Operational Impacts of Vibration and Noise on Offshore Helicopter Pilot Fatigue: Field Data Analysis

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Thesis submitted for the degree of PhD in

Structural Integrity of Aircraft

Supervisor: Doctor Manuel José Moreira de Freitas
Co-Supervisor: Doctor Pedro Rodrigues da Costa

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Impactos Operacionais da Vibração e do Ruído na Fadiga de Pilotos de Helicópteros Offshore: Análise de Dados de Campo

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Declaration/ *Declaração*

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Resumo

No setor de petróleo e gás, os trabalhadores viajam de helicóptero entre locais terrestres e offshore. A duração dos voos varia de 45 a 90 minutos por perna voada, com muitos tripulantes de voo excedendo rotineiramente 10 horas de período de serviço de voo (PSV) e limitados a 8 horas de serviço de voo (SV) por dia. No ar, os pilotos enfrentam condições que contribuem para a fadiga física e mental. Este estudo avalia a exposição dos pilotos de helicópteros a altos níveis de ruído em decