2/S76C++/AW139/S92. To all many thanks for their time and review inputs.

Lastly, I would like to thank all my family, friends, and co-workers for their understanding and outstanding support throughout the academic journey. Specifically, during the period of realization of this research project and who contributed to its success. Thank you all very much!

## Resumo

Na indústria de petróleo e gás, os trabalhadores são transportados principalmente por helicóptero de terra para/de alto mar. O trabalho varia de 45 a 90 minutos de tempo de voo para cada segmento de perna. Com uma atividade de rotina onde o período de carga de trabalho das tripulações de voo muitas vezes varia, até 12 horas de período de serviço e um máximo de 8 horas de voo. Durante os voos, os pilotos são expostos a diversas condições de trabalho que causam fadiga física e psicológica. Este estudo de pesquisa tem como objetivo avaliar a exposição de pilotos de helicóptero à vibração de corpo inteiro (VCI) e ao ruído sonoro como principal causa de fadiga e a idade como factor secundário. No sentido de cumprir com o objetivo do estudo de investigação, foi seleccionada, oportunisticamente, uma amostra dimensional de 50 pilotos, de uma população situada no país de Angola, sendo uma do sexo feminino e 49 do sexo masculino. É uma amostra não probabilística de conveniência composta por uma única empresa. A metodologia empregue foi uma questionario voluntário online. Realizado por meio de um estudo correlacional com delineamento transversal realizado online e foi compilado a partir de diversas questões relacionadas aos factores humanos. Em termos de resultados, o autor gostaria de enfatizar a exposição de outros efeitos externos que também teriam contribuído para o cansaço dos pilotos. No entanto, para este estudo, eles foram negligenciados. Os dados recolhidos foram utilizados para desenvolver a análise do melhor esquema de escala de serviço nos operadores aéreos de helicopteros de suporte à industria petroliferica de óleo e gas. Participantes forma pilotos de helicoperos, 97% eram do sexo masculino, 63% com idade inferior a 40 anos, 71% copilotos, 63% tinham licença de piloto comercial e 58% com menos de dez anos de experiência. Escala de rotação de serviço, quando combinados quase 75% consideraram o melhor esquema de rotação entre 21 a 28 dias de serviço (ON) / folga (off). Fadiga afetada o desempenho e alerta degradada relatado por mais de 56%. Acenando ocasionalmente durante o voo a cabeça em 34,8%, mas apenas 21,7% recusaram um voo devido à fadiga.



Palavras-Chave: Helicóptero, vibração de corpo inteiro, perda auditiva, turnos, segurança de voo, fadiga.

## *Abstract*

*In the oil and gas industry, workers are mainly transported by helicopter from Onshore to/from Offshore. The travel varies between 45 to 90 minutes of flight time for each leg segment. Under a routine activity, the flight crews workload period often varies up to 12 hours of duty period and a maximum of 8 hours flying. During flight missions, pilots are exposed to several work-related conditions that cause physical and psychological fatigue. Accordingly, this research study aims to evaluate the exposure of helicopter pilots towards whole-body vibration (WBV) and noise as the leading cause of fatigue and age as the secondary factor. In the direction of fulfilling the research study goal, a sample size of 50 pilots were opportunistically selected, from a population working in Luanda, Angola; being one Female and 49 Males. The study is non-probabilistic with a convenience sampling composed of a single company. The methodology employed was a voluntary online survey, accomplished by a correlational study with a cross-sectional design conducted online and was compiled of several questions related to human factors. In terms of results, the author would like to emphasize the exposure of other external effects impacting the pilot's fatigue; however, for this study, these contributing factors were neglected. The data collected were utilized to develop the analysis of the most effective roster scheme in the helicopter offshore service provider. Looking at the pilot demographics, 97% were male, 63% with age below 40 years, 71% copilots, 63% have a commercial pilot license, and 58% with less than ten years of experience. Schedule Schemes and Rostering, when combined almost 75% considered best rostering scheme between 21 to 28 days on/off. The study highlights the fact that fatigue affects and degrades performance and alertness as reported by more than 56 %. Occasionally nodding during flight by 34.8%; however, only 21.7% turned down a flight due to fatigue.*

**Keywords:** *Helicopter, Whole-Body Vibration, Hearing Loss, Rostering, Safety, Fatigue.*

# List of Contents

## List of Figures



## List of Tables

## List of Graphics

## List of Abbreviations

| | |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| BMI | Body Mass Index |
| BVI | blade vortex interaction |
| CAA | civilian aviation authority |
| CFIT | control flight into terrain |
| CRM | Crew Resource Management |
| dB | Decibels |
| dBA | A-weighted decibels |
| EASA | European Aeronautical Safety Agency |
| FDM | Flight Data Monitoring |
| FRMS | Fatigue Risk Management System |
| GSO | *Gabinete de Segurança Operacional* (Flight Safety Department) |
| HL | Hearing Loss |
| HNVED | helicopter noise and whole-body vibration estimated exposure dose |
| HOGE | Hover out of ground effect |
| HUMS | Health and Usage Monitoring System |
| Hz | hertz |
| ICAO | International Civilian Aviation Organization |
| ILFN | Infrasound and Low-Frequency Noise |
| IOGP | International Oil and Gas Producers |
| ISO | International Organization for Standardization |
| MCC | Multi-Crew Coordination |
| MR | Main rotor |
| MTOW | Maximum takeoff weight |
| NIHL | Noise-Induced Hearing Loss |
| OFF | OFF is a period of rest or off duty of work |
| ON | On is a period of work schedule. |
| OPEC | Organization of the Petroleum Exporting Countries |
| OSHA | Occupational Safety and Health Administration |
| PPE | personal protective equipment |

| | |
|---|---|
| QM | Quality Management |
| SMS | Safety Management System |
| TCDSN | Type certificate data sheet for noise |
| TR | Tail rotor |
| VAD | Vibro acoustic Disease |
| WBV | whole-body vibration |

## Chapter I Introduction

Technologically speaking, the human body is a unique machine as it holds secrets not yet unfolded or discovered. Nevertheless, people continuously try to fool their "systems" (body and mind), by systematically pushing the limits, and yet failure is still present when it comes to reaching its full knowledge.

The aviation industry is progressively improving the operational safety measures; therefore, not surprising that Pilot Fatigue remains one of the prominent subjects of concern among the human factors elements. Among the several Human Factors definitions, the author defines it as *a scientific discipline that involves a multidisciplinary effort generating information in the field of human sciences, with the interaction and integration of the physical sciences with the various applications of systems engineering. It is the continuous seek to create an optimized connection between the interface of man-machine and other elements as a whole in its activities, providing general human wellbeing. Studying man, in regards to the understanding of the abilities, limitations, physiological and psychological effects, anthropometry and sociology, among other members or workgroups where people management and decision making can play a fundamental role. The enhance analysis of the relationship between man-machine, regarding the interaction between occupational ergonomics, environmental conditions, the performance of systems, equipment, written and or oral procedures, qualified human performance, training, effective performance, safe environment and comfort.*

The objective is to improve the relationship between man-machine-other elements and the environment, used in work and everyday life based on knowledge guidance. It is harmonizing any conflict between the relationship and any practical problem in the real world. Minimize job problems between man-machine-other elements by using methods or techniques, creating harmony in the overall system between each other and thus resulting in operational safety. In helicopter accidents, aircrew human error has been the main reason for the outcome. Usually, being the leading cause of accidents by 70 - 80% and considered a known fact and accepted as part of the aviation industry (Shappell & Wiegmann, 2000). The SHELL model shows how pilots will always have a final decision towards the risk elements of each flight operations, pilot, environment and helicopter (ICAO 9859, 2018). An essential and fundamental aspect is to have a general balanced overall fitness to fly, a pilot in command has to make decisions based on experience, training, health conditions, emotional state, fatigue and other factors (Čokorilo, Mirosavljević, Vasov, & Stojiljković, 2013).

Based on the nature of the helicopter operational characteristic's, the levels of fatigue experienced by a helicopter crew is far greater than pilots who operate fixed-wing aircraft. Fixed-wing pilots find themselves exposed to less equipment vibration and on the other hand higher noise levels from engines. A broader concern comes in the offshore industry. It is a topic with little development, with high international recognition and industry interest. The research study has a higher relevance of interest since the author is an active helicopter pilot in this specific industry. The majority of most available studies come from observers, authors outside the aeronautical industry, with limited or none flying experience. Several side effects widely studied in helicopter pilots since late 1940s have determined several pre associated work-related conditions. Pilots are exposed mainly to whole-body vibration and noise, and diseases associated with vibration and noise exposure. Reporting fatigue-related sickness, in helicopter pilots, has a particular interest since there are fewer helicopter pilots worldwide.

Offshore helicopter daily activities consist of transportation to/from an onshore heliport or airport to offshore installations (rigs and or vessels). With high international interest, the author has recognized particular attention in this study which must be further developed. Previous studies have revealed several side effects widely studied in helicopter pilots and absolute silence has been yet the leading way to act by the industry. The aeronautical industry has mainly focused on commercial transportations of aeroplanes activities. Slow recognition for the damage caused to pilots and their quality of life, directly affecting their families. The last resource matter has been set in this issue prevailing business and manufactures over staff workers. Several published scientific studies in both medical and aeronautical industries have demonstrated some kind of correlation. Some determined pre associated work-related illness or sickness condition that pilots experience due to exposed vibration and noise conditions. Sometimes widely above international recommended safe and health occupations. While the author has observed a gap in the subject studies, there is a necessity for further information gathering towards a comprehensive understanding of the cause and effects of the Pilots fatigue. The measurements of fatigue are of great use to assess safety levels of pilot readiness for occupational duties. For better calculating in pilot ratio per operation, identify the best pilot rostering schemes by mitigating risk.

A correlational study with a cross-sectional design was conducted for the gathering of data through internet Google Forms and compiled of 39 questions. The online survey conducted related to human factors (fatigue, sleep, rest periods, rotation schemes, physical and psychological self-awareness of wellbeing). A population of 87 Helicopter Pilots in Angola, on a state-owned helicopter company called SonAir.

### *1. Purpose of the Study*

The purpose of the author is to: calculate Helicopter Pilots approximate estimated vibration and noise exposure levels. Furthermore, it is to enrich management's decision making towards the best rostering scheme augmenting the mitigating levels of fatigue. Both through scientific analyses, associating pilot's fatigue levels to determine their operational fitness to fly during the rotation period of ON (working). The author intends to demonstrate that the measurements will be of great use in studies in the Whole-Body Vibration (WBV) and Noise exposure as well as towards Hearing Loss (HL) in helicopter activities.

### *2. Objectives and Research Questions*

The overall objective of the author is to enhance the safety standards in the offshore oil and gas industry worldwide towards pilot fatigue.

In this research work:

- Provide offshore helicopter operators with a better understanding of the correct rostering schemes to implement in each business activities based on the intensity through analytical data collected relating Fatigue Resource Management System (FRMS).

- Develop and create a simplified risk matrix, which enables offshore helicopter operators the ability to measure the estimated fatigue levels with a quick risk-mitigating tool during the rotation period of ON.
- Lastly, contribute to the development of a tool to add to the operator's Safety Management System (SMS).

The author's contributive intention is to diminish the literature gap presently available by responding to the investigating questions:

I. Exposure to whole-body vibrations, above-average noise from the blades and engines is the general result of the helicopter pilot's fatigue of impact?

II. Is age and the total of flight hours exposed daily a direct association of having a significant impact on the fast recovery of the health effects on the body and fatigue of pilots?

III. A safer analysis toward fatigue measurement related to working flight hours per each rotation scheme ON/OFF, is the result of better understanding in the selection of the best rostering scheme 7, 14, 21, 28 or 35 days ON/OFF and scheduling in association with sleep habits as well as pilots primary role of responsibilities?

## Chapter II Theoretical Contextualization

The following part is the contextualization of helicopter pilots daily activity. The author explains pilots psychological and physiological states of normal, pilots daily stress and three most noticeable side effects contributing to pilots fatigue.

### 1. *Pilots Psychological & Physiological states of normal*

In Angola, the offshore oil rig support flights are mainly conducted from Luanda International Airport *4 de Fevereiro*, and this means longer transit flights. Pilots do this every day. Pilots must have outstanding medical records and be daily genuinely healthy to be able to fly. However, it also means knowing to face changes on a day-to-day basis, towards the mind (psychological) and body (physiological) states of ordinary. Landing on a platform requires helicopter pilots to test their abilities to the maximum, since flying out of ground effect (HOGE), with variables factors and threats (obstacles: rig cranes, antennas, near ships or vessels, weather: variable winds, reduced visibility, deck: dimension, position, entry and exit point and height). Several stressful conditions contribute to the decrease of the normal state of awareness and safety performance of helicopter pilots. "*A helicopter pilot´s psychomotor performance may be affected by a number of factors, including (but not limited to) fatigue, time on task, workload, environmental conditions, and operational stressors"* (McMahon & Newman, 2018). Pilots are required to present themselves before a flight in well-rested conditions. *Sleep is vital to a pilot just as food, water and air. Disruption has been shown to create significant fatigue-related risks* (Gregory, Winn, Johnson, & Rosekind, 2010).

### 2. *Pilot's daily stress*

The high degree of concentration towards the flying activity leads to inheriting daily stress or fatigue, affecting both body and mind and ultimately the soul itself. "*Sustained helicopter operations in hostile environments may produce high levels of cognitive fatigue because of time on task, prevailing environmental conditions, the nature of the task, high cognitive workloads, operational or individual stressors, and poor quality and quantity of* *sleep"* (Rabinowitz, Breitbach, & Warner, 2009). Scientific data has proven that cognitive fatigue affects both cognitive and psychomotor performance (Kato, Endo, & Kizuka, 2009; Lorist, Kernell, Meijman, & Zijdewind, 2002). Helicopter pilots have it worse, the vertical lift and aerodynamic philosophy of flight itself are different from aeroplanes. Pilots are affected with several side effects, some similar but others completely different. The majority of helicopters are not equipped with washroom. Pilot's physiological needs may sometimes be delayed, thus causing internal noon seen damages over time and in the long run.

### *3. Three most noticeable side effects that contribute to pilots fatigue*

In this research, the author focuses on explaining how fatigue may be affected by **three main predictor causalities**. First **whole-body vibrations (WBV)** (Arora & Grenier, 2013; Blackman, 2019; Bovenzi, 1996; Ishimatsu, Meland, Hansen, Kåsin, & Wagstaff, 2016; Kåsin, Mansfield, & Wagstaff, 2011). Secondly, **Hearing loss (HL)** due to noise (En–tong et al., 2008; Fitzpatrick, 1988; Kuronen, Toppila, Starck, Pääkkönen, & Sorri, 2004; Lang & Harrigan, 2012; McReynolds, 2005; Morfey, 1973). Lastly, due to **Age** and its natural progress (Bovenzi, 1996; Campos, Ramkhalawansingh, & Pichora-Fuller, 2018; Fitzpatrick, 1988). Meanwhile, having two **measurable subjective variables**; the number of **hours flown** and the number of **hours or days of rest** between flights.

The author will explain through the literature review how these three main predictors are affected by the number of hours a helicopter pilot flys. Furthermore will show a clear correlation towards the importance of rest periods between flight and rostering schemes of ON/OFF.

# Chapter III Literature Review

The following part is the analysis of past studies in the scientific area, and the authors focus on the study within the literature review. It is centred on the research study theme and analysis to seek answers relative to the research questions. It focuses on the Whole-Body Vibration, hearing loss and Age as a direct impact on fatigue to helicopter pilots. Lastly, a clear correlation is and shown between all three main contributors to fatigue.

## 1. *Whole-body vibration (WBV)*

Among several means of transportation, the helicopter has by far the highest levels of vibrations. **Vibrations** in a mechanical movement, that oscillates about a fixed point, in the form of wave and transferring energy. Helicopter pilots will feel both types of exposed vibration, localized vibration and Whole-Body Vibration (WBV). **Localized vibration** felt on the pilot’s hands and feet while holding or touching a vibrating object like the cyclic and collective and to his feet when he is using the pedals. **Exposure** depends on the size and contact surface of both hand and feet of the pilot on controls. WBV mainly felt on pilot’s skin, lower back, thorax, shoulders, neck and head. In helicopters, vibration is transferred through fuselage structure exiting through the landing gear suspension on to the tarmac or surface on the ground. “*Described in the orthogonal coordinated reference system X, Y, Z connected to the human skeleton”* (Auffret, Delehaye, & Merges, 1980; ISO 10056, 2001; ISO 2631, 2018). Also in rotation about these axes roll, pitch and yaw. In the air, it is directly neutralized on the human body acting as a suspension (interior) in the form of lift and exterior in the form of vortex´s created on the end of the rotor blades.

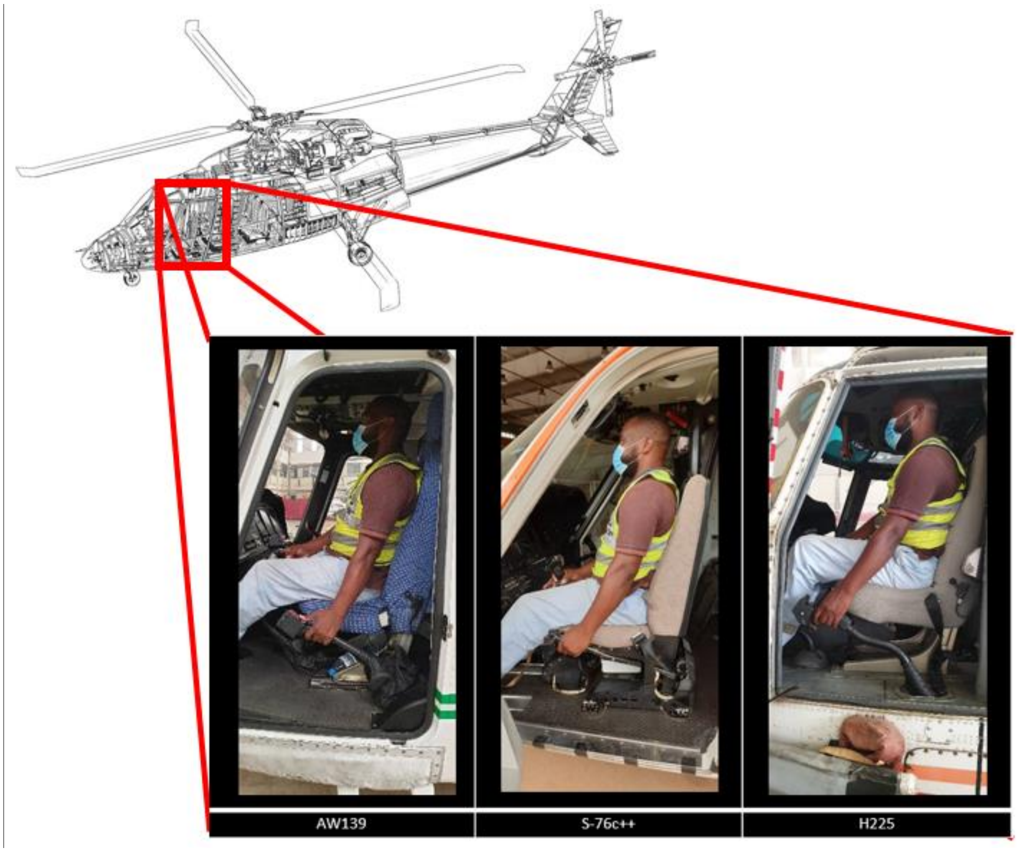



Figure 1: Pilot fixed position of the body while flying.
Source: Author´s Creation. The author took the photographs of Maintenance Technician Edson Rocha seating on AW139, S-76C++ and H225 with Cellphone on the 21/08/2020.

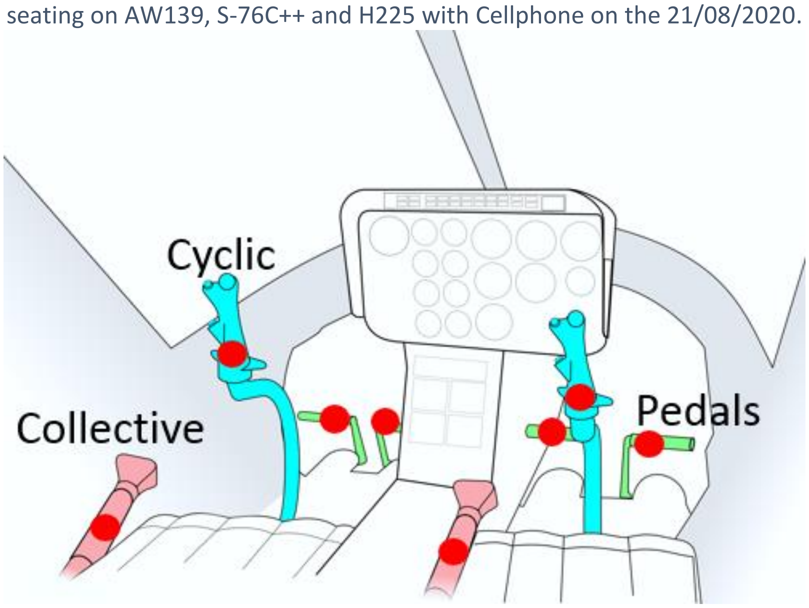



Figure 2: Localized vibration on the pilot's hands and feet (cyclic, collective and pedals).
Source: Author´s Creation

"*The helicopter has the same analogy as the house fan, whereas to the vibration, in high-frequency form, on the fan it's displaced on the surface of the casing"* (Mansfield, 2004). When **experiencing whole-body vibration**, it is felt in the entire body, transmitted through the seat surface, back and headrest and also though the floor. Entering the pilot's body specifically through waist and butt, back, neck, skull, hands and feet. It is also necessary to bear in mind that vibration radiation is present to other body parts such as skin, elbows, knees and thorax. Whole-Body Vibration (WBV) is **affecting both the comfort and performance of pilots**. The first is argumentative since the human body does not have a comfort receptor. On other hands, humans have a pain receptor despite being subjective. However, the pilot´s comfort may be measurable when he is free or in lack of pain. The measurable pain and comfort will have the liability of health disorders in the long term depending on the vibration magnitude, waveform, exposure time, pilot's sensitivity and general health.

Many other studies have revealed **several health effects**. However, back pain has been most commonly reported. Other disorders include sciatica pain, hearing damage, nervous system, skeleton (bones, joints and degenerative changes in the spinal, including lumbar inter-vertebral disc disorders), muscular system, and skin. The circulatory systems, in general, affects kidneys, digestive system, cardiovascular system (elevated to high blood pressure), liver, urinary system and neurological (stress-related symptoms). Several studies also give high strength, consistency and plausibility towards the association between the pathogen with the risk of exhibiting symptoms that may result in the disease when increased exposure is present. To be able to proof, however, experimental evidence is required. Demonstrating would only be possible when evaluating several subjects during several years, and even then it is a scientific study that may be subjective. Several, control factors would be unforeseeable and with great difficulty to control.

The majority of **people are most sensitive** to WBV between 1 to 20 Hz of the frequency range (Mansfield, 2004). Some people are sensitive enough to feel between 0.01 to 1 Hz. Usually, pilots feel this range of frequency the so-called "motion sickness" while attending simulator training and the main reason for feeling nauseogenic (Mansfield, 2004).

Helicopter pilot's **prolonged seating position** may create discomfort and possible pain added to the exposure of WVB. A high revelling of which might result in performance degradation and ultimately lead to the cause of increasing fatigue. "*Although technology has changed, and will continue to advance, the human operator working within this technological system has not evolved or changed physiologically"* (Gregory et al., 2010).

The **vibration felt on the human skeleton** inside the helicopter causes accumulated muscular irritation and inflammation in the lumbar region. Relaxation in muscles during daily activities, cause noticeably increased reaction time. Tunnel vision, distraction, lower vigilance, concentration and decline in psychomotor performance may jeopardize flight safety (Fletcher & Dawson, 2001; McMahon & Newman, 2018).

Studies have used psychomotor reactions to quantify the effects of **cognitive fatigue**, and the result demonstrated a reduction in pilot performance on levels towards situational awareness (attention, vigilance and alertness). **Situational awareness** defined by (Endsley, 1988) as *"... the perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of their status in the near future"*, has been widely reported in recent studies focused on attentional processes such as vigilance, stating that fatigue and stress are high contributors to its decrease (Sneddon, Mearns, & Flin, 2013). As a **consequence of cognitive fatigue**, deteriorations in psychomotor was highly noticed (Kato et al., 2009; Sirevaag et al., 1993). Excess of sustained flight operations may result in a reduction in pilot's capability of executive control and therefore may also pose a potentially significant risk to operational flight safety.

Vibration **exposure over time** may be the leading cause of executive control problems reflecting in reduced reaction time and precision or accuracy on hands and feet. Explaining the deterioration of performance and possible over control in flight in decisive moments of flights, particularly in the landing and taking off phases. The WBV exposure directly driven from the helicopters main rotor, the force of gravity towards its weight in a downforce vector contrary to the intention of lift and its counter-torque force applied by the tail rotor. Since flight in the helicopter in simplified terms is the result of the action of the air blown downwards, *downwash,* from the rotor blades spinning causing a lift force reaction with upwards vector greater than its weight. Two forces act on each other with a shock reaction, creating micro-vibrations pending on the force applied and the time it takes towards the force applied. Independently, in helicopters, the cause itself will be a continuous vibration effect noticeable and measurable since one can fell its effects on the structure of the helicopter. "*Study to the psychomotor skills of helicopter pilots in offshore activities with medium average of 90 nautical miles range from land have demonstrated a deterioration of performance over time in both hands and feet, respectively 22,6% in the hands and 39,9% in the feet decrease in tracking accuracy, having a 77% differential effect between the hands and feet, with the feet being affected much more than the hands"* (McMahon & Newman, 2018).

The **European Directive (EU 2002/44/EC)** (European Parliament, 2002) *"defines the following:*

*(a)* ***'hand-arm vibration'****: the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders;*

*(b)* ***'Whole-body vibration'****: the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine".*

A helicopter pilot while flying (figure 1) has **stress imposed due to WBV, causing its cells to accelerate unevenly** pending on the body´s direct feeling impact. The impact, felling mostly in the feet, knees, hands and elbows (when holding collective and cyclic), waist, lower back, thorax, neck and cervical spine (Figure 2). The directive states, **hand-arm vibration shall have a daily exposure limit** value standardized to an eight-hour reference period shall be 5 $m/s^2$ (113.98 dBA). With autopilot technology, pilots are less exposed to this type of hand-arm vibration.

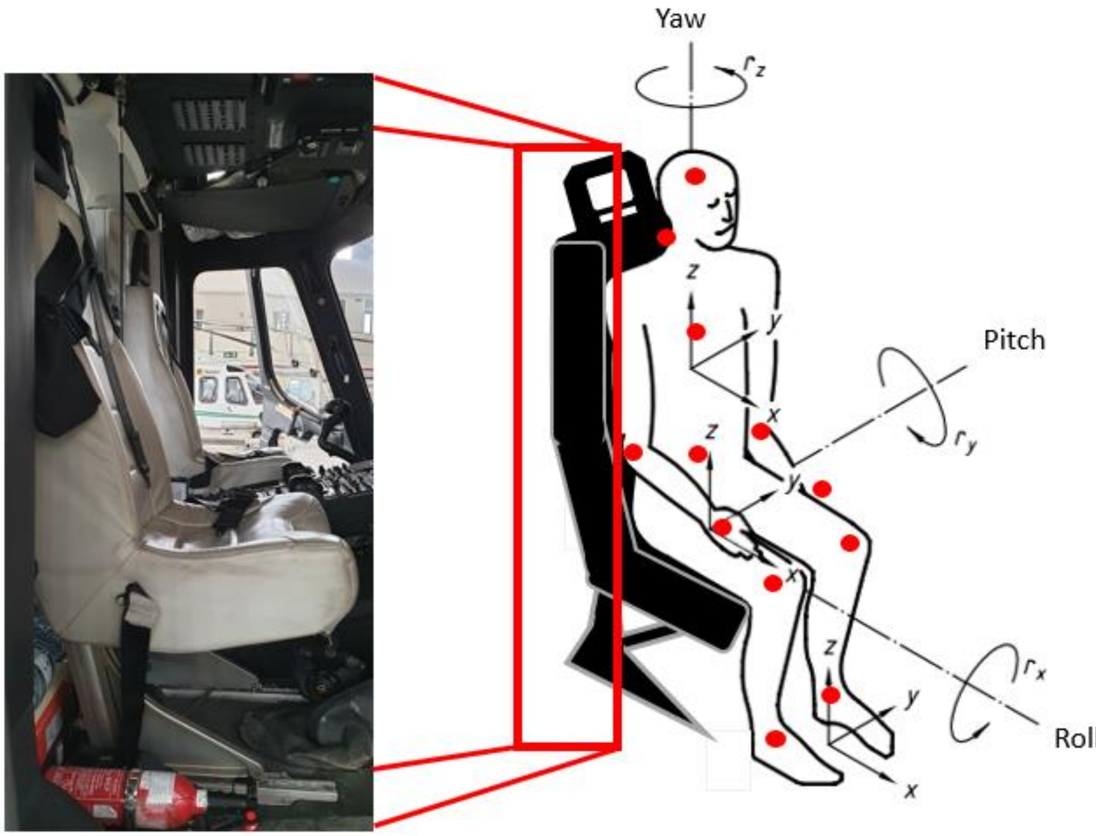



Figure 3: Representation of the location of the felt impact of vibrations on the pilot.
Source: Author´s Creation, adaptation of Basicentric axes of the human body for seating position (Auffret et al., 1980; ISO 10056, 2001; ISO 2631, 2018). The author took a photograph of AW189 Seat with Cellphone on the 21/08/2020.

The side effects of cell vibrations are several but in flight have the leading cause, the possibility of delay or incorrect function of each inner body organs functions. "*Although not well studied muscular fatigue, microtrauma and tissue failure, metabolic compromise, microvascular damage, degenerative changes or combinations of these may be present"* (Gaydos, 2012). A prolong and continuous periods each day during *x* amount of years may also cause complete organ failure or result in permanent malfunction. Many loading cycles to which a structure is exposed can result in fatigue failure, mainly due to vehicle structures vibration. The association between helicopter structure as well as the pilot's body structure is clear. Mainly in the skin surfaces, when **exposed to high-frequency noise** can result in fatigue failure and radiate throughout, causing malfunctions (Hubbard, Lansing, & Runyan, 1971).

The **European Directive (EU 2002/44/EC) on human exposure to mechanical vibration** guides the risk of lower back morbidity, the trauma of the spine and severe discomfort. The quantity used as a predictor of the hazard due to WBV **exposure not be exposed to vibration in 8 hours** daily work phase of more than 1.15 $m/s^2$ (101,21 dBA), (European Parliament, 2002). Further supporting documents **ISO 2631 sets boundaries of 0.43 $m/s^2$ and 0.87 $m/s^2$ (92.67 and 98.79 dBA)** stating that exposures exceeding these limitations are likely to pose a level of health risk (ISO 2631, 2018). Although the set boundaries in ISO 2631, there is **no mention of the accumulation of vibration doses nor any information towards the combination of sources of acoustic exposure.** It is a clear fact that helicopter aircrew exposed to vibrations and several acoustic sounds sources both felt physically on the body

Modern helicopters like the AW139 and AW189 have significantly reduced levels of cockpit vibration. Newer design factors such as the number of rotor blades, anti-vibration dampers placed within the seating, gearboxes and engines enhanced designed of ergonomics reducing an ongoing source of pilot discomfort which is different in other helicopters like the S-76 C++ and EC225 proposed in this study. However, all types of helicopters may be subjected to aeronautical and environmental factors. *"A part of the problem of back pain with helicopter pilots is that there are no standardized test protocols for the measurement of helicopter vibration and no design manufacturing limitations worldwide as to maximum vibration exposure"* (McMahon, 2019).

Data acquisition systems collect computer-based data relative to vibrations. Maintenance mechanic monitors vibration measurements, generally with the use of USB external interface and despite having risk management towards vibration. The reason is to provide frequency weightings and reducing the effect on the body, usually using digital signal processing techniques. Systems that conduct successful vibration measurements have a five-step process typically. Although for this study, no measurement of the vibration and analysis and post-processing is used. To understand the process observation in the calibration of helicopter rotor blades author was present in the task with SonAir avionic mechanics.

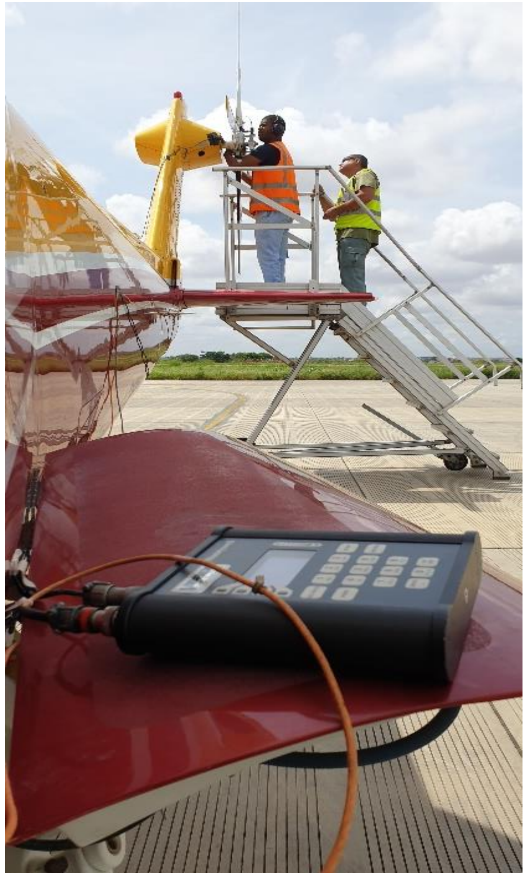


Figure 4: Balance of the tail rotor blades with digital signal processing techniques.
Source: Photograph taken by the author on the 01/03/2019 at FNLU of Maintenance Technician Flávio Silva and Maintenance Senior Avionics Specialist Elvis Alves

### *1.1 Low Back Pain*

Low back pain (LBP) is a common issue within a flight. However, helicopter pilots have significant pain within hours of flying, and for more than 40 years, reports have issued this situation. **Fatigue towards lumber muscle**, caused by vibration widely reviewed in literature and its one of the leading causes. Studies where subjects with 30 to 40 hours of flight per month, as little as 3 to 4 hours per day recorded significate low back/lumbar region and or buttocks pain. Other studies also stating a general description as dull or achy and that this LBP or discomfort may affect flight performance, safety and operational effectiveness in emergencies (Auffret et al., 1980; Boshuizen, Bongers, & Hulshof, 1990; Cunningham, Docherty, & Tyler, 2010; Gaydos, 2012; Kåsin et al., 2011; Ladner, 1997). The prevalence of helicopter back pain due to spine loads in the vertical direction referenced in Ladner´s study, that listed several studies revelling a precise estimate in the total average order of more than 74%, between studies conducted in the time frame from the year of 1962 and 1996 (Ladner, 1997). Cunningham stated however that a higher prevalence recorded, 83% in military pilots and 81% in civilian pilots, out of 440 military pilots and 475 civilian pilots tested (Cunningham et al., 2010). Vibrations felt during flight causes acute pain mainly through mechanical compression due to pilot's static seated environment position and postural stress in flight from prolonged setting. Resulting irritation and inflammation of a localized region are usually defined, in some cases radiating, although the pathology source mainly herniated nucleus, varying pain in diverse areas: muscles, tendons, ligaments and spinal nerves (Auffret et al., 1980; Baig et al., 2014; De Oliveira, Simpson, & Nadal, 2001; M. H. Pope et al., 1987; Malcolm H Pope, Wilder, Seroussi, & Donnermeyer, 1985). In **vivo measurements** revealed, in the seated position. The helicopter pilots, while exposed to WBV suffers in the Z-axis lumbar vertebrae in both horizontal and vertical directions, and also a flexion-extension rotational component. (Panjabi, Andersson, Jorneus, Hult, & Mattsson, 1986). LBP is frequently reported to **last for a few days or longer**, depending on the **type of pain if acute or chronic** (Auffret et al., 1980). Several exercises can help relieve pain, and sometimes, pain is only felt a few hours after the flight. However, the author acknowledges that **several factors may contribute to LBP**. Such as **age** (Bovenzi, 1996; Ladner, 1997), **height, weight, Body Mass Index** (BMI)(Ladner, 1997) and seating posture (Malcolm H Pope et al., 1985). The author also acknowledges that these factors may have a contributing factor towards the increase or decrease of pain. The longer daily flight hours exposed, greater to 4 hours a day and greater to 70 total hours per month may result in accumulated acute pain. When countermeasures emplaced, it helps in the mitigation of hazard. Otherwise, the ultimate risk will transient and acquire chronic pain or disease. When a pilot's condition reaches this point, impairment to work or permanently disabled for activity may occur. "*Back pain among helicopter aircrews is prevalent across the spectrum of airframes and countries…. Clear effects on aircrew health and the potential to jeopardize flight performance, safety and operational readiness"* (Gaydos, 2012).

A **solution** commonly used in other industries is to lower vibration dose. Similarly used in the helicopter activities with AW139, reducing the speed of the vehicle will commonly result in a reduction of vibration. "*If however the exposure cannot be reduced by engineering means, then reducing the number of operation per exposed person might be the only option for reducing vibration exposure dose. Achieved by reducing demands on the pilot by job rotation"* (Mansfield, 2004). A conventional industry good practises **ON and OFF rotations** of more than 15 days for pilots and thus providing body to selfheal. However, other measures are sometimes needed to provide an effective reduction of risk, similarly done in the aviation industry by **controlling the fatigue** of crews with the use of a Fatigue Risk Management System (FRMS) (ICAO 9859, 2018). Accumulated fatigue is consequently present in WBV. It is expressive and depending on the degree of **exposure time while flying** a helicopter. Especially when exposed to higher values than to those safely recommended in safe and health organizations that regulate job-related occupations.

When flying the body, mind, and soul must be one. A pilot must feel the machine as part of its body, and all sensory sources make flying and the flight itself safe and perfect (free from malfunctions). Neglecting or disregarding any sensory source of its max capacity, it is like losing a limb and not being unique. Hearing for a pilot is one of the essential sensory sources of balance. Therefor essential to flying, some may consider being the second most important after sight, although it is subjective. The **auditory system** is one of the four combined vibration-sensing organs, and it is **the final sensory system for whole-body vibration**. At frequency ranges above 20Hz, like in helicopters, vibrating surfaces can act as loudspeakers (Mansfield, 2004). Thus, having an enormous impact on **hearing damage**.

### *2. Hearing Loss (HL)*

The human body with **self-degeneration** may tend to lose hearing abilities with time. Although HL previously documented in civilian and military aviation, little has been relative to offshore oil and gas activities due to the daily prolonged exposure periods. The most significant contributor to risk is considered to be large pressure-amplitude. Values that are equal or above 90dB SPL and low frequency at or below 500Hz of noise, which in this case for helicopter pilots it is a big concern. HL **develops slowly** as a result of exposure continuously or intermittent to loud noises, commonly the same as heard from engines and rotors in helicopters. **Pilots may become disabled**, depending on the severity of HL. "*Hearing is an important physiological sensory source of information in flight. A derivative of noise is vibration, which is sound at a lower frequency. Although there is physical energy involved that is felt more than heard, and its side-effect's on the body are also capable of impairing a pilot"* (Reinhart, 2008). When it comes to HL, studies show several side effects that are imperative to safe flying. With time, exposure and age, it may tend to worsen the pilot's conditions. The prolonged exposure to main and tail rotor loud noise create a continuous and cyclic movement of the eardrum on its function in working back and forth with each sound wave. This exposure may damage its correct function. The outer ear obstruction or damage may affect the signal continuation, causing a break in the bridge between the three parts of the ear (figure 5) and ultimately HL in the middle and inner ear. McReynolds study stated the benefits of **hearing correctly**, evidences an increased ability to communicate and hear an alarm, reduced fatigue and increased health (McReynolds, 2005).

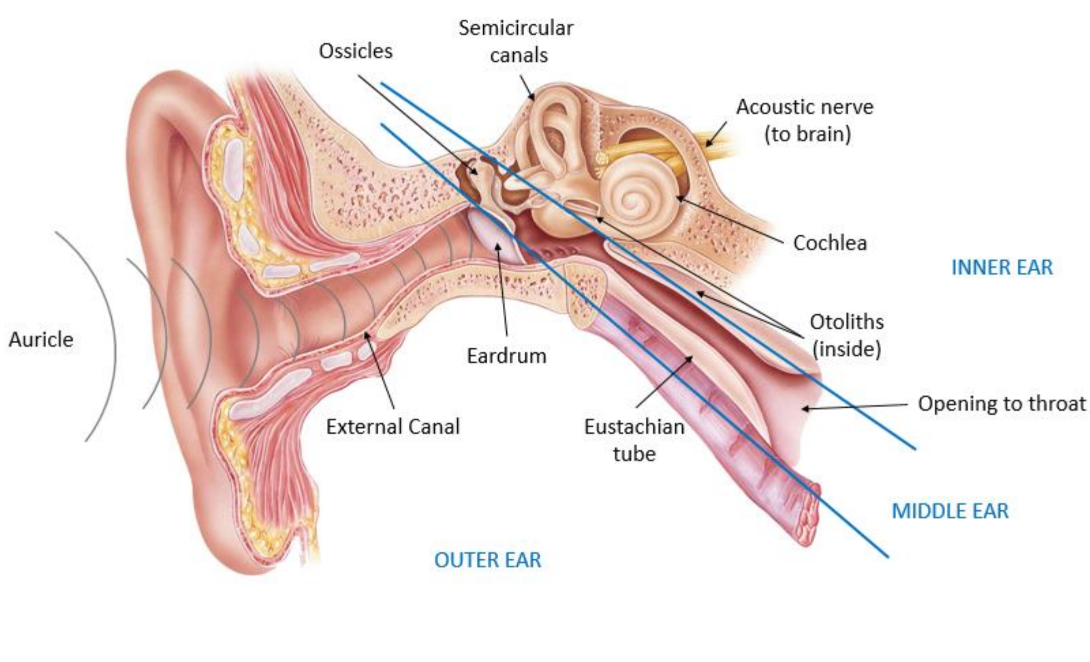



Figure 5: Divided parts of the ear (outer, middle and inner ear)
Source: Author´s Creation, an adaptation of The ear divided into inner, middle and outer parts (Reinhart, 2008)

**Continuous noise exposure** due to sustained flight operations may pose a potentially significant risk to the pilot's health and as a result of operational flight safety. Infrasound and low-frequency noise (ILFN) that works in the range of 0 – 500 Hz are agents of disease when excessively exposed in individuals as whole-body vibration. It leads to developing Vibro Acoustic Disease (VAD), termed by (Alves-Pereira & Castelo Branco, 2007) of the condition, in other words hearing loss or impairment. "*VAD has been diagnosed within several professional groups employed within the aeronautical industry"* (Alves-Pereira & Castelo Branco, 2007). Studies have shown that **blade slap**, cause more annoying noise spectrum in critical bandwidths of the ear's response. That helicopters have a typical spectrum of 90 – 1000 Hz region of significant contributions to annoyance and ear damage pending on position and exposure period. When it comes to **flying helicopters, there are several noise sources associated**. Separately from the engines, there is a particular emphasis to main and tail rotors with steady, periodic and random loads on the rotor blades, as well as volume displacement and nonlinear aerodynamic effects at high blade Mach numbers (George, 1978). Several sources generate the **sound environment created around the pilot inside the cockpit**. The main can be said to be due to main and tail rotor blade forces (7 forces) and blade volume while rotating, engine sound while working and drive-train components. Depending on the rotation, clockwise or counterclockwise, the sound will have an intensely higher felling on the side of the advancing blade. As a result, it may cause a slight percentage more significant to the opposite pilot in the cockpit, nevertheless convincingly felt when exposed during a prolonged period while flying. The **sound intensity** will also be a factor to consider. The **phase of flight** with higher emphases is an approach. Frequently executed at lower speeds have higher disk loads. They are resulting in lower harmonic loads of the blade slaps, causing higher and more concentrated noise. Acoustic wind tunnel tests show that tail rotor noise is predominant when compared to the main rotor noise in a climb flight phase by approximately 10 dBA or more when compared to the descent flight phase. The main rotor dominates total noise radiation due to blade vortex interaction (BVI) by approximately 6 dBA or more and in general level flight, hover, descent and climb conditions exposing pilots to variations between 85 – 115+ dBA

(0.177 $m/s^2$ - 5.62 $m/s^2$) with frequency variations between 315 – 8000 Hz (Yin, van der Wall, & Oerlemans, 2008).

### *2.1 Type certificate data sheet for noise (TCDSN)*

The approved EASA certification noise levels are part of the aircraft certification process. These noise levels established in compliance with the applicable noise standards, defined in ICAO Annex 16 Volume I. They are the basis against which the National Aviation Authorities of EASA Member States issue individual noise certificates, to aircraft on their registers using the EASA Form 45. Comparing the type of aircraft, as per table 1 below, the exposure of noise varies between 90.3-101.4 dB at given specific stages of flight. However, this may vary depending on the pilot's experience and flight conditions (wind, rain, day, night, visibility, weight, speed, angle of approach). The internal cockpit noise pilots are exposed, is a high contributor to fatigue. The high radiation noise levels have prejudiced the very operation which the helicopter uniquely fitted to perform – in this case, offshore transportation. The hours of exposure during daily activities add up sometimes up to 10 to 12 hours of duty period and up to 8 hours of flying.

Table 1: Noise Exposure by Flight Condition with MTOW.
Source: Author´s Creation, *(Agustawestland, 2012; Corporation, 2013; European Aviation Safety Agency, 2013; Holder, Piazza, & Grappa, 2016; Leonardo Helicopters, 2013) **(Corporation, 2016; Helicopters, 2014; Holder et al., 2016; Leonardo Helicopters, 2016)

| HELICOPTER | MTOW * (Kg) (TCDS) | Nº MR + TR BLADES* (TCDS) | NOISE (EPNdB)** | | |
|---|---|---|---|---|---|
| | | | TAKEOFF | OVERFLIGHT | APPROACH |
| S-76C++ | 5 307 | 4 + 4 | 96,0 – 97,3 | 93,2 – 96,3 | 97,7 – 98,3 |
| AS332L2 | 9 300 | 4 + 4 | 94,6 – 99,7 | 93,4 – 98,7 | 96,1 – 100,7 |
| EC225LP | 11 000 | 5 + 4 | 95,6 – 100,4 | 93,5 – 99,4 | 98,9 – 101,4 |
| AW139 | 7 000 | 5 + 4 | 90,3 – 98,5 | 90,7 – 97,5 | 94,1 – 99,5 |
| AW189 | 8 600 | 5 + 4 | 91,3 – 96,3 | 95,2 – 94,3 | 99,1 – 99,3 |

However, the **recommended exposure daily dose** is far lower when it comes to the real values exposed and referenced above. The United States of America, as of its **Occupational Safety and Health Administration (OSHA**) state that, the daily dose of noise exposure shall be an average of 90 dBA over a total time of 8 hours, at 92 dBA a total of 6 hours, at 95 dBA a total of 4 hours, at 97 dBA a total of 3 hours and at 100 dBA a total of 2 hours daily exposure (OSHA, 2020). On average, regarding helicopter types referred in table 1 above, **95,5 dBA is the average value of pilot exposure during daily flight activity**. It is safe to state that reference this amount of exposure, pilots should only be exposed daily a total of 4-6 hours as the maximum amount of flying time. Considering that headphones used may be considered a mild condition protective equipment, with a different amount of equipment's to choose from in the market, it is subjective. The internal cockpit noise levels often substantially exceed the accepted hazardous limits (Lowson & Ollerhead, 1969).

Table 2: Daily Recommended hours of Noise Exposure per Flight.
Source: Author´s Creation *(Corporation, 2016; Helicopters, 2014; Holder et al., 2016; Leonardo Helicopters, 2016) **(OSHA, 2020)

| HELICOPTER | AVERAGE PILOT NOISE EXPOSURE /FLIGHT (EPNdB)* | OSHA RECOMMENDED DAILY EXPOSURE (hours)** |
|---|---|---|
| S-76C++ | 96,46 | Less than 4h |
| AS332L2 | 97,2 | 3h |
| EC225LP | 98,2 | Less than 3h |
| AW139 | 95,1 | 4h |
| AW189 | 95,91 | Less than 4h |

Rotating blade noise in extreme cases will result in hearing loss In-flight crews as a result of lower levels over a more extended period. In contrast, in-ground crews is a result of short-term exposure to intense noises over a shorter period when not working in an airport attending or providing service to several aircraft (Hubbard et al., 1971).

**Accumulated fatigue** is therefore present, and a fact when flying a helicopter since there is a definite addition of **two sources of fatigue, WBV and noise**. However, knowing to be strongly subjective and depending on exposure time. Both prominent contributors to increase cognitive fatigue, which may affect pilots in respect to possible delayed reactions, alter perspectives of situation awareness and lead to jeopardizing decision making. Hearing Loss might always be present in aviation until aviation changes to electrical engines. However, even then there is yet a lack of evidence that it will not produce rotor vibration and noise or even if the levels will be higher or lower. Therefore it will always be an issue to oversight and monitor the risk to its pilots and crewmembers. Knowing this, operators need to find means to implement the reduction of excessive vibration and noise being experienced by pilots today.

This **industrial problem calls for self-awareness** and employees general knowledge towards HL. Operator's safety department shall: annually conduct education and training on HL, noise monitoring in the work environment, provide notification and information to employees of noise exposure, noise surveys to identify potential hazardous on noise level, identify possible staff health condition anywhere noise levels exceed 80 dBA, require the mandatory use of proper personal protective equipment (PPE) and signs posters should be at the entrance to any working area. In consequence, it provides an employee with a safer work environment and practices towards prevention in Noise-Induced Hearing Loss (NIHL). Recommendation for the use of pilot headphones with active noise cancelling systems. With this system in pilot headphones, the acoustic field inside the *ear cup detected and an antiphase signal fed back into the cup to cancel out some of the sound energy*" (Owen, 1995).

### 3. *Age*

Age is a reference that the science comity with relation to time has determined and proven to be associated with the process of the **body's self-degeneration**. Humans are affected by different forms and ways. Science has also revealed, microscopically that each human beings body cells are susceptible to have their body self-degenerate faster than others. If one was to accelerate time, the intensity of its effects towards the body cells is highlighted and become more noticeable, just like travelling at the speed of sound in a fighter jet. The simple correlation may state that if the human body cells are accelerated, the cells normal vibrations cycle may be bound to cause change or damage. Therefore cause alterations in our wellbeing, to what is considered to be a normal state of self-degeneration with elapsed time. The **combinations of noise and WBV** is that acceleration, "the fuel", towards the **increase of fatigue when added to age**. Abbate proved that WBV affects neuropsychic /emotional responses. Correlation towards a psycho-emotional state with an increase of age. Abbate's study revealed not only above-normal values in irritability, but also a weakness, loss of physical energy, cognitive inefficiency and emotional disorganization (Abbate, Micali, Giorgianni, Munaò, & Brecciaroli, 2004; Kryger, Roth, & Dement, 2011). "*Three factors that can dramatically affect sleep are age, alcohol and sleep disorders"* (Gregory et al., 2010; Kryger et al., 2011). Ultimately **age also affects sleep and lack of sleep causes sleep disruption** and therefore causing an increase in fatigue, not only mentally but also physically. "*At approximately age 50, significant changes in sleep begin to occur that include less deep sleep (also known as REN sleep or slow-waves sleep), more* *frequent awakenings, and less consolidation of nocturnal sleep periods. In addition, most sleep disorders increase in prevalence and severity with age"* (Gregory et al., 2010; Kryger et al., 2011). When it comes to **HL studies, several show side effects that are age-related**.

A significant reduction, inadequate or decline in monaural and binaural cues to sound localization, adequate self-motion perception, environmental spatial orientation, awareness of auditory objects and events, ability to make appropriate postural adjustments, to remain orientated in space, and to initiate appropriate and timely reactions to changes in the environment (Campos et al., 2018; En–tong et al., 2008; Kuronen et al., 2004). **With age, the middle and inner ear change their physical characteristics**, as seen in figure 6. In the **middle ear**, change is present in the ossicles. Calcification, stiffening of joints and dislocations of the three bones, result in several middle ear infections or inflammation associated with fluid or trapped gas.

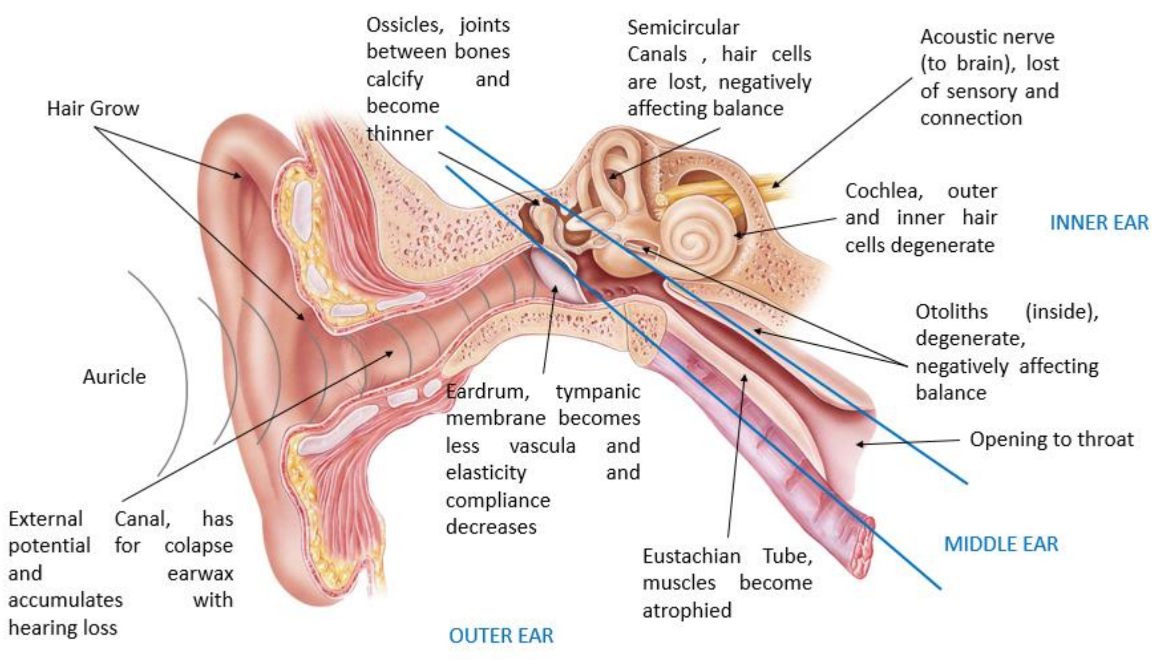



Figure 6: The ear changes with age-associated to HL.
Source: Author´s Creation, an adaptation of The ear divided into inner, middle and outer parts. (Reinhart, 2008).

In the **inner ear**, change is present in the cochlea where thousands of receptors that produce electrical impulses to the acoustic or auditory nerve to the brain. Therefore any damage to the receptors is bound to result in HL by nerve or noise. The **exposure to high noise** will result in what is called to temporary noise-induced hearing loss (NIHL) when the receptors are damaged. However, over time most will repair themselves, it is essential that **pilot rest, to provide self-restoration** (En–tong et al., 2008; McReynolds, 2005; Reinhart, 2008). High noise-exposed by pilots, calls for risk management towards fatigue relating to noise or HL in helicopter pilots and demonstrates tremendous importance to the rest of the body to selfheal. Many helicopter pilots report ringing in ears after a flight.

Despite pilots having **personal owned headphones**, with noise-cancelling systems, duration of flights and associated exposure noise may result in a certain degree of damage to the auditory nerve. Therefore potential **damage is time and intensity related**. The crucial result to pilots is the inability to detect the sounds and its intensity efficiently and clearly being aware of the cues and their role in the execution of a safe flight (En–tong et al., 2008). Although increasing numbers of preventive measures against noise damages have been currently put in place, helicopter pilots still subjected to potentially harmful levels of noise well above the threshold in the values above 80.2 and 99.5 dBA (McReynolds, 2005). The actual consequences of such exposure remain poorly documented. Campos et al. stated in their study that those with **hearing loss may allocate more cognitive resources to listening**, thereby reducing the cognitive resources that remain available to support mobility. Paralleled age-related hearing and vestibular losses are social isolation and reduced participation. Leading to physical and or cognitive inactivity and declines in functioning, which commonly compared in association to own fatigue (Campos et al., 2018).

Whereas to **safety-related**, it becomes clear that it automatically compromised due to physical and cognitive inactivity and declines in functioning due to cognitive load. Affected crew member suffering of HL, may require double the regular use of his cognitive energy. On the other hand, a healthy crew member without knowledge of colleagues condition may become more fatigued. Continuous task confirmations and repetition of requesting tasks and actions may be required. Ultimately, resulting in increased fatigue for both pilots.

### 4. Correlation of WBV, HL and Age with Pilot Fatigue

A clear correlation of WBV, HL and age calls for risk management towards fatigue since it affects the pilot's Situation Awareness (SA) and of extreme importance to conduct a safe flight. When relating to helicopter pilots, it demonstrates supreme importance for the rest of the body in its self-healing process. Despite SA being essential for any aviation activity and indifferent from aircraft or type has flown, fixed or rotor wings, for helicopter pilots and low-level operations like in the offshore industry it is indeed crucial. The aeronautical industry for this cognitive skill defines it as *''the perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of their status in the near future*" (Endsley, 1988). SA means having a mental picture of the existing inter-relationship of all the surrounding environment (location, flight conditions, configuration and energy state of aircraft, terrain, obstructions or obstacles, airspace and meteorological conditions (present and imminent future) and being in a state of pure synchronism with the helicopter through pilots readiness, alertness and performance. Whenever this synchronism is affected due to fatigue, the flight is at risk since its cognitive skill may be affected. The lack of SA may result in loss of control, airspace infringement, entering in adverse meteorological clouds, loss of separation and Control Flight Into Terrain (CFIT). Good SA is essential with regards to terrain when flying in an offshore area of operations (IOGP, 2017). Several factors may contribute to the decrease of SA and in Endsley "aircrew decision Model" from 1988. However, apparent failure towards individual pilots fatigue may have been neglected in Endsley´s aircrew decision model. Pilot's general wellbeing is essential. A proposed, correlation between WBV, HL and Age in figure 7 shows how SA and safety may be compromised when fatigue, sleep disruption and stress is present. A pilot under the influence of decreased SA may lead to incorrect or precipitated decision making and improper or negligent actions towards flight, therefore jeopardizing general operations safety.

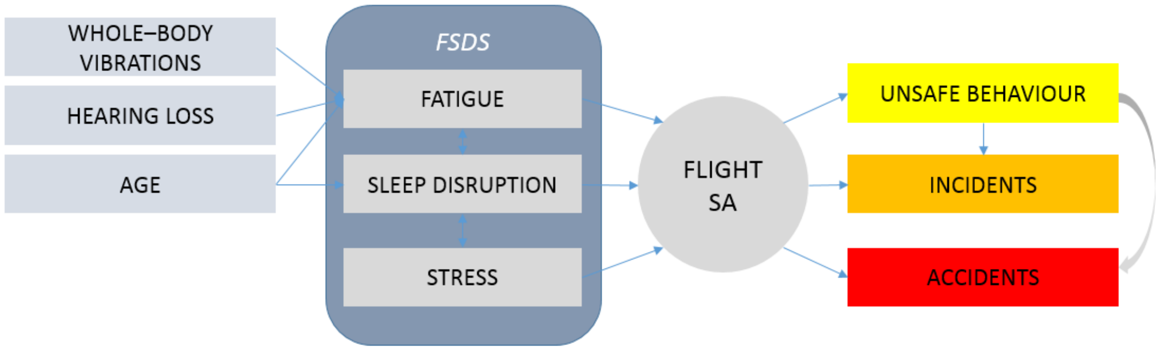



Figure 7: The Proposed relationship between WBV, HL and age with in-flight SA and unsafe behaviour, incident/accident.
Source: Author´s Creation, an adaptation of Work Situation Awareness (Sneddon et al., 2013)

Explanation in figure 8 shows how Endsley 1988 aircrew decision model with Fatigue Sleep Disruption and Stress (FSDS) affect SA. Sneddon stated, "*Higher levels of stress and fatigue are linked to lower levels of work situation awareness, which in turn are indicative of increased participation in unsafe work behaviours, and higher accident risk".* (Sneddon et al., 2013).

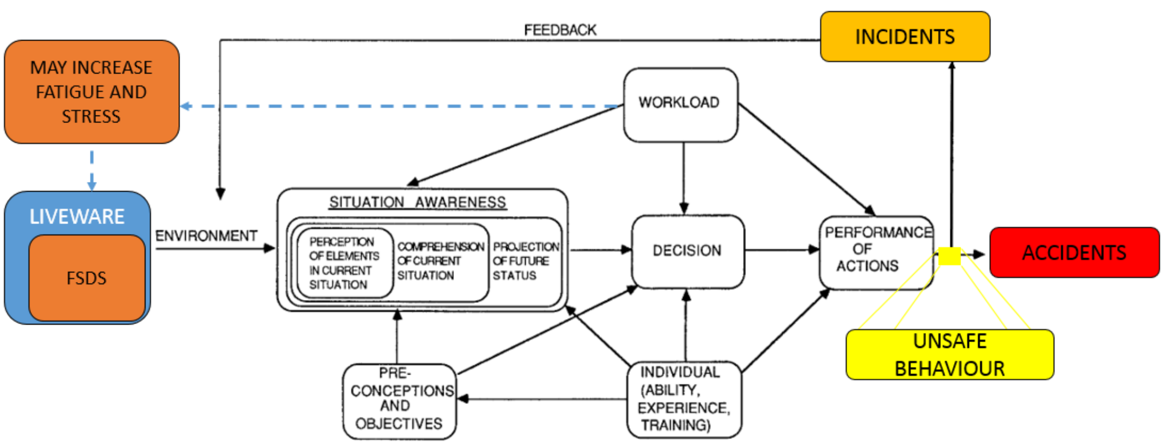



Figure 8: Aircrew decision model with Fatigue, Sleep Disruption and Stress (FSDS) affecting SA.
Source: Author´s Creation, an adaptation of the Aircrew Decision Model (Endsley, 1988)

Studies since 1983 have shown a clear **correlation between age and total flight hours** (Fitzpatrick, 1988; Owen, 1995). Bovenzi study also revealed a prevalence of chronic LBP with the increase of age (Bovenzi, 1996). A **clear association between noise and fatigue**, since noise is a form of energy, it acts directly on our body as well as on the hearing mechanism just like vibration.

**Reinhart et al. references exposure** of allowable noise inferior to the values of OSHA and ISO (Reinhart, 2008). The author believes values may have a considerable influence on the accumulated fatigue to pilots. Significantly enough to confirm that NIHL can be induced from as little as 5 dBA difference from the limit value. Thus with the belief of contributing to the camouflage towards an industrial problem. However, no information can be confirmed. It is a fact that both recommended regulations OSHA and ISO have nothing towards several energy sources. In the case of the helicopter, they have at least six to eight energy sources, noises from; main rotor, tail rotor, each turbine engine and the vibration caused by rotation of both rotors and mechanical vibration released from engines. The **combination of all energy sources** when analyzed in decibels can foresee an increase in the estimated value of exposure daily limit. Compared to Reinhart´s values, in both regulations to maximum exposure limits. Calculations in figure 9, show an increase between 4,55 dBA and 9,33 when combined, with WBV inferior limit or with the superior limit. Comparing to the maximum **exposure limits from all three references,** in some cases an increase between 9,55 dBA and 14,33 dBA when combined with WBV inferior limit or with WVB superior limit.

Abundant scientific data exist in the aviation industry to demonstrate that affecting the **circadian rhythm**, or biological clock degrades the alertness and performance. Affecting behaviour and mood and therefore putting at risk pilot's effectiveness (Gregory et al., 2010; Kryger et al., 2011). **Sleep disruption** may lead to sleep disorder if unattended, causing insomnia (decreased alertness and performance reaction time), restless legs syndrome, circadian rhythm sleep disorder, sleep apnea and snoring (Gregory et al., 2010; Kryger et al., 2011; Rabinowitz et al., 2009). Ultimately posing a potential higher risk to operational flight safety, the older a helicopter pilot is.

| NOISE EXPOSURE LIMITE TIME/DAY (hours) | Basic Flight Physiology (REINHART) (dBA) | OSHA Federal Regulation 1910.95 (03 APRIL 2020) (dBA) | ISO 2631-2018 Maximum Exposure Level (dBA) | WBV LIMITE *inf.* (dB2) | WBV LIMITE *sup.* (dB2) | ISO2631 CALCULATED AVERAGE HL+WBV EXPOSURE LIMITE inf. dBtotal/H (dBA) | ISO2631 CALCULATED AVERAGE HL+WBV EXPOSURE LIMITE sup. dBtotal/H (dBA) | CALCULATED AVERAGE HL+WBV EXPOSURE LIMITE TIME/DAY (hours) |
|---|---|---|---|---|---|---|---|---|
| 8h | 85 | 90 | 90 | 92,67 | 98,79 | 94,55 | 99,33 | 6H15 |
| 7h | 86 | 91 | 91 | 93,67 | 99,79 | 95,55 | 100,33 | 5H30 |
| 6h | 87 | 92 | 92 | 94,67 | 100,79 | 96,55 | 101,33 | 4H45 |
| 5h20 | 88 | 93 | 93 | 95,67 | 101,79 | 97,55 | 102,33 | 4H20 |
| 4H40 | 89 | 94 | 94 | 96,67 | 102,79 | 98,55 | 103,33 | 3H55 |
| 4h | 90 | 95 | 95 | 97,67 | 103,79 | 99,55 | 104,33 | 3H30 |
| 3h30 | 91 | 96 | 96 | 98,67 | 104,79 | 100,55 | 105,33 | 3H00 |
| 3h | 92 | 97 | 97 | 99,67 | 105,79 | 101,55 | 106,33 | 2H30 |
| 2h40 | 93 | 98 | 98 | 100,67 | 106,79 | 102,55 | 107,33 | 2H05 |
| 2h20 | 94 | 99 | 99 | 101,67 | 107,79 | 103,55 | 108,33 | 1H40 |
| 2h | 95 | 100 | 100 | 102,67 | 108,79 | 104,55 | 109,33 | 1H15 |
| 1h30 | 97 | 102 | | | | | | |
| 1h00 | 100 | 105 | | | | | | |
| 00h30 | 105 | 110 | | | | | | |
| 00h15 | 110 or less | 115 | | | | | | |

Figure 9: Exposure Limits, TWO Acoustic Sources Towards NIHL.
Source: Author´s Creation, adaptation of Allowable noise exposure, the OSHA Federal Regulation 1910.95 and the ISO 2631 Maximum Exposure Level with a study analysis of exposure limit due to more than one acoustic source of NIHL (ISO 2631, 2018; OSHA, 2020; Reinhart, 2008) Note: Values in blue colour are calculations based on standards and the sum of two acoustic sources. Colour code boxes refer to the increasing degree of operational safety towards fatigue based on noise exposure limits (green being safe, red being unsafe).

Table 3: Body organs and its side effects when in stress after exposed to WBV, Noise Limits & Age.
Source: Author´s creation and compilation (Gradwell & Rainford, 2015)

| BODY SYSTEM | BODY ORGAN | SIDE AFFECT[1] |
|---|---|---|
| Nervous system | Brain, spinal cord and nerves. | Mood swings, depression, irritability, aggressiveness, lack of energy, problems with concentration, panic attacks and anxiety. |
| Musculoskeletal system | Muscle and Joints (Knees, elbows, lower back, neck) | Pain, inflammation, tension, decreased bone density, stiffness in the shoulders and back.<br><br>*(Age a significant factor)* |
| Endocrine system | Ovaries/ Testicles | Decreases testosterone and estrogen production, reducing fertility and sexual desire. |
| Gastrointestinal system | Intestines | Decreases nutrient absorption, reduces metabolism, constipation, increases the risk of inflammatory bowel diseases (esophagitis, gastritis, colonitis, ileitis, and proctitis), decreases enzyme activity and diabetes. |
| | Stomach | Can cause ulcers, irritable bowel syndrome, food allergies, stomach cramps, reflux, nausea and weight fluctuations. |
| | Pancreas | It has elevated insulin secretion that can lead to diabetes, as well as damage to arteries and obesity. |
| Circulatory system | Heart (Arteries, veins, blood vessels and lungs) | Increased blood pressure, fast heart rate, increased risk of heart attack and stroke, increased "bad" cholesterol.<br><br>*(Age a significant factor)* |

All the literature gives a clear view of the risks related to fatigue that come with WBV, Age and Hearing Loss. A focused approach established with the research questions that could then enlighten possible outcomes from hypothesis within each question.

[1] Exposure side effects over time.

## Chapter IV Research Questions

To better understand and fulfil the purpose of the research study, several questions and hypothesis were placed to each question. They focused on obtaining a clear view of possible fatigue impact in pilot's fitness to fly.

Table 4: Question and Hypothesis. Source: Author´s creation

| | |
|---|---|
| **RQ 1:** Exposure to whole-body vibrations, above-average noise from the blades and engines is the general result of the helicopter pilot's fatigue of impact. | H1: Prolonged periods of Whole-body Vibration can result in pilot higher fatigue impacts.<br><br>H2: Whole-body Vibration and above-average noise can cause hearing loss.<br><br>H3: Hearing Loss is a contributor to pilot fatigue.<br><br>H4: The longer the rest period, the safer the pilot are to fly. |
| **RQ 2:** Is age and the total of flight hours exposed daily a direct association of having a significant impact on the fast recovery of the health effects on the body and fatigue of pilots? | H5: Helicopter pilots have their cells and organs more affected the higher the Age.<br><br>H6: Age induces higher recovery time from fatigue.<br><br>H7: Cells and organs are affected by the abnormal acceleration due to vibration and therefore result in further fatigue.<br><br>H8: Age is a great contributor to fatigue.<br><br>H9: Cells and organs are affected and result in further fatigue and possible shutdown or malfunction of |

| | |
|---|---|
| | metabolism, which may result in diseases and ultimately in the pilot being unfit to fly.<br><br>H10: Malfunction of metabolism may result in discomfort, increase stress and fatigue, diseases and ultimately in pilot unfit to fly.<br><br>H11: Best number of hours per day is in between 4 to 6 hours of flying per day. |
| **RQ 3:** A safer analysis toward fatigue measurement related to working flight hours per each rotation scheme ON/OFF, are the result of better understanding in the selection of the best rostering scheme 7, 14, 21, 28 or 35 days ON/OFF and scheduling in association with sleep habits as well as pilot's primary role of responsibilities. | H12: ON/OFF rotation scheduling cannot be helpful because the body does not regenerate to its perfect state of health.<br><br>H13: ON/OFF rotation scheduling can be helpful because body, mind and soul can rest and regenerate it is almost or perfect state of health.<br><br>H14: Bearing the industries best practice and the national Angolan Aviation laws, 21 ON 21 OFF is the best rotation for pilots.<br><br>H15: Bearing the industries best practice and the national Angolan Aviation laws, 28 ON 28 OFF is the best rotation for pilots.<br><br>H16: Delaying fatigue may result in a sudden drop in our immune system and causing a collapse of psychological and physical fitness. |

H17: Pilots fly safer and withhold longer health conditions and careers by flying more and resting less but trying to keep pilots fit shape.

H18: Pilots fly safer and withhold longer health conditions and careers by flying less and resting more but trying to keep pilots fit shape.

H19: Study is unable to provide sufficient knowledge to understand which is better. Further study must be carried out with a higher sample to try to understand the different types of energy levels within different hemispheres.

H20: There may be reasonable data value that one rotation scheme is better than the other, scientifically proven or on bases of a pilot report of wellbeing and fitness conditions.

In order to fulfil the research study questions, a methodology is required. As followed, within figure 10, *Research Methodology,* the author presents the *Conceptual Scheme of Analysis of Fatigue Towards Pilots Operational Fitness to Fly* (figure 11).

# Chapter V Methodology

The following part is the detailed explanation of the methodology used in the research study. Relatively to the study design, participants and sampling, data collection, survey, measures and data analysis.

## *1.1 Study Design*

The general methodology followed by this research study, presented in figure 10. The philosophy behind the methodology is based in part on the ICAO 9854 SMS hazard identification using a proactive approach, safety risk mitigation strategies, categories of reduction or segregation and author's adaptation towards the research (ICAO 9859, 2018). ICAO defines the proactive approach to identify hazards as:

***"Proactive:*** *This methodology involves collecting safety data of lower consequence events or process performance and analyzing the safety information or frequency of occurrence to determine if a hazard could lead to an accident or incident. The safety information for proactive hazard identification primarily comes from flight data analysis (FDA) programmes, safety reporting systems and the safety assurance function"* (ICAO 9859, 2018).

The approach on safety risk mitigation strategies, category of reduction or segregation defined as:

***"Reduction:*** *The frequency of the operation or activity is reduced, or action is taken to reduce the magnitude of the consequences of the safety risk"* (ICAO 9859, 2018).

***"Segregation:*** *Action is taken to isolate the effects of the consequences of the safety risk or build in redundancy to protect against them"* (ICAO 9859, 2018).

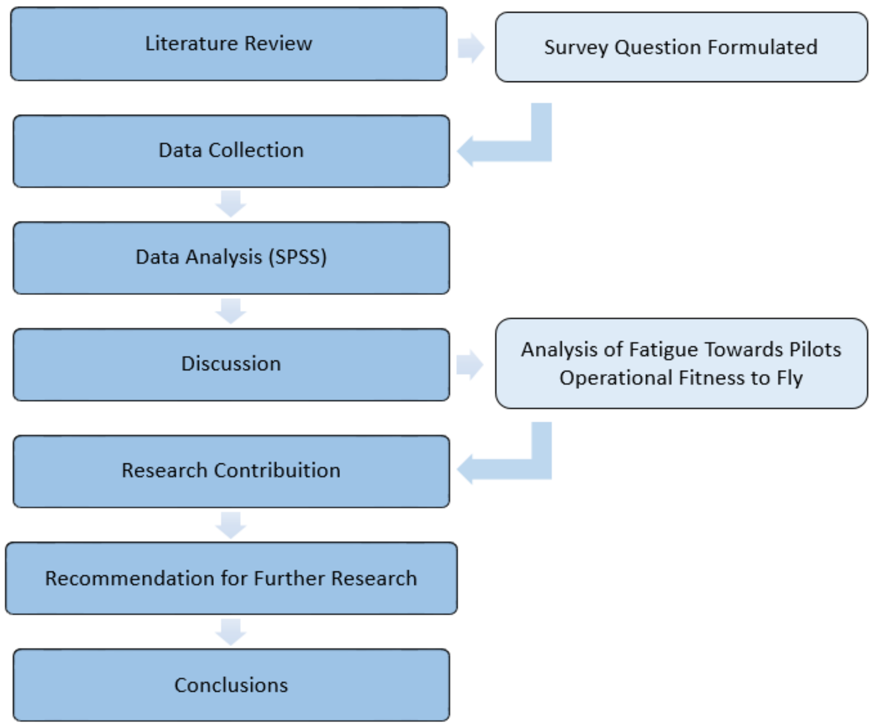



Figure 10: Research Methodology.
Source: Author´s Creation

Based on the literature review and to the aim of the research study, a set of questions were formulated to survey subjects. To ensure that the participant's privacy could be assured, and the time required could be optimized. An individual structured online survey approach was chosen as the most appropriate method. After data collection, IBM-SPSS was used to conduct data analysis. The scope of the discussion will focus on the use of the developed conceptual scheme of analysis of fatigue towards the pilot's operational fitness to fly in figure 11. The scheme used with the intent analyse and understand fatigue on the bases of direct or indirect influence on flight safety. Fatigue analysis based on body exposure to WBV, HL and Age compared to the number of with flight hours and rest periods between flights. In order to fulfil the research scope objectives, the author understands that it was relevant to perform a correlational study with a cross-sectional design, based on self-report survey. The survey was conducted online via Google Forms, under the approval of SonAir and reinforced to conduct under operational safety (GSO). The survey compiled of several questions related to human factors to collect data on fatigue, sleep, rest periods and rotation schemes. The data collected was aimed to provide an understanding of the conditions which may result in fatigue towards the crew, being reported or observed by crew members due to lack of awareness or knowledge. The study on the variables conducted to offshore pilots working in the southern hemisphere precisely in the country of Angola.

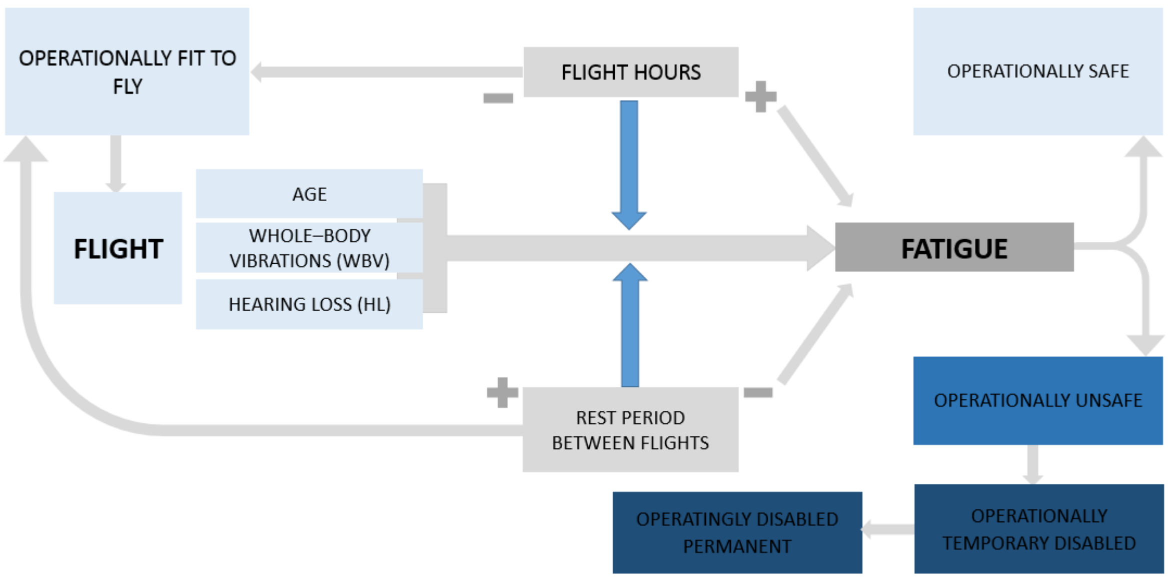



Figure 11: Conceptual Scheme of Analysis of Fatigue Towards Pilots Operational Fitness to Fly.
Source: Author´s Creation

The above scheme, figure 11, illustrates how fatigue can affect the pilot´s fitness to fly. Clear association in how the three leading causes, that is focused on this research study, are affected when a pilot is exposed to an excessive number of flying hours per day. It also explains how the number of hours flown is inversely proportional to the periods of rest. As a result, having a direct impact on the consideration of pilots to be operationally fit to fly. The author defines, Operationally Fit to Fly (OFTF) as, *a pilot or flight crew member that is fit to fly based on: the annual medical safe review, psychological and physiological fit to fly on a daily base, has an individual responsibility to reduce risk by assessing himself based on safety standards and relates his actions in respect of his own and others lives who may fly with, being crew member and or passengers.*

### *1.2 Participants and Sampling*

The **population study size** of offshore helicopter pilots is situated in the southern hemisphere, in western Africa, precisely in the country of Angola within the state held company SonAir. The company has a history of more than 40 years of existence in the oil and gas offshore air support flying both fixed and rotor-wing, a subsidiary company of the national state-held oil company Sonangol. Due to low offshore activities and company restructuring, out of 87 subjects, only 50 were considered the population size and considered active helicopter pilots. In which one is Female, and 49 are Male pilots. The demographic feature selected is the age and gender of participants. It is **non-probabilistic with a convenience sampling** composed by one company, SonAir, with active helicopter pilots of the offshore industry in Angola. The pilots in this study are all class 1 aircrew medical certified, selected by an institutional listing, identified by name and license, with a corporate, personal email account. To determine the **sample size for a given level of accuracy**, the worst-case percentage of 50% as a minimum acceptable sample size, which would represent 25 pilots. The reason was that fatigue could be subjective, and several factors can contribute to fatigue levels with a general overall level of accuracy intent. The **confidence level** used for this research was **95%** with a **confidence interval** (margin of error) of **plus-or-minus 4**. The reason for choosing this audience is because the author is part of the workforce, and has the intention to identify the best type of rotation scheme, taking into account fatigue and rest management. The **number of participants** that replied to this enquiry was 46, equivalent to 92% of the active population. The answers are unquestionable and genuinely reflect the population of active pilots.

### *1.3 Data Collection: technique, instrument, measures and procedures.*

Rigorous measures used to make this survey reliable. The author sought to understand and interpret the results and how they may influence flight safety. Through body exposure of WBV, cause-effect of HL and age with shifts, rest periods and the number of hours of flight that may lead to increase or accumulated fatigue.

### *1.3.1 Survey*

Based on the research study, a set of questions formulated. An individual structured online survey approach was chosen as the most appropriate method. **Advantages** of the online survey are that data can be rapidly collected. The internet is a productive area to conduct such research, and one target varies population, both active and non-active pilots. Time-saving in gathering information. The ability of subjects to self-do. Environmentally clean without the use of paper. **Disadvantages** are that some pilots are with a high rate of age, above 50, and some have very little knowledge of proper internet use in this matter and how to conduct the online surveys. Language barriers or difficulties in some subjects may result in lack of interest in participating. However, to mitigate these issues, a “how to do it” form would be provided at request in the flight safety office. Pilots with difficulties in this matter would receive online login and survey procedures, although no one requested.

### *1.3.2 Measures*

#### *1.3.2.1 Demographics*

The respondents were rotor-wing pilots, operating in two-pilot (multi-crew) environment operations mainly in offshore activities. The author asked participants age, gender and academic qualifications.

#### *1.3.2.2 Professional*

To **measure exposure to WBV and noise, which has a direct impact on HL**. The author asked pilots to report the number of total hours each pilot had in current activity. The number of flight hours where participants considered in feeling under the influence of fatigue, primary role in determining the level of responsibility in the company, number of years of experience in the industry and their opinion towards the best rostering scheme. To **measure exposure to WBV and noise levels affecting HL, that may result in fatigue and to comprehend the level of understanding of fatigue**. The author asked questions regarding pilots flight performance, phases of flight were fatigue most affects the performance, self "nodding off" in flight, refusal of flight service due to being under the influence of fatigue.

The author acknowledges that older helicopter models and manufacture may have had higher values of WBV. However, for this study, it was not focused since it is a fact that all helicopters have high values of WBV some with values above from recommended daily exposure. The author also acknowledges that serval factors result in HL like, not wearing protective equipment while on the ground on the ramp. Pilots not wearing appropriate headphones with active noise reduction, poor ear care or high noise exposure with social activities (positioning near speakers in concerts, night clubs and bar or parties, use of earphones with high volume and even the use of cotton swabs to clean ears).

#### *1.3.2.3 Sleep Quality and Fatigue*

To **measure the level of stability of the internal biological (circadian) clock,** the author asked participants to report their sleeping habits and difficulty in sleep. The ability to sleep during a night shift, resting periods between night shifts and day shifts. Ability to sleep during the day and knowing that the possibility exists to sleep during the night shift influence the daytime sleep habits before reporting for night shift and external factors affecting by 25% the ability of sleep during the day. The same scale used in the Sleep Condition Indicator by the University Of Oxford (Arianna Huffington, 2016).

To **measure knowledge towards human factors,** the author asked a direct question, pilots having human factor training or not. It was validated using a Yes or No answer. Also acknowledge of full understanding to physiological effects of the human body within pilots, relative to flying. It was measured using a 5 point scale, being 1 none and 5 excellent.

To **measure the shifts and best rostering schemes,** the author asked the number of consecutive day shifts. Pilot's knowledge of own fatigue accepted values towards a natural body rest period, required after daily activities. Personal opinion question asked towards the best rostering scheme and the number of hours of flight before being under the influence of fatigue. The same scale used in the NEMSPA Sleep and Fatigue Survey (Gregory et al., 2010).

The author acknowledges that personal opinion is subjective and based on personal experience on recalled memory events and knowledge towards fatigue management and to fatigue risk management system. Therefore a bias is present to overstate desirable behaviours and minimize undesirable ones.

To **measure the fatigue,** the author asked participants to report their ability to detect self and colleagues when under the influence of fatigue, the understanding of the side effects of fatigue and psychological effects when under the influence of fatigue. A comparison study based on manufactures reported vibration data and compared to OSHO and ISO 2631 standards and recommended daily exposure limit values towards WBV and Noise. The second relating directly to the cause of HL. The author acknowledges that several important factors may also contribute to pilot fatigue. Cockpit climate condition (helicopter with and without air conditioning), outside temperature, the previous rest period between flights, family relationship and personal issues, time awake previous to flight, road traffic, distance and time from home to workplace, corporate pressure, commercial pressure, cockpit comfort and ergonomics, cockpit crew individual and combined experience awareness and others. However, ignored despite some reports made by some pilots in the survey in the last survey question, which is an open question.

#### *1.3.2.4 Technique Used*

For the collection of data, the author used a survey resource (Google Forms) through a questionnaire, a total of 39 questions, some drawn from previous studies from NEMSPA Sleep and Fatigue Survey, Questions 16 - 28 (Gregory et al., 2010) and the Sleep Condition Indicator – By Colin Espie, University Of Oxford, questions 29 - 36 (Arianna Huffington, 2016). The **advantage** a safety department has, it can quickly determine the likability of sleep disorder and the alertness within night shift. Fatigue apparent and estimated levels, shift scheme and the relation between day and night, the number of consecutive days of work to understand predictive whole-body vibration dose exposure. The **disadvantage** is that for the first part of the questions from the NEMSPA survey questions had no evaluation scale. Therefore a similar scale from Sleep Condition Indicator had to be adapted, which can affect the outcome towards the points scale. However, the author believes it is admissible because it is subjective to each pilot and other measures analyzed with the risk analyses matrix of fatigue.

### *1.3.3 Instruments*

A survey in electronic format. With the clear and objective multiple-choice, closed and open mixed question plan applied to a representative sample.

#### *1.3.3.1 Procedures*

A letter was written to SonAir CEO, requesting formal authorization to conduct a survey, through GSO and the collection of data related to vibrations from DMAR (rotor-wing maintenance department). A questioner to all pilots with a generic goal conducted under the companies formal approval focused on improvement. Through the department of GSO, on the bases of safety, a survey to mitigate possible risk in FRMS and human factors awareness conditions. The online survey applied between the 3$^{rd}$ of April of 2020 and the 1$^{st}$ of May of 2020, using Google Forms survey. Data collected from DMAR was related to the helicopter models; S76c++, EC225LP and AS332L2. All data related to vibration information of helicopters was referenced previous past flights.

### *1.3.4 Questionnaire Summary*

The following questionnaire summary (table 5), focuses on explaining the variables: demographic, professional and criteria variables. Based on three parts and the questions associated with each section.

Table 5: Questionnaire Summary.
Source: Author´s creation

| Variables | Location | Item Sample |
|---|---|---|
| ***Demographics*** | **PART I** | |
| 1. Age | **Demographic** | **1 – 3** |
| 2. Gender | **Information** | |
| 3. Academic Qualification | | |
| ***Professional*** | **PART II** | |
| 1. Pilot License | **Professional** | **4 – 9** |
| 2. Instrument Rated | **Information** | |
| 3. Military Experience | | |
| 4. Number of Hours | | |
| 5. Main Role in the Organization | | |
| 6. How long in the aviation industry | | |
| ***Criteria Variables:*** | **PART II** | |
| 1. Human Factors | **Sleep Quality and** | **10 – 15** |
| 2. Fatigue (Sleep) | **Fatigue** | **16 – 36** |
| 3. Rotation Scheme | | **37 – 38** |
| 4. Other Information | | **39** |

### *1.4 Data Analysis*

The following section describes how data analysis is collected and conducted. It varies by advisor or publisher although the initial approach is to do as follows:

1. Analytical strategy with the following approaches adopted (steps that took: exploratory, incomplete questionnaires eliminated, exploratory analysis, final distribution)

2. Procedures: IBM-SPSS (Statistical Package for the Social Sciences) version 26 for Windows was used to conduct all statistical analyses.

Once the data collected steps, one and two applied. The results then compiled and presented as of the below.

## Chapter VI Results

The following part describes the data collected through survey applications and the main results obtained from the sample study. A total of 46 responses were received, representing 92% of the studied population size of 50 pilot’s which were considered operational and approximately 52.87% of the population company size of 87 helicopter pilots. The author explains the statistical analysis, sample characterization, professional information, human factors, shifts, sleep, fatigue, sleep condition indicator and the summary of results.

### 1. *Statistical Analysis*

The statistical analysis involved measures of descriptive statistics (absolute and relative frequencies, means and respective standard deviations) and inferential statistics. The level of significance for rejecting the null hypothesis was fixed at ($\alpha$) ≤ .05. Fisher's test and Student's t-test for independent samples were used. The assumptions of the Student t-test were analyzed.

The normality of distribution was analyzed with the Shapiro-Wilk test and the homogeneity of variances with the Levene test. When these assumptions were not satisfied, the Mann-Whitney non-parametric test was used as an alternative to the Student's t-test for independent samples.

### 2. *Sample Characterization*

A total of 46 subjects collaborated in the study. The majority were male (97.8%), Graduate (34.8%) and co-pilot (71.7%). The average age was 39.2 years, ranging from a minimum of 28 to a maximum of 62 years.

Table 6: Sociodemographic Characterization (N = 46).
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Gender | | |
| Female | 1 | 2,2 |
| Male | 45 | 97,8 |
| Age (M;SD) | 39,2 | 9,4 |
| Academic Qualification | | |
| Bachelor Degree | 15 | 32,6 |
| High School | 15 | 32,6 |
| Graduate Degree | 16 | 34,8 |
| Main Role | | |
| Air Check man | 1 | 2,2 |
| Captain | 8 | 17,4 |
| Chief Pilot | 1 | 2,2 |
| Co-pilot | 33 | 71,7 |
| Instructor | 1 | 2,2 |
| Type rating Examiner (TRE) | 1 | 2,2 |
| Type rating Instructor (TRI) | 1 | 2,2 |

## 3. *Professional Information*

The majority of pilots surveyed had a Commercial Pilot License (CPL H) (69.6%). In general, the majority of pilots had an instrument rating qualification and only 2.2% reported not having. On average, the pilots had 3465 flight hours and had been working in aviation for 15 years. Only 26.1% reported having military experience in similar functions as a pilot.

Table 7: Pilot License.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Airline Transport Pilot license (ATPL (H)) | 14 | 30,4 |
| Commercial Pilot License (CPL (H)) | 32 | 69,6 |

Table 8: Instrument Rated.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| No | 1 | 2,2 |
| Yes | 45 | 97,8 |
| Total | 46 | 100,0 |

Table 9: Flight Hours and Aviation Experience.
Source: Author´s Creation with SPSS

| | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| Current number of hours | 200 | 18000 | 3465,00 | 4273,760 |
| How long have you been working in the aviation industry? | 6 | 42 | 14,83 | 10,989 |

Table 10: Military Experience in Similar Role.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| No | 34 | 73,9 |
| Yes | 12 | 26,1 |
| Total | 46 | 100,0 |

## *4. Human Factors*

All Pilots had received training in Human Factors in their initial pilot course. Almost half of the sample (47.8%) classified the knowledge they have about the physiological effects of flight on the human body. The ability, under the influence of fatigue, to detect a body by understanding the effects of fatigue as very sufficient. A little more than half (58.7%) classify the knowledge they have about their ability to detect whether their colleague is under the influence of fatigue as sufficient. About 94% say they perceive the physiological effects of fatigue on the human body.

Table 11: Human Factors Training.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Yes | 46 | 100,0 |
| Total | 46 | 100,0 |

Table 12: Human Factors Knowledge.
Source: Author´s Creation with SPSS

| | | None | Insufficient | Sufficient | Very sufficient | Excellent |
|---|---|---|---|---|---|---|
| Understanding of the Physiological effects of flying in the human body. | Freq. | 0 | 3 | 17 | 22 | 4 |
| | % | 0,0% | 6,5% | 37,0% | 47,8% | 8,7% |
| Ability to detect if your body is under the influence of fatigue. | Freq. | 0 | 1 | 18 | 22 | 5 |
| | % | 0,0% | 2,2% | 39,1% | 47,8% | 10,9% |
| Ability to detect if your colleague is under the influence of fatigue | Freq. | 0 | 5 | 27 | 12 | 2 |
| | % | 0,0% | 10,9% | 58,7% | 26,1% | 4,3% |
| Understanding of the side effects of fatigue | Freq. | 0 | 3 | 19 | 22 | 2 |
| | % | 0,0% | 6,5% | 41,3% | 47,8% | 4,3% |

Table 13: Understanding of Psychological effects.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| No | 3 | 6,5 |
| Yes | 43 | 93,5 |
| Total | 46 | 100,0 |

## 5. *Shifts*

Half of the pilots indicate that they work in shifts of 3 or 4 consecutive days (50%). Most (63%) of pilots have 2 to 3 days of rest when changing from day shifts to night shifts and (60.9%) of pilots have 1 day of rest when changing from night shifts to day shifts.

Table 14: Consecutive Working Day Shifts.
Source: Author´s Creation with SPSS

| | | 1 or 2 days | 3 or 4 days | 5 or 6 days | 7 days |
|---|---|---|---|---|---|
| How many consecutive DAY shifts do you typically work? | Freq. | 6 | 23 | 14 | 3 |
| | % | 13,0% | 50,0% | 30,4% | 6,5% |

Table 15: Rest Transition from DAY to NIGHT Shifts.
Source: Author´s Creation with SPSS

| | | 24 hrs | 2 to 3 days | 4 to 5 days | Greater than 7 days |
|---|---|---|---|---|---|
| How long are you typically off when transitioning from day shifts to night shifts | Freq. | 15 | 29 | 1 | 1 |
| | % | 32,6% | 63,0% | 2,2% | 2,2% |

Table 16: Rest Transition from NIGHT to DAY shift.
Source: Author´s Creation with SPSS

| | | 24 hrs | 2 to 3 days | 4 to 5 days | Greater than 7 days |
|---|---|---|---|---|---|
| How long are you typically OFF when transitioning from NIGHT shifts to DAY shifts? | Freq. | 28 | 16 | 1 | 1 |
| | % | 60,9% | 34,8% | 2,2% | 2,2% |

## *5.1 Best Rostering Scheme*

Majority of the pilots reported the best rostering scheme being 21 on 21 off with 45.7% while 28.3% reported being 28 on 28 off.

Table 17: Pilots Opinion Towards Best Rostering Scheme.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| 7 on 7 off | 1 | 2,2 |
| 14 on 14 off | 10 | 21,7 |
| 21 on 21 off | 21 | 45,7 |
| 28 on 28 off | 13 | 28,3 |
| Other (30 on 30 off) | 1 | 2,2 |
| Total | 46 | 100,0 |

# *6. Sleep*

Most indicate that they usually sleep between 5 to 6 hours on night shifts although a high percentage (71.7%) recon the needs to sleep between 7 to 8 hours to feel restored entirely and alert during the day. When asked to describe daytime sleep habits before a night shift, 37% said they try sleeping as much as possible during the day, and 39.1% indicate that they try to take naps with less than 2 hours. More than half of the sample (54.3%), indicates that noise affects their sleep during the day. At the same time, 32.6% consider that what affects them most is temperature or children (playing, needs for attention or school support). For about 42%, knowing that they can sleep during the night shift, influences their daily habits, if they have something to do. On the other hand, 32.6% affirms that this possibility does not affect their daily habits.

Table 18: Hours of Sleep During NIGHT Shift.
Source: Author´s Creation with SPSS

| | | 1- 2 h | 3- 4 h | 5- 6 h | > 6 h |
|---|---|---|---|---|---|
| How much do you typically sleep during NIGHT shift? | Freq. | 1 | 8 | 19 | 18 |
| | % | 2,2% | 17,4% | 41,3% | 39,1% |

Table 19: Self Requirement of Sleep to Feel Alert.
Source: Author´s Creation with SPSS

| | | 5 to 6 hours | 7 to 8 hours | > 8 |
|---|---|---|---|---|
| How much sleep do you typically require to feel completely rested and alert during the day? | Freq. | 5 | 33 | 8 |
| | % | 10,9% | 71,7% | 17,4% |

Table 20: Sleeping Habits During the Daytime, Before Reporting for NIGHT shift.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| I attempt to sleep as much as possible during the day. | 17 | 37,0 |
| I generally take a 1-2 hour nap before coming to work. | 10 | 21,7 |
| I generally take a 2+ hour nap before coming to work. | 1 | 2,2 |
| It depends on how much sleep I had the night before. | 16 | 34,8 |
| It depends on how much sleep I had the night before, I generally take a 1-2 hour nap before coming to work. | 1 | 2,2 |
| It depends on how much sleep I had the night before, I generally take a 2+ hour nap before coming to work. | 1 | 2,2 |
| Total | 46 | 100,0 |

Table 21: Ability to Sleep affected Prior NIGHT shift.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Children (playing, needing attention, school) | 15 | 32,6 |
| Sleep area | 12 | 26,1 |
| Work Interruptions | 4 | 8,7 |
| Personal concerns (worrying) | 11 | 23,9 |
| Noise | 25 | 54,3 |
| Temperature | 15 | 32,6 |
| Work-related concerns | 8 | 17,4 |
| Social Interruptions | 14 | 30,4 |
| Spouse /Roommate | 5 | 10,9 |

Table 22: Possibility of Sleep at Work.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| That possibility always influences my daytime habits. | 6 | 13,0 |
| That possibility definitely influences my daytime habit If I have something important to do during the day. | 6 | 13,0 |
| That possibility does not influence my daytime habits. | 15 | 32,6 |
| That possibility might influence my daytime habits if I have something important to do during the day. | 19 | 41,3 |
| Total | 46 | 100,0 |

## *7. Fatigue*

For more than half of the pilots, fatigue degraded their performance and for 56.5%, fatigue degraded their alertness. The phases most affected by fatigue are Takeoff / en-route (52.2%) and Engine Shutdown (19.6%). About half of the pilots (45.7%) rarely caught themselves "nodding off" during a flight and 34.8% occasionally. A percentage of 21.7% indicates that they have already turned down a flight due to fatigue.

Table 23: Affected Flight Performance due to Fatigue.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Performance degraded | 33 | 71,7 |
| Alertness degraded | 26 | 56,5 |
| Can´t concentrate | 9 | 19,6 |

Table 24: Affected Phase of Flight
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Approach/Landing | 2 | 4,3 |
| Descent | 2 | 4,3 |
| Engine Shutdown | 9 | 19,6 |
| Engine start/taxi | 3 | 6,5 |
| Pre-flight planning | 2 | 4,3 |
| Pre-flight/walk -around | 4 | 8,7 |
| Takeoff/en-route | 24 | 52,2 |

Table 25: “Nodding Off” during Flight.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Never | 9 | 19,6 |
| Occasionally | 16 | 34,8 |
| Rarely | 21 | 45,7 |
| Total | 46 | 100,0 |

Table 26: Turned Down a Flight Due Fatigue.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| No | 36 | 78,3 |
| Yes | 10 | 21,7 |
| Total | 46 | 100,0 |

### *7.1 Flight Hours and Body Under Influence of Fatigue*

Analyzing subjects opinion towards self-report of feeling under the influence of fatigue after “X” amount of hours of flying more than 70% believe being between 3 to 6 hours. The majority, however, 37% reported being after 5 to 6 hours of flying, on the other hand, 34.8% reported between 3 to 4 hours of flying.

Table 27: Pilots Report of Feeling Under Influence of Fatigue After “X“ Number of Hours.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| 1 - 2 hours | 1 | 2,2 |
| 3 - 4 hours | 16 | 34,8 |
| 5 - 6 hours | 17 | 37,0 |
| 7 - 8 hours | 12 | 26,1 |
| Total | 46 | 100,0 |

## 8. *Sleep Condition Indicator*

After analyzing the quality of sleep with the Sleep Condition Indicator, it was possible to characterize 52.2% of the sample as with sleep is in GOOD shape and 47.8% as sleep is in GREAT shape.

Table 28: Sleep Condition Indicator.
Source: Author´s Creation with SPSS

| | N | % |
|---|---|---|
| Your sleep is in good shape | 24 | 52,2 |
| Your sleep is in great shape | 22 | 47,8 |

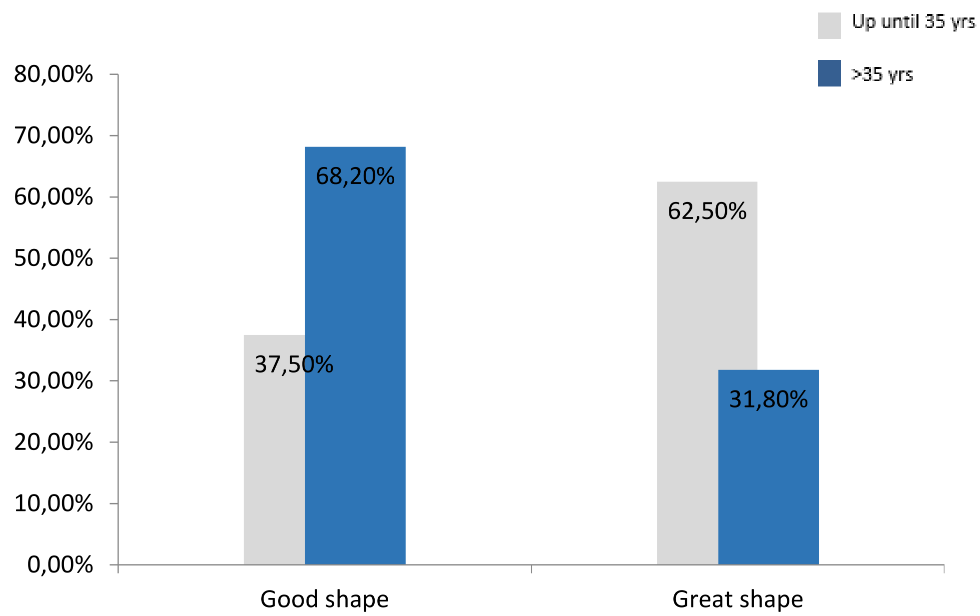
### *8.1 Sleep Quality and Age*

In the youngest subjects, 62.5% characterized as having their sleep in GREAT shape while in the older subjects this percentage is only 31.8%, the difference being statistically significant, Fisher's test, $p = .045$.

Table 29: Sleep Quality Related to Pilots Age.
Source: Author´s Creation with SPSS

| | | Sleep Quality | | |
|---|---|---|---|---|
| | | Your sleep is in GOOD shape | Your sleep is in GREAT shape | Total |
| Up until 35 yrs. | Freq. | 9 | 15 | 24 |
| | % Age | 37,5% | 62,5% | 100,0% |
| >35 yrs. | Freq. | 15 | 7 | 22 |
| | % Age | 68,2% | 31,8% | 100,0% |
| Total | Freq. | 24 | 22 | 46 |
| | % Age | 52,2% | 47,8% | 100,0% |

Graphic 1: Quality of Sleep, Related to Pilots Age.
Source: Author´s Creation with SPSS



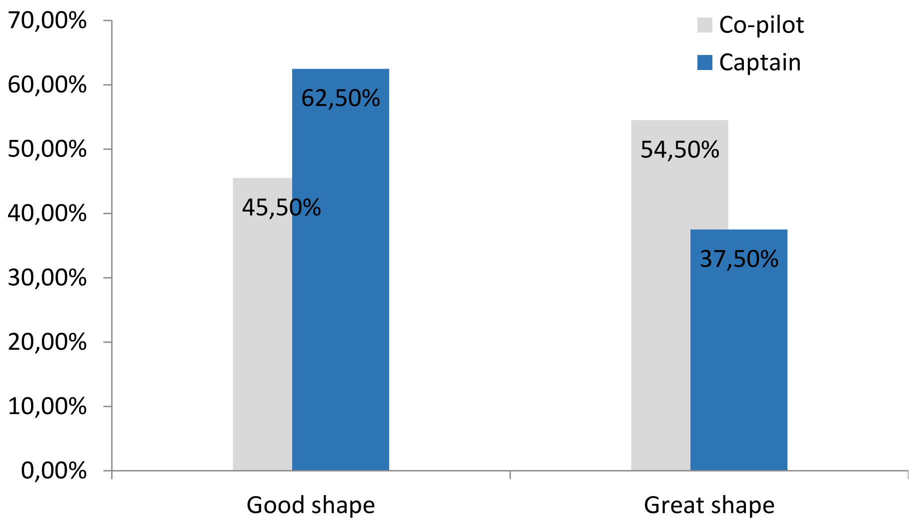

## *8.2 Quality of Sleep and Profession*

In co-pilot`s 54.5% were characterized as having their sleep in GREAT shape while in captains, this percentage is 37.5%. However, the difference is not statistically significant, Fisher's test, $p$ = .454.

Table 30: Quality of Sleep within the Profession.
Source: Author´s Creation with SPSS

| | | Sleep quality | | |
|---|---|---|---|---|
| | | Your sleep is in GOOD shape | Your sleep is in GREAT shape | Total |
| Co-pilot | Freq. | 15 | 18 | 33 |
| | % profession | 45,5% | 54,5% | 100,0% |
| Captain | Freq. | 5 | 3 | 8 |
| | % profession | 62,5% | 37,5% | 100,0% |
| Total | Freq. | 20 | 21 | 41 |
| | % profession | 48,8% | 51,2% | 100,0% |

Graphic 2: Quality of Sleep within the Profession.
Source: Author´s Creation with SPSS



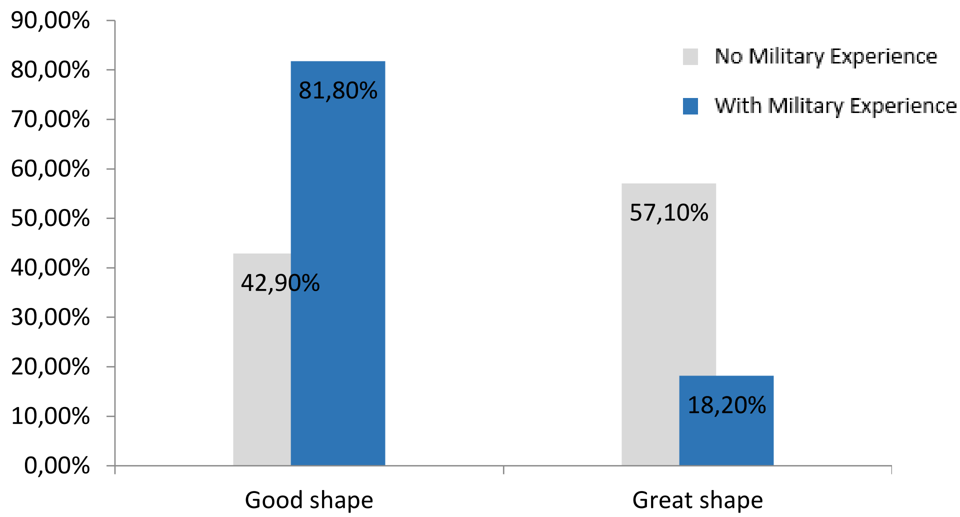

## *8.3 Quality of Sleep and Military Experience*

In subjects without military experience, 58.8% characterized as having their sleep in GREAT shape. In comparison, in subjects with military experience, this percentage is only 16.7%, the difference being statistically significant, Fisher's test, p = .018.

Table 31: Quality of Sleep with Military Experience. Source: Author´s Creation with SPSS

| Military Experience | | Sleep quality: Your sleep is in GOOD shape | Sleep quality: Your sleep is in GREAT shape | Total |
|---|---|---|---|---|
| No | Freq. | 14 | 20 | 34 |
| | % Military Exp. | 41,2% | 58,8% | 100,0% |
| Yes | Freq. | 10 | 2 | 12 |
| | % Military Exp. | 83,3% | 16,7% | 100,0% |
| Total | Freq. | 24 | 22 | 46 |
| | % Military Exp. | 52,2% | 47,8% | 100,0% |

Graphic 3: Quality of Sleep of Pilots with Military Experience.
Source: Author´s Creation with SPSS




## *8.4 Quality of Sleep and Flight Hours*

Subjects with sleep quality characterized as GOOD shape have, on average, more flight hours (4581.58 vs 2246.91), although the difference is not statistically significant, Z = -0.528, p = .598.

Table 32: Quality of Sleep Relation with Total Flight Hours.
Source: Author´s Creation with SPSS

| | Your sleep is in GOOD shape | | Your sleep is in GREAT shape | | |
|---|---|---|---|---|---|
| | M | DP | M | DP | Sig. |
| Horas de voo | 4581,58 | 5321,88 | 2246,91 | 2267,22 | ,598 |

## *8.5 Quality of Sleep and Working in the Aviation Industry*

Subjects with sleep quality characterized as GREAT shape have fewer years in the aviation industry (11.5 years vs 17.88 years), the difference being statistically significant, Z = -5.831, p = .001.

Table 33: Quality of Sleep Relative to the Number of Years in the Aviation Industry.
Source: Author´s Creation with SPSS

| | Your sleep is in GOOD shape | | Your sleep is in GREAT shape | | |
|---|---|---|---|---|---|
| | M | DP | M | DP | Sig. |
| Working in the Aviation Industry. | 17,88 | 12,62 | 11,50 | 7,87 | ,001*** |

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

## *9. Summary of Results*

*Table 34: Summary of Results*
Source: Author´s Creation with SPSS

| | N(46) | % |
|---|---|---|
| Gender | | |
| Male | 45 | 97,8 |
| Age (M;SD) | 39,2 | 9,4 |
| Academic Qualification | | |
| Bachelor or Graduate Degree | 31 | 67,4 |
| Pilot License | | |
| Commercial Pilot License (CPL (H)) | 32 | 69,6 |
| Instrument Rated | | |
| Yes | 45 | 97,8 |
| Captain or Higher responsibility | 13 | 28,3 |
| Co-pilot | 33 | 71,7 |
| Flight Hours & Aviation Experience | | |
| Hours (M;SD) | 3465 | 4273 |
| Years of industry (M;SD) | 14 | 10 |
| Military Experience in Similar Role | | |
| No | 34 | 73,9 |
| Human Factors Training & Knowledge | | |

| | | |
|---|---|---|
| Yes | 46 | 100 |
| Knowledge to Self-detect | 45 | 97,8 |
| Knowledge to detect Colleagues | 41 | 89,1 |
| Knowledge of the side the effects of fatigue and its psychological effects | 43 | 93,5 |
| Schedule Schemes and Rostering | | |
| Working between 3 to 6 days consecutive (combined value) | 37 | 80,4 |
| 2 to 3 days off prior transitioning DAY/NIGHT | 29 | 63 |
| 24 hours OFF between NIGHT to DAY shift | 28 | 60,9 |
| Best Rostering between 21 and 28 ON/OFF (combined value) | 34 | 74 |
| Sleep | | |
| Typically Sleep 5 to 6 hours on night shifts (combined value) | 37 | 80,4 |
| Typically require to feel completely rested and alert During the day | 33 | 71,7 |
| Attempt to sleep during the day depending on how much sleep he had the night before (combined value) | 33 | 71,8 |
| Ability to sleep affected (noise) | 25 | 54,3 |
| Ability to sleep affected (noise & children) (combined value) | 40 | 86,9 |
| Ability to sleep affected (noise & temperature) (combined value) | 40 | 86,9 |
| Affected Flight Performance due to Fatigue | | |
| Performance Degraded | 33 | 71,7 |
| Alertness Degraded | 26 | 56,5 |
| Performance Degraded & Can´t Concentrate (combined value) | 42 | 91,3 |
| Alertness Degraded & Can´t Concentrate (combined value) | 35 | 76,1 |
| Phase of flight (Takeoff/en-route) | 24 | 52,2 |
| Nodding off Rarely or Occasionally | 37 | 80,5 |
| Turned down a flight due to fatigue (No) | 36 | 78,3 |
| Feeling under the influence of fatigue after “x” numbers of hours (3 - 4 hours) | 16 | 34,8 |
| Feeling under the influence of fatigue after “x” numbers of hours (5 - 6 hours) | 17 | 37 |
| Feeling under the influence of fatigue after “x” numbers of hours (between 3 – 6 hours) (combined value) | 33 | 81,8 |
| Sleep Condition & Quality | | |

| | | |
|---|---|---|
| Good Shape | 24 | 52,2 |
| Great Shape | 22 | 47,8 |
| Up until 35 yrs (good; great) | (9) 37,5 | (15) 62,5 |
| >35yrs (good; great) | (15) 68,2 | (7) 31,8 |
| Co-pilots (good; great) | (15) 45,5 | (18) 54,5 |
| Captain (good; great) | (5) 62,5 | (3) 37,5 |

**Pilot subjects** represented a population of 97% of were male, 63% with age below 40 years, 73% with no military background or experience on related function as a pilot, 71% acting responsibility as co-pilot with 67% either having a bachelor or graduate degree, 69,6% having commercial pilot license with 58% of them having less than ten years in the aviation industry. **Human factors** knowledge and training reported by all pilots and 93.5% of them have an understanding of the physiological effect of flying in the human body. Reported being able to self-detect when under the influence of fatigue by 97.8% and able to detect colleagues by 89.1% when under the influence of fatigue, with an equal value of 93.5% pilots reported knowing the side effects of fatigue and its psychological effects. **Schedule Schemes and Rostering** for offshore oil and gas activities, 80.4% reported working between 3 to 6 days consecutive with 63% reporting having at least 2 to 3 days OFF prior transitioning between day to night shifts. Meanwhile, 60.9% reported having 24 hours OFF between nights to day shifts. When combined, almost 75% of the pilots believe the best rostering scheme is between 21 to 28 days on/off. **Sleep habits** demonstrated that 80.4% of the subjects are capable of sleeping 5 hours or above during night shift, 89.1% recon to require to sleep above 7 hours to feel completely rested and alert during the day. Prior a night shift pilots reported having difficulties to sleep during the day, 54.3% due to noise and with equal value 32.6% due temperature and children (playing, needing attention, school). A general acknowledge of pilots was reported that of knowing the possibility to sleep during the night shift influences or might influence their daytime sleeping habits by more than 67.3%. Subjects without military experience, 58.8% were characterized as having their sleep in GREAT shape. In comparison, **subjects with military experience**, this percentage is only

16.7%. Subjects with fewer years in the aviation industry and younger with fewer flight hours with the sole responsibility of Co-pilot have their sleep in GREAT shape. The difference is statistically significant in the number of years in the industry and age. However, not statistically significant in the number of flight hours and the primary role. **Fatigue,** subjects reported having affected and degraded their performance and alertness by more than 56 % and at least 19% with lack of capacity to concentrate. The phase of flight affected after takeoff until engine shutdown reported being between takeoff/en-route phase by 52.2% with occasionally nodding off during flight by 34.8%. However, despite facts, only 21.7% of the pilots turned down a flight due to fatigue. Subject's general opinion considered that the number of hours that they felt safe before under the influence of fatigue when combined was 71.8% between 3 to 6 hours.

Analysing the results, it becomes clear. The author discusses revealing facts and answers the research questions. However, safety calls for further development, and the author reveals good insight into research contribution by presenting new mitigating tools for the aviation industry.

# Chapter VII Discussion & Research Contribution

The following part describes the discussion, answers to the research question and the author's research contribution.

## *1. Discussion*

The scope of the discussion was limited to what are the most relevant factors and their interaction on the bases of direct or indirect effect on flight safety.

**Several country (Angola) constraints** such as road-heavy traffic, road condition, tropical weather, basic essential human needs (water and electricity) affecting family living conditions, distance from work and poor healthcare. As a consequence, prior flight, it all prevents Pilots from reporting to duty in well-rested conditions. Complex psychomotor skill is a mandatory ability that a helicopter pilot must-have. For a flight mission, pilots require to have good feet/hand coordination performance. Reasonable evidence can be scientifically proven towards WBV, HL and age as significant contributors to pilot fatigue in general cognitive fatigue and psychomotor performance.

**Safety concerns** regarding the pilot's alertness and ability to safely perform a helicopter flight task within the normal and emergency operations environment are questionable. Despite that, a pilot can trick and deceive its body and delay its fatigue. A Pilot cannot bear the long term outcome since fatigue is accumulative. However, mitigating can help helicopter pilots fly safer and withhold more prolonged health conditions and careers. Mitigating can help to understand each operation best rostering scheme, since its well documented offshore activities in each regional area.

**More tests daily** should be conducted to **monitor the performance** of helicopter pilots. A subject sample should be mostly emphasised on a worldwide scale and with contribution and participation of aviation advisors within all IOGP members. The **focus shall be a better understanding of cognitive fatigue and the effects of psychomotor overall general pilot performance and the relation towards flight safety and its effectiveness in stressful events or emergencies**. Although, a shock of results may be the overall acknowledge when testing with large scale, on another, companies may have concerns on overall results in what it represents towards economic effects. Concerns, although may arise of the cost-benefit towards the hazard presented and risk mitigation plans and countermeasures employed as part of FRMS.

The **results for the author were conclusive** and revelled more done can assure effective and safe helicopter activities in the oil and gas industry. Believed, to a certain amount of range, that serious incidents and accidents may become prevented. By applying measures referred to in this study, the use of fresher crews to all offshore activities.

To **enhance safety and reduce human factor risk**, to a level As Low As Reasonably Practicable (ALARP) being both **technically feasible and economically justifiable**. Operators should focus on improvements in training towards Human Factors (annual training). Emphasize on the safety management and operational control by creating a wave effect of more self-awareness of the leading major human factors (fatigue, sleep, stress). **Operators will play the role of substantial contributors to operational safety. Operators will contribute to the avoidance of serious operational incidents and accidents, avoid financial compensation or insurance claims and at the same time towards SMS training in risk and hazard analysis.** Training in Safety Management System (SMS) and Quality Management (QM) has a considerable impact on operational staff workers. The overall result will be a minimisation of human error, a change in aviation culture relative to safety and quality and industry-standard aviation best practices.

Investment in equipment's like Health and Usage Monitoring System (HUMS) and Flight Data Monitoring (FDM) is only half the solution since human interference is always present. "*The FDM and HUMS equipment could only prevent about 50% of accidents caused by operations outside of the Flight Manual or Operations Manual limitations and tail rotor and critical rotating parts before failure"* (Clark, Edwards, Perry, Campbell, & Stevens, n.d.).

### *1.1 Answers to Research Questions*

**RQ I: Exposure to whole-body vibrations, above-average noise from the blades and engines is the general result of the helicopter pilot's fatigue of impact?**

**H1: Prolonged periods of Whole-body Vibration can result in pilot higher fatigue impacts.**

The literature review has revealed that the fatigue effect is predominant. Related mainly but not limited to the lumbar region and therefor causing what is known to be LBP to helicopter pilots. The results are acute pain mainly through mechanical compression due to pilot's static seated environment position and postural stress in flight from prolonged setting. Resulting irritation and inflammation of a localized region varying pain in diverse areas: muscles, tendons, ligaments and spinal nerves. The inflammation and discomfort caused to these regions cause pilots to feel fatigued. Mainly on the physical level, ultimately crews tend to become anxious to the relief of this discomfort or LBP by merely removing themselves from the current state. If continuously discomfort for pilot's is present, felt on the skin, lower back, thorax, shoulders, neck and head pilot may change its humour. Affects may be present in communication, crew resource management (CRM), multi-crew coordination (MCC), flight performance, safety and operational effectiveness in emergencies. WBV and noise are a significant impact on pilots fatigue, pending on the exposure and the areas affected.

**H2: Whole-body Vibration and above-average noise can cause hearing loss.**

As previously referred, the longer the rest period, the better fit is the pilot to fly and therefore safer to fly. Cognitive levels refresh to excellent alertness levels when pilots have a good night of 8 hours of quiet and restful sleep, resting and restoring both physically and mentally.

**H3: Hearing Loss is a contributor to pilot fatigue.**

Since there is a clear correlation between WBV and HL in being a high contributor to pilot cognitively and physically fatigued. Meanwhile, as age progresses, fatigue is too more noticeable due to sleep disruption, and humans tend to sleep less.

**H4: The longer the rest period, the safer the pilot is to fly.**

Also, the time the subject exposed to WBV and noise determines the higher the risk of safety jeopardized and higher awareness of pilot considered operationally unfit to fly. The body needs time to selfheal, and it only achieves operational fit to fly levels when it rests.

**RQ II: Is age and the total of flight hours exposed daily a direct association of having a significant impact on the fast recovery of the health effects on the body and fatigue of pilots?**

**H5: Helicopter pilots have their cells and organs more affected the higher the Age.**

Age affects every human body cells. Some people faster and more than others. However, the presented study was not able to determine such condition relative to cells and organs.

**H6: Age induces higher recovery time from fatigue.**

Yes, to recover from fatiguing bodies are subjective. Therefore, it may vary from person to person or with different genders. Usually, the majority of people needs rest and a good 8-hour cycle of continuous sleep for a full recovery, but even though it may be subjective. Some people require more time other less. Since age tends to change sleep and rest habits literature makes clear that the older the pilot becomes the more extended periods of recovery are required.

**H7: Cells and organs are affected by the abnormal acceleration due to vibration and therefore result in further fatigue.**

The presented study was not able to determine such condition relative to cells and organs and in the result in further fatigue.

**H8: Age is a great contributor to fatigue.**

Yes, the recovery period is higher. Therefore, fatigue levels will be higher since it is accumulative. The Pilot will require higher needs of rest and sleep periods. Microsleep is often recommended for pilots with day and night complicated rostering schedules.

**H9: Cells and organs are affected and result in further fatigue and possible shutdown or malfunction of metabolism, which may result in diseases and ultimately in the pilot being unfit to fly.**

When referring to the hypothesis presented in the study, it was not able to determine such condition relative to cells and organs being affected and resulting in further fatigue. Although, possible shutdown or malfunction of metabolism, which may result in temporary sickness or diseases and ultimately in the pilot in being unfit to fly. However, it will require further study.

**H10: Malfunction of metabolism may result in discomfort, increase stress and fatigue, diseases and ultimately in pilot unfit to fly.**

A stated fact can be that WBV, noise and age all play a part in malfunction or delay or organs functions. The exposure time frame during helicopter activities is also one of the reasons. However, the current study did not reflect sufficient evidence. Literature, although, in several studies, did reveal several health effects, back pain most commonly reported. Other disorders include sciatica pain, hearing damage, nervous system, skeleton (bones, joints and degenerative changes in the spinal, including lumbar inter-vertebral disc disorders) muscular system, skin, circulatory systems. In general, it affects kidneys, digestive system, cardiovascular system (elevation of high blood pressure), liver, urinary system, reproductive system and neurological (stress-related symptoms). Several studies also gave high strength, consistency and plausibility towards the association between the pathogen. With the risk of exhibiting symptoms that may result in a specific disease when increased exposure is present. To be able to proof, however, experimental evidence is still required to be able to demonstrate. The demonstration, however, would only be possible when evaluating several subjects during several years. Even then, its scientific study may be subjective because of several factors would be unforeseeable and with great difficulty to control.

**H11: Best number of hours per day is in between 4 to 6 hours of flying per day**

A detailed study on scientific facts of fatigue and safety, having in mind possible monthly pilot costs versus operational efficiency relative to maximum hours permitted to fly legally. The number of average hours per day recommended in this study is of 4 hours, good industrial practices, national Angolan aviation laws and the best understanding in determining crew ratio per aircraft. When analysed to the recommended total flying hours per day, a total of 3h15 min recommended for EC225 but on the other hand, a total of 4 hours recommended for AW139. Reflection, only due to different values of vibration exposure levels between both aircraft as per Table 2 and Figure 9. When analysed, the maximum recommended total flying hours per day. It recommends that subjects stay between the range of 5h30 min and 6h15 min limit of flying time in one single day. The reason is simple, due to accumulated cognitive and physical fatigue during the single working day. A guaranteed rest period of 45 minutes, recommended after 4 hours of flying.

**RQ III: A safer analysis toward fatigue measurement related to working flight hours per each rotation scheme ON/OFF, are the result of better understanding in the selection of the best rostering scheme 7, 14, 21, 28 or 35 days ON/OFF and scheduling in association with sleep habits as well as pilots primary role of responsibilities?**

**H12: ON/OFF rotation scheduling cannot be helpful because the body does not regenerate to its perfect state of health.**

Wrong, it can be helpful and beneficial. When it comes to safety, all mitigating measures shall be implemented if they are cost-beneficial. To assure that pilots are at their best operational fitness to fly both mentally as physically.

**H13: ON/OFF rotation scheduling can be helpful because body, mind and soul can rest and regenerate it is almost or perfect state of health.**

Yes, the longer the rest period, the more fit mentally and physically the pilot will be to conduct safer to flights.

**H14: Bearing the industries best practice and the national Angolan Aviation laws, 21 ON 21 OFF is the best rotation for pilots.**

No. Nevertheless, pilots reported a preference in 21ON 21 OFF rotation scheme. A bias analysis is acknowledged form the author since subjects are in this specific rotation scheme.

**H15: Bearing the industries best practice and the national Angolan Aviation laws, 28 ON 28 OFF is the best rotation for pilots.**

Yes, although a bias and subjective analysis in the survey is present since it is a question that refers to personal opinion. Pilots reported a preference in 21ON 21 OFF. However, the conclusion after scientific analysis, literature review and authors contributive data on calculations of vibrations to the current research study, the best rotation scheme recommended is 28 ON 28 OFF. Reason for authors affirmation is on bases of operators economic benefits, longer rest periods for the body to selfheal, decreased vibration dose exposure, better-mitigated fatigue levels, acknowledge of longer health conditions and pilots longevity in a career. Also, this permits maximum pilots efficiency towards operators permitting Pilots to fly up to 100 hours by law per 28 days and work up to 30 hours per 7 consecutive working days (DE.110/19 MinTransportes, 2019).

**H16: Delaying fatigue may result in a sudden drop in our immune system and causing a collapse of psychological and physical fitness.**

Fatigue may affect pilots physically and mentally, and both may or may not always come at the same time since fatigue is subjective. Pilots may try to fool themselves, but fatigue sometimes is unforeseeable (internal). Since fatigue is accumulative, those with limited knowledge or in lack of training in how to identify its risks may jeopardize the safety of the flight. A pilot may simply enter a state of pure fatigue. He may feel a drop in his immune system when ignoring mitigating measures to assess possible fatigue or stress hazards and risks. When unimplemented fatigue and stress risk management, it may become too late in a flight. Trying to delay is also unforeseeable and also not recommended. Rest is definitely necessary and mandatory, both physically and mentally.

**H17: Pilots fly safer and withhold longer health conditions and careers by flying more and resting less but trying to keep pilots fit shape.**

No, pilots should fly the recommended average flight hours in this research study, 4 to 6 hours per day. It will, for sure grant longer health conditions and careers. Rest periods will help selfheal helicopter pilot's bodies and prevent chronic LPB. Reducing in all other symptom's reported in several studies such as sciatica pain, hearing damage, nervous system, skeleton (bones, joints and degenerative changes in the spinal including lumbar inter-vertebral disc disorders) muscular system, skin, circulatory systems, in general, affecting kidneys, digestive system, cardiovascular system (elevated to high blood pressure), liver, urinary system, reproductive system and neurological (stress-related symptoms).

**H18: Pilots fly safer and withhold longer health conditions and careers by flying less and resting more but trying to keep pilots fit shape.**

Yes, although a balance should be foreseen commercially and business-wise. It may be impossible, but if so at high risk. Pilots should fly the recommended average flight hours in this research study, 4 to 6 hours per day. It will, for sure grant longer health conditions and careers. If the tools presented in this research study are applied to identify the best rostering scheme, a balance can be found, between rest periods and the number of flying hours recommended per day.

**H19: Study is unable to provide sufficient knowledge to understand which rotation scheme is better. Further study must be carried out with a higher sample to try to understand the different types of energy levels within different hemispheres.**

No, the research study was able to provide sufficient knowledge to which may be the best rotation scheme for this specific company. The author acknowledges that each company has its type of operations. Therefore it may require to assess what may be better for their operations in their geographical area and hemisphere. To understand the energy levels of the pilot's further study is recommended with body mass index, height and age within each rotation.

**H20: There may be reasonable data value that one rotation scheme is better than the other, scientifically proven or on bases of a pilot report of wellbeing and fitness conditions.**

Based on the research study in pilots flying between 4 to 6 hours per day, scientific facts from reviewed literature and study presented a total average per day is dependent of helicopter type flown and recommendation below based on a rotation scheme cycle of 28 ON 28 OFF.

The conclusion for most affective rotation scheme is 28 ON 28 OFF.

*Benefits and Reason*

- Pilots can fly 100 hours by law per 28 days and work up to 30 hours per 7 consecutive working days (DE.110/19 MinTransportes, 2019). With the rotation scheme recommended,
- Subjects on their 28 ON will be able to fly 24 working days per shift ON conducting a total average of 4 hours per each working day (totalling average of 96 hours within each rotation ON), resting 1 day after 6 working days within the rotation ON (totalling 4 days of rest within each rotation ON),
- Subjects on their 28 OFF may have more time for the body to selfheal, although subjective and not studied in this research. Several studies have revealed that the body takes about approximately 15 to 20 days to selfheal.

Subjects will have more time. To release accumulated cognitive fatigue and stress. Take care of other related issues of their responsibility to be able to fly. For example: simulator training, annual medical reviews and license reissues within the civilian aviation authority (CAA) after updates,

- Financially this not only downsizes operational pilot's ratios and therefore maximizes cost efficiency and minimizes company operational daily costs,
- Consequently, it helps to comply with IOGP standards, minimum of 50 flying hours per 90 days per pilot,
- Commercially, since offshore clients and or members of IOGP typically relate to IOGP standards, this may also help to comply with client's standards and thus higher quality standards,
- Complying with this study will promote more prolonged health conditions and careers,
- Less exposure to excessive vibration doses and high noise levels that result in hearing loss,
- Higher pilot's situational awareness, alertness and performance,
- Operators Safety standards will be set to predictive measures, last level os ICAO SMS safety standards,
- Operators daily analysis of fatigue levels for continuous monitoring and mitigating measures.

To emphasis, the understanding of all questions and hypothesis in the usable form figures 13 and 14. Will explain in the research contribution how operators can introduce the following tool "simplified risk matrix toward WVB and HL" in their safety management system. Through this risk matrix operators can withhold higher standards of safety. Operators will also be able to analyses safety standards daily with "Performance Risk Chart for HL & WBV Daily Exposure" in figure 15. For all of this to happen a proposed formula measuring helicopter noise and whole-body vibration estimated exposure dose (HNVED) was created in the risk analysis.

## 2. Research Contribution

The following section, the author presents several tools that will contribute to the safety standards in helicopter operations. Based on the initial risk analysis conducted, Three advanced tools below of grate use. A formula to measure Helicopter calculated and estimate noise and Whole-Body Vibration exposure dose (HNVED), WVB & HL Matrix and the Performance Risk Chart.

### 2.1 Risk Analysis

The presented results above reveille the need to revise the research methodology and the author believed it was necessary to add a further step as per figure 12. A safety risk management analysis adds to the fatigue analysis of the pilot's operational fitness to fly.

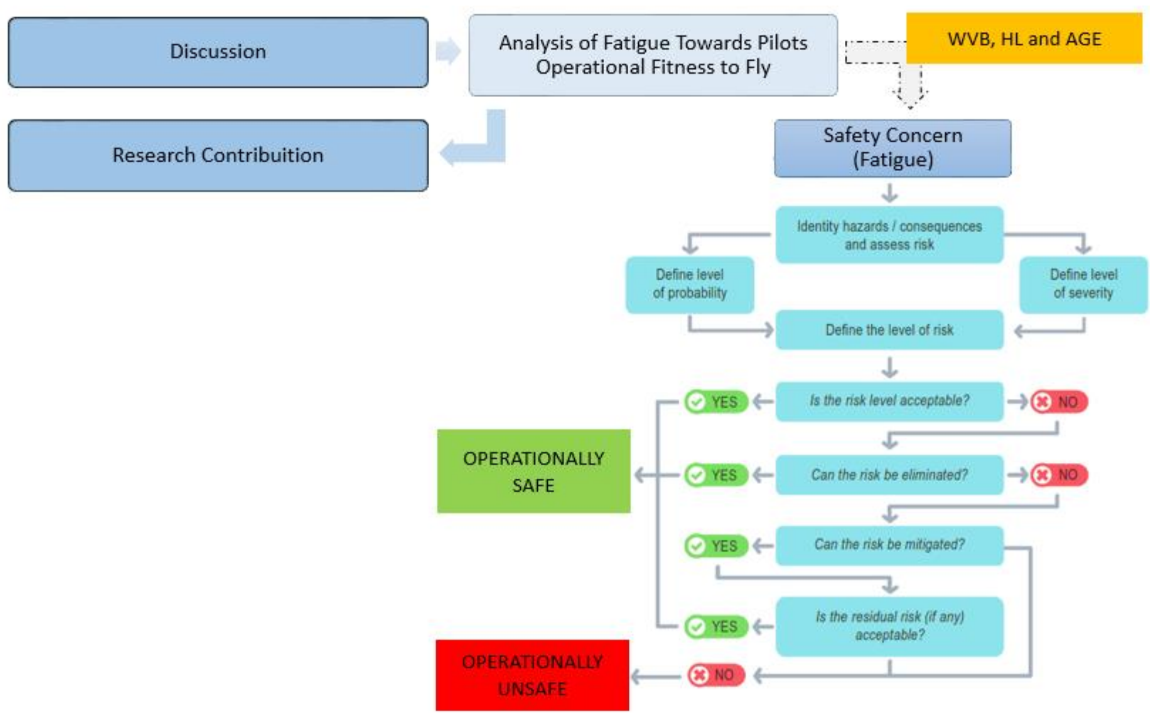



Figure 12: Research Methodology Revised with Safety Risk Management Analysis
Source: Author´s Creation and adaptation from Safety risk management decision aid (ICAO 9859, 2018)

The reason was a better understanding of limitation and risk in an exposure. Fatigue not commonly observed until it is at a stage that can be considered harmful. The worst scenario for pilots in helicopter operations resulting in a serious incident or a fatal accident. The author acknowledges a better contribution, providing a tool that may deliver a better understanding of companies SMS and FRMS systems. Continuous monitoring and control of residual risk may be achieved to a considered acceptable or tolerable level within pilot fatigue towards WBV, HL and relative to Age.

The author believes based on accumulated fatigue assessment in the form WVB with the combination of Noise that it is a direct result in HL. Based on manufactures vibrations values on table 1 & 2, the European Directive (EU 2002/44/EC) predictor of the hazard due to WBV and supporting documents, ISO 2631, relative to exposures limitations adding to the operators and pilots awareness of the probability and severity to pose a level of health risk. The author considers the risk severity, based on ICAO 9854, to be between HAZARDOUS and MAJOR with an imposed probability risk to be between FREQUENT and EXTREMELY IMPROBABLE (ICAO 9859, 2018). The author acknowledges that severity and probability may be higher or lower in each operator. It depends on the number of staff members on each rostering scheme, FRMS implementation and human factors awareness training in fatigue management.

Following the research aim, in the development and creation of a simplified risk matrix which enables offshore helicopter operators the ability to measure the estimated fatigue levels. A quick flight safety operator's risk-mitigating tool and pilot's quick self-test observation could be calculated based on pilot reports of flying hours during ON rostering scheme.

A proposed formula measuring helicopter noise and whole-body vibration estimated exposure dose (HNVED):

1.1 Combined noise from multiple acoustic sources

$$dB_{total} = 10 * LOG\left(\sum_{i=1}^{n}\left(10^{\left(\frac{dBi}{10}\right)}\right)\right)$$

2.1 Helicopter Noise and Whole-Body vibration estimated exposure dose in combination with a variant of (a) for multiple acoustic sources in decibels (dB)

$$HNVED = (dB_{total}) * TFT$$

$$HNVED = \left[10 * LOG\left( 10^{\left(\frac{manfAvg\mathrm{ND}(\mathrm{d}B1)}{10}\right)} + 10^{\left(\frac{manfAvgVD(dB2)}{10}\right)}\right)\right] * TFT$$

| | |
|---|---|
| HNVED | Helicopter calculated and estimate noise and Whole-Body Vibration exposure dose |
| manfAvgND (dB1) | The average manufacture value of Noise Dose. Value calculated from the sum of all the minimum and maximum values form TCDSN reference TAKEOFF, OVERFLIGHT and APPROACH and divided by three (3).<br>**Note:** Value in helicopters, depending on age, model and size category, stands typically between 85 – 115 dBA. |
| manfAvgVD (dB2) | Is the average manufacture value of Whole-Body Vibration Dose, or value obtain from HUMS on a helicopter.<br>**Note:** When no value obtained, 95,73 dBA shall be estimated average reference value from ISO 2631-2018. |
| TFT | Total Flight Time in hours. |

According to the recommendations of the International Standard using the system of measuring vibration proposed by ISO 2631, on seat pan of the vehicles during actual flying conditions (ISO 2631, 2018) and the alternate method of assessment of exposure. As stated in the European Directive (EU 2002/44/EC) *"The assessment of the level of exposure may be carried out on the basis of an estimate based on information provided by the manufacturers concerning the level of emission from the work equipment used"* (European Parliament, 2002).

### 2.2 WVB & HL Matrix

Results revealed the need for a tool that would help the operational safety department within helicopter operators. Equally, there was no observed reference throughout the literature review. With two exposure sources, accumulated fatigue is present in helicopter pilots. The author felt the need to study this issue further. The author analysis and recommends is the revision from 8 hours daily maximum exposure value to 6h15min when direct exposure received from two sources or more "hardware/machine/helicopter". Based on the formula (b) a created risk analysis matrix tool is presented in figure 13 and 14. The tool is a simplified risk matrix toward WVB, and noise that may result in HL that operators may add to the safety management system manual. It enables offshore helicopter operators the ability to measure the estimated fatigue levels and perform possible risk management. The risk analysis matrix tool adds the known values from ISO 2631 towards noise and whole-body vibration daily limits exposure. The tool performs an estimated but mostly precise value towards the exposure levels of crew/pilot. It builds a self or collective awareness of fatigue measurement with possible risk towards the operational condition, and it enhances the exact probability values towards fitness condition.

| Age | 18-23 | 24-29 | 30-35 | 36-41 | 42-51 | 52-60 | 61 - 65 |
|---|---|---|---|---|---|---|---|
| Hours Flown | 91 - 100 | 86 - 90 | 75 - 85 | 60 - 75 | 40 - 59 | 20 - 39 | 1 - 19 |
| Nº of Landings | >110 | 100 - 110 | 80 - 99 | 60 - 79 | 40 - 59 | 20 - 39 | 1 - 19 |

| Position | SIC | SENIOR SIC | PIC | SENIOR PIC | AIRCHECK | LTC | SENIOR LTC | FI | TRI | TRE | CF | CP | FO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days on Rotation 21 | | | | | | | | | | | | | |
| Days on Rotation 28 | | | | | | | | | | | | | |
| Days on Rotation 35 | | | | | | | | | | | | | |

| Fleet | AW139 | AW189 | S-76C++ | AS332L2 | EC225 |
|---|---|---|---|---|---|
| | HL (95,1) | HL (95,91) | HL (96,46) | HL (97,2) | HL (98,2) |
| | WBV ( ) | WBV ( ) | WBV ( ) | WBV ( ) | WBV ( ) |
| HL (dBA) Exposure LIMITE to Hours/day | 90 dBA | 92 dBA | 95 dBA | 97 dBA | 100 dBA |
| | 8H/day | 6H/day | 4H/day | 3H/day | 2H/day |
| WBV (dBA) Exposure LIMITE to Hours/day | 92,67 - 98,79 dBA | 94,67 - 100,79 dBA* | 97,67 - 103,79 dBA* | 99,67 - 105,79 dBA* | 102,67 - 108,79 dBA* |
| | 8H/day | 6H/day | 4H/day | 3H/day | 2H/day |

| EST. HL + WBV EXPOSURE dBA total/day | Helicopter Noise and Whole-Body Vibration Estimated Exposure Dose (HNVED) (seated or standing) | | | | | |
|---|---|---|---|---|---|---|
| | ≤ 393,75 | ≤ 442,97 | ≤ 492,18 | ≤ 541,40 | ≤ 566,44; ≤ 590,62 | ≤ 623,10 |
| RISK Condition | ACCEPTABLE | | TOLERABLE | | UNACCEPTABLE | |
| Operational Condition | Safe to fly | Ok to fly | Able to fly, may have limitations | Cautioned but able to fly, limitations may be enforced | Limited to fly | Unsafe to fly |

| PILOT NAME AND SIGNATURE | | SAFETY OFFICER NAME & SIGNATURE | | SAFETY MANAGER SIGNATURE | |
|---|---|---|---|---|---|

*Figure 13*: Safety Risk Analysis Matrix towards WBV and HL in Helicopter Pilots.
Source: Author´s Creation, ISO 2631,2018 Noise Daily Limits and WBV daily Limits (ISO 2631, 2018).

<table>
<tr><td>Height (cm)</td><td>160</td><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td><td>192</td><td>194</td><td>196</td><td>198</td></tr>
<tr><td>weight (kg)</td><td>58</td><td>60</td><td>62</td><td>64</td><td>66</td><td>68</td><td>72</td><td>72</td><td>74</td><td>76</td><td>78</td><td>80</td><td>82</td><td>84</td><td>86</td><td>88</td><td>90</td><td>92</td><td>94</td><td>96</td><td>98</td><td>100</td><td>102</td><td>104</td><td>106</td><td>108</td><td>110</td><td>112</td><td>114</td><td>116</td><td>118</td><td>120</td><td>125</td><td>130</td><td>135</td></tr>
<tr><td rowspan="2">Sports Activity</td><td colspan="5">5-7 days a week</td><td colspan="5">4 days a week</td><td colspan="5">3 days a week</td><td colspan="5">2 days a week</td><td colspan="5">1 day a week</td><td colspan="5">0 days a week</td><td colspan="5" rowspan="2"></td></tr>
<tr><td colspan="5">1/2 h/day</td><td colspan="5">1h/day</td><td colspan="5">1 1/2 h/day</td><td colspan="5">2h/day</td><td colspan="5">daily bi training</td><td colspan="5"></td></tr>
<tr><td>Smoke</td><td colspan="5">don´t smoke</td><td colspan="5">casual or social smoker</td><td colspan="5">1/2 pack/day</td><td colspan="5">1 pack/day</td><td colspan="5">1 1/2 pack/day</td><td colspan="5">2 packs/day</td><td colspan="5"></td></tr>
<tr><td>Alcohol</td><td colspan="5">don´t drink</td><td colspan="5">casual or social drinker</td><td colspan="5">1 glass cup/day</td><td colspan="5">1 1/2 glass cup/day</td><td colspan="5">2 glass cups/day</td><td colspan="5">2 1/2 glass cups/day</td><td colspan="5"></td></tr>
<tr><td>Lower Back Pain (LBP)</td><td colspan="5">Very Slight</td><td colspan="5">Slight</td><td colspan="5">Little</td><td colspan="5">Achy</td><td colspan="5">Very Achy</td><td colspan="5">Painful</td><td colspan="5"></td></tr>
<tr><td rowspan="2">Points After Sleep Survey Analysis*</td><td colspan="5">31 - 36</td><td colspan="5">24 - 30</td><td colspan="5">17 - 22</td><td colspan="5">11 - 16</td><td colspan="5">6 - 10</td><td colspan="5">0 - 5</td><td colspan="5" rowspan="2"></td></tr>
<tr><td colspan="5">Sleep in Very good shape, keep current attitude</td><td colspan="5">Sleep in good shape, but many steps can make it better</td><td colspan="5">Some Sleep problems, it's important to examine sleep habits</td><td colspan="5">Sleep problems, it's important to examine sleep habits and make changes</td><td colspan="5">Sleep problems seem to be severe</td><td colspan="5">Sleep problems seem to be severe, medical checkup recommended</td></tr>
<tr><td>Fitness condition</td><td colspan="5">Fit to fly</td><td colspan="5">Good to fly</td><td colspan="5">Ok to fly,</td><td colspan="5">CAUTION, REST SHOULD be recommended</td><td colspan="5">REST SHALL be recommended</td><td colspan="5">UNFIT TO FLY, rest MANDATORY</td><td colspan="5"></td></tr>
<tr><td colspan="36">Remarks:</td></tr>
</table>

| PILOT NAME AND SIGNATURE | | SAFETY OFFICER NAME & SIGNATURE | | SAFETY MANAGER SIGNATURE | |
|---|---|---|---|---|---|

*Figure 14: Safety Risk Analysis Matrix towards WBV and HL in Helicopter Pilots. (cont.)*

Source: Author´s Creation, *Variant Scale of the Sleep Condition Indicator – By Colin Espie, University Of Oxford, questions 29 – 36. (Arianna Huffington, 2016)

## *2.3 Performance Risk Chart*

An additional contribution deemed necessary at this time by the author, enhancing the knowledge of individual limits and an understanding of the exposure limits. With the same philosophy of performance charts from aircraft, the author felt necessary to understand the tolerable limits of exposure and maximum tolerable limits (figure 15). Before entering in a state of complete accumulated fatigue due to noise, vibration exposure felt on the whole-body and Age. Exposure value groups created to evaluate the tolerance levels and ways of mitigating risk by segregation added based on ICAO SMS 9859 criteria's and definitions.

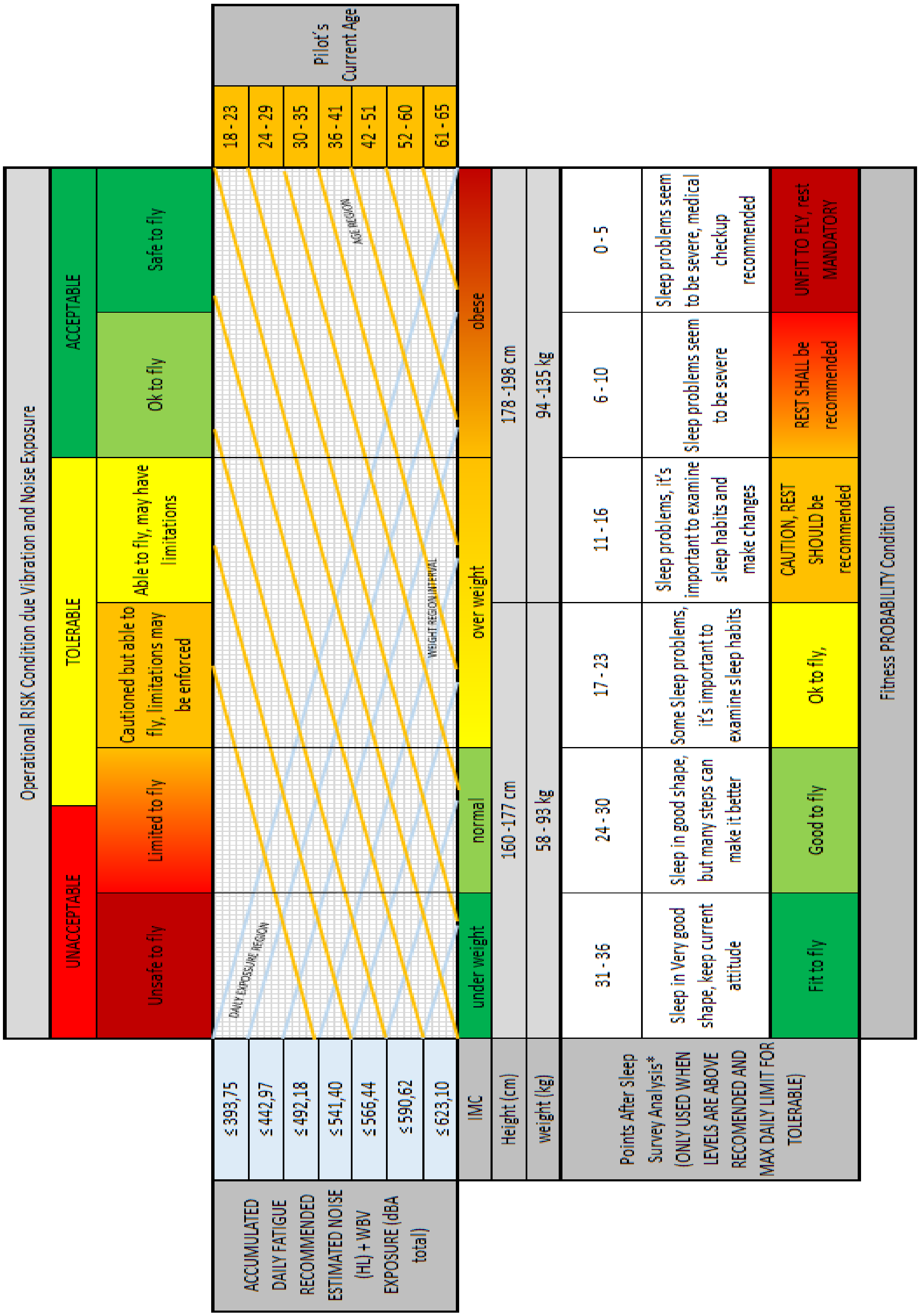



*Figure 15*: Performance Risk Chart for HL & WBV Daily Exposure.
Source: Author´s Creation

The research contributing tools focuses on the objective of the research study: the general overall enhancement of safety standards in the offshore oil and gas industry worldwide towards pilot fatigue.  Provide offshore helicopter operators with a better understanding of the correct rostering schemes to implement in each business activities. The ability of offshore helicopter operators to measure the estimated fatigue levels. The use of a quick risk-mitigating tool during the rotation period of ON. Lastly, contribute to the development of a tool that can add higher safety standards to the operator’s Safety Management System (SMS).

## Chapter VIII Limitations of Study

This study has several limitations when researching with self-report. A considered bias where participants may overstate desirable behaviours and minimise undesirable ones a report is based on perception, experience and recalled memory events. (Donaldson & Grant-vallone, 2002).

- The study was limited to the country of Angola, one out of a total of 3 companies conducting the same offshore activity. The other two companies, however, have less than one-third of the total number of helicopter pilots in the country.
- The sample used in this study was limited in the sense that only tested SonAir Pilots and not all national helicopter operators were involved.
- The data were collected through online surveys, although with a meagre rate of Captains responded. A total of 46 responses from pilots (33 Co-pilot`s and 13 Captains) were received out of 87 pilots (66 Co-pilot`s and 21 Captains) although in both cases achieving at least 50%.
- The survey was conducted in a period where flight activity was below average due to offshore crew change reduction by oil and gas operators. Crude prices, oil production and OPEC (Organization of the Petroleum Exporting Countries) reduction and lastly due to the coronavirus pandemic.
- No vibration data was able to be assessed in the maintenance department (DMAR) with the use of manufactures software. The use of Health and Usage Monitoring System (HUMS), in obtaining a total value of fuselage vibration and transfer to the onboard crew. Therefore an estimated average of 95,73 dBA from the specified value of ISO 2631-2018 was used for estimated calculations of the HNVED formula.

The limitations of this research study only foresee the requirement for further studies on the subject, in order to fully understand the fatigue levels and how Age, WBV and HL from noise will affect helicopter pilots. The real answer lays in the critical contributors to the understanding of pilots being or not operationally fit to fly (OFTF).

## Chapter IX Recommendations for Future Study

The complexity of human response to vibration is such that a solution to some of the specific problems might not find in the literature. In cases with such complexity, the only means of determining a solution is by experimentation to analyse and define the pathogen-disease causality resulting in increased fatigue and performance degraded or ultimately imposed accumulated stress. Therefore, it is essential to conduct such research in suitable facilities with personnel of different genders and age in this line of work activity that is continually available to be studied, investigated and advised on such problems during prolonged periods of years. Recommendations for further study in:

(i) A prospective interventional study calls for different conditions. In the northern hemisphere, where meteorology is different, and offshore activity is triple than in Angola. It would be highly recommended to enhance the understanding of the subject matter; in regards to exposure of vibration levels and associated pilot fatigue. *Reason of Study* is the weather conditions; for example, in the northern hemisphere might contribute to the worsening of pilot fatigue in joints, muscles and ligaments pain.

(ii) A prospective interventional study in vibration dose exposure and associated pilot fatigue limitations of subjects within 28 ON / 28 OFF rotation scheme, and subjects exposed may fly to above 70 hours per rotation. *Reason of study* is to compare previous studies that have referenced subjects may lead to acute pain when exposed to accumulated fatigue in the lower back. Helicopter pilots should not have to transient to acquire chronic LBP or disease that may result in the subject feeling impaired to work or permanently disabled.

(iii) Analysing the countermeasures emplaced to mitigate the hazard and risk in avoidance of entering this region (chronic LBP or disease) should be mitigated. *Reason of study* to provide valuable information relative to the threshold.

(iv) Research analysis on reduction in the exposure amount of vibrations transmitted to crews cockpit and passengers cabin.

(v) Preventing measures to back pain in helicopter pilots, advancement should address improvement in seat comfort and cockpit ergonomics.

(vi) Real work-related studies during a more extended period are needed to understand better the real threat to the helicopter pilot's fatigue and health in the short and long terms. The application of the results of experimental studies should address with caution to the real work environment.

(vii) The effect of body mass index and seating position affects helicopter pilots fatigue.

Highly added valuable factual information would provide this unique occupational group towards a better understanding of helicopter pilot accumulated fatigue levels and pilots considered operationally fit to fly. Lastly, more insights guarantee more comprehensive conclusions.

## Chapter X Conclusions

The presented study revealed that the exposure to Whole-Body Vibration and above-average noises is a general result and high contributor to helicopter pilot fatigue impact. A significant drawback in studies used to outline the relationship between WBV, low back disorders and fatigue. Findings strongly suggest that mechanical vibration will induce muscular fatigue. Per se can induce pathological changes in the spine and its supportive structures, resulting in increased susceptibility of the spine to injury. However, the results of this study do not provide a sufficient basis to establish if the stress-induced to the health may result in fatigue. Therefore, the epidemiological evidence of an excess risk for low back disorders among professional helicopter pilots is likely to be the result of a complex interaction between vibration exposure and postural overload occurring in flying. The conclusions shall only apply to male helicopter pilots, as there is a scarceness population of the female helicopter pilot. Current guidelines and exposure limits recommended standards and regulations for WBV are also only applied to male helicopter pilot´s. A practical consequence of the shortage of information on female helicopter pilots exposed to WBV. Real work-related studies during a long period are needed to understand better the real threat to helicopter pilot's fatigue and health in the short and long terms. Noise exposure with continuous above-average recommended levels, in time it will result in a change to the auditory system. Physical characteristics and several side effects result in Hearing Loss. The significant reduction that affects the pilot's awareness to; sound localization, self-motion perception, spatial orientation, auditory events. All of which causes the inability to make appropriate postural adjustments, remain orientated in space and to conduct timely reactions to changes in the surrounding of pilots SA. In such a scenario, all pilots, both on fixed or rotor wing operations, shall be affected. Nevertheless, the second (being a rotary wing) has a prevalence of higher fatigue values. The potential damage to the ear calls for risk management towards fatigue relating to noise or HL in helicopter pilots. It demonstrates tremendous importance to the resting periods permitting the body to self-heal.

Pilots age and the total daily flight hours exposure will have a direct association with the recovery periods, health effects on the body and fatigue. Literature reviews show how the lack of inadequate rest periods will proportionally affect safety and pilots performance. The older pilots get, the lower the quality of sleep is observed. With age, change is bound in the middle and inner ear. A clear demonstration that potential damage may be related to time and intensity exposure. The author considers age as being relevant when it comes to the ability to recover from acute fatigue levels rapidly. Such characteristic should affect all pilots, whether being on fixed or rotor wing operations. Acknowledging that rotary-wing pilots have a prevalence of higher fatigue values, many of them report ringing in their ears after a flight, which can potentially represent evidence of a hearing degradation. A clear demonstration that the damage may be related to time and intensity exposure. The potential damage to the ear calls for risk management towards fatigue relating to noise or HL in helicopter pilots. It demonstrates tremendous importance to the resting periods permitting the body to self-heal.

The research contributing tools presented focus on the objective of the research study: the general overall enhancement of safety standards in the offshore oil and gas industry worldwide towards pilot fatigue. Results revealed a safer analysis of fatigue measurement related to working flight hours per each rotation scheme ON/OFF. The best understanding in the selection of the best rostering scheme would be 28 ON / 28 OFF. The present study provides the necessary tools for offshore helicopter operators to obtain a better understanding of the correct rostering schemes to implement in each business activities. Offshore helicopter operators can measure the estimated fatigue levels with the quick risk-mitigating tool during the active rotation period (ON). The sleep condition indicator gives us a clear understanding of the effect of the qualities of sleep. It proves that scheduling in association with sleep habits as well as pilots primary role of responsibilities are important and should have oversight. The higher the responsibility and those with military experience are more susceptible to have less quality of sleep in comparison to non-military pilots or of lower responsibilities. The tools, *Safety Risk Analysis Matrix towards WBV and HL in Helicopter Pilots* and *Performance Risk Chart for HL & WBV Daily Exposure,* contribute to the development of higher safety standards in operator's Safety Management System (SMS) and in the industry as a whole. Are helicopter operations safe enough? Are pilots operationally fit to fly? Aviation industry continues to evolve based on safety lessons; operators should be eager to learn and obtain more knowledge towards the development of the more effective rostering scheme, should take into consideration the potential hazardous factors of WBV, hearing loss due to noise and age. The ultimate enhancement of overall operations and pilots safety.

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# Appendices

## *Appendix 1: Pre-Notice Letter of Survey*

Pre-Notice Letter

I am a helicopter offshore pilot attending a Masters Degree in Air Transport Operations at Instituto Superior de Educação e Ciências (ISEC) in Lisbon – Portugal; currently, developing a research study towards a thesis in offshore pilot fatigue. The purpose of this survey is to obtain relevant information regarding fatigue risk in the offshore industry. The data gathered will help the process of mitigating fatigue analysis.

Your participation is essential!

Please answer the following questionnaire. It takes no more than 12 minutes. All answers are anonymous and aimed for academic purposes.

On behalf of the research team, I would like to thank you for your cooperation.

## *Appendix 2: Survey Questions*

**OFFSHORE PILOT AVIATION SAFETY SURVEY**

***I – DEMOGRAPHIC INFORMATION***

1. Gender:
   ◯ Female ◯ Male

2. Age (years):
   ______

3. Academic Qualification
   High School ◯ Bachelor´s Degree ◯ Graduate Degree ◯ Master ◯ PhD

***II – PROFESSIONAL INFORMATION***

4. Pilot license:
   ◯ Commercial Pilot (CPL(H)) ◯ Airline Transport Pilot (ATPL (H))

5. Instrument rated:
   ◯ Yes ◯ No

6. Military experience, in an aviation-related occupation:
   ◯ Yes ◯ No

7. Current number of hours? (Your best estimate is fine)
   __________

8. Main role in the Organization?
   ◯ Co-pilot
   ◯ Captain
   ◯ Air Check man
   ◯ Instructor
   ◯ Line training Captain
   ◯ Type Rating Instructor (TRI)
   ◯ Type Rating Examinator (TRE)
   ◯ Chief fleet
   ◯ Chief Pilot

9. How long have you been working in the aviation industry? (Your best estimate is fine)
   __________

***III - SLEEP-QUALITY AND FATIGUE***

10. Did you have training in Human Factors during your pilot training course?
    ◯ Yes ◯ No

11. Classify your understanding of the PHYSIOLOGICAL EFFECTS OF FLYING IN THE HUMAN BODY
    ◯ 1- None ◯ 2- insufficient ◯ 3- sufficient ◯ 4- Very sufficient ◯ 5- Excellent

12. Classify your ability to detect IF YOUR BODY is UNDER the INFLUENCE OF FATIGUE
    ◯ 1- None ◯ 2- insufficient ◯ 3- sufficient ◯ 4- Very sufficient ◯ 5- Excellent

13. Classify your ability to detect IF YOUR COLLEAGUE is UNDER the INFLUENCE OF FATIGUE
    ◯ 1- None ◯ 2- insufficient ◯ 3- sufficient ◯ 4- Very sufficient ◯ 5- Excellent

14. Classify your UNDERSTANDING OF THE SIDE EFFECTS OF FATIGUE
    ◯ 1- None ◯ 2- insufficient ◯ 3- sufficient ◯ 4- Very sufficient ◯ 5- Excellent

15. Do you understand the psychological effects on the human body when under the influence of fatigue?
    ◯ Yes ◯ No

(NEMSPA Sleep and Fatigue Survey, Questions 16 - 28 (Gregory et al., 2010))

16. How many consecutive DAY shifts do you typically work?
    ◯ 1 or 2 ◯ 3 or 4 ◯ 5 or 6 ◯ 7 ◯ greater than 7

17. How long are you typically OFF when transitioning from DAY shifts to NIGHT shifts?
    ◯ 24 hours ◯ 2 to 3 days ◯ 4 to 5 days ◯ 6 to 7 days ◯ greater than 7 days

18. How long are you typically OFF when transitioning from NIGHT shifts to DAY shifts?
    ◯ 24 hours ◯ 2 to 3 days ◯ 4 to 5 days ◯ 6 to 7 days ◯ greater than 7 days

19. How much do you typically sleep during NIGHT shift? (average /typical)
    ◯ < 1 h ◯ 1- 2 h ◯ 2- 3 h ◯ 3- 4 h ◯ 4- 5 h ◯ 5- 6 h ◯ 6- 7 h ◯ > 7 h

20. How much sleep do you typically require to feel completely rested and alert during the day?
    ◯ < 5 hours ◯ 5 to 6 hours ◯ 6 to 7 hours ◯ 7 to 8 hours ◯ > 8

21. Describe your sleeping habits during the daytime, before reporting for night shift (check all that apply)?
    ◯ I attempt to sleep as much as possible during the day.
    ◯ It depends on how much sleep I had the night before.
    ◯ I generally take a 1-2 hour nap before coming to work.
    ◯ I generally take a 2+ hour nap before coming to work.

22. Describe your sleeping habits during the daytime, before reporting for night shift (check all that apply)?

◯ I can sleep well during the day if I was awake the night before.
◯ I have difficulty sleeping during the day, even if I was awake the night before.
◯ I can sleep well during the day, regardless of how much I slept the night before.
◯ I am able to take short naps (less than 2 hours) during the day.
◯ I am generally unable to even take short naps (less than 2 hours) during the day.

23. Which of the following significantly (at least 25% of the time) affects your ability to sleep during the day? (check all that apply)

◯ Children (playing, needing attention, school)
◯ Spouse /Roommate(s).
◯ Sleep area.
◯ Noise.
◯ Temperature
◯ Work Interruptions
◯ Social Interruptions
◯ Personal concerns (worrying)
◯ Work-related concerns
◯ other

24. How does knowing that the possibility exists for you to sleep during a night shift influence your daytime (before the night shift) sleeping habits?

◯ That possibility does not influence my daytime habits.
◯ That possibility might influence my daytime habits if I have something important to do during the day.
◯ That possibility definitely influences my daytime habit If I have something important to do during the day.
◯ That possibility always influences my daytime habits.

***25.*** In what ways has fatigue affected your flight performance? (check all that apply)

◯ can´t concentrate ◯ performance degraded ◯ alertness degraded ◯ other

26. When your flight performance is affected by fatigue, which phase of flight performance is most affected?

◯ Pre-fight planning ◯ pre-flight/walk -around ◯ Engine start/taxi ◯ takeoff/ enroute ◯ descent ◯ approach/Landing ◯ Engine Shutdown

27. How often do you catch yourself “nodding off” during a flight?

◯ Never ◯ rarely ◯ occasionally ◯ somewhat frequently ◯ frequently

28. Have you ever turned down a flight due to fatigue?

◯ Yes ◯ No

(Sleep Condition Indicator – By Colin Espie, University Of Oxford, questions 29 - 36 ) (Arianna Huffington, 2016)

***29.*** How long does it take you to fall asleep?

| | | |
|---|---|---|
| ◯ | 0–15 min. | 4 points |
| ◯ | 16–30 min. | 3 points |
| ◯ | 31–45 min. | 2 points |
| ◯ | 46–60 min. | 1 point |
| ◯ | >60 min. | 0 points |

30. If you then wake up one or more times during the night, how long are you awake in total? (Add up all the time you are awake.)

| | | |
|---|---|---|
| ◯ | 0–15 min. | 4 points |
| ◯ | 16–30 min. | 3 points |
| ◯ | 31–45 min. | 2 points |
| ◯ | 46–60 min. | 1 point |
| ◯ | >60 min. | 0 points |

31. If your final wake-up time occurs before you intend to wake up, how much earlier is this?

| | | |
|---|---|---|
| ◯ | 0–15 min. | 4 points |
| ◯ | 16–30 min. | 3 points |
| ◯ | 31–45 min. | 2 points |
| ◯ | 46–60 min. | 1 point |
| ◯ | >60 min. | 0 points |

32. How many nights a week do you have a problem with your sleep?

| | | |
|---|---|---|
| ◯ | 0– 1 | 4 points |
| ◯ | 2 | 3 points |
| ◯ | 3 | 2 points |
| ◯ | 4 | 1 point |
| ◯ | 5–7 | 0 points |

33. How would you rate your sleep quality?

| | | |
|---|---|---|
| ◯ | Very poor | 0 points |
| ◯ | Poor | 1 points |
| ◯ | Average | 2 points |
| ◯ | Good | 3 point |
| ◯ | Very Good | 4 points |

34. In your opinion, does your sleep affect your mood, energy, or relationships? *(variation)*

| | | |
|---|---|---|
| ◯ | Not at all | 4 points |
| ◯ | A little | 3 points |
| ◯ | Somewhat | 2 points |
| ◯ | Much | 1 point |
| ◯ | Very much | 0 points |

35. In your opinion, does your sleep affect your concentration, productivity, or ability to stay awake?

| | |
|---|---|
| ◯ Not at all | 4 points |
| ◯ A little | 3 points |
| ◯ Somewhat | 2 points |
| ◯ Much | 1 point |
| ◯ Very much | 0 points |

36. How long have you had a problem with your sleep?

| | |
|---|---|
| ◯ I don't have a problem | 4 points |
| ◯ < 1 month | 4 points |
| ◯ 1–2 months | 3 points |
| ◯ 3–6 months | 2 points |
| ◯ 7– 12 months | 1 point |
| ◯ > 1 year | 0 points |

37. When flying, how many hours would you consider to be safe before you feel your body is under the influence of fatigue?

◯ 1 - 2 hours ◯ 3 - 4 hours ◯ 5 - 6 hours ◯ 7 - 8 hours

38. In your opinion, what is the best rostering scheme for offshore oil and gas Pilot flying activities?

◯ 7 on 7 off ◯ 14 on 14 off ◯ 21 on 21 off ◯ 28 on 28 off ◯ 35 on 35 off ◯ Other

39. If you have any further comments about your experiences or this survey, please provide detailed information.

_____________________________

For assistance with this survey, please call +244949235911, +351965486148 or email carlosluciano18@hotmail.com.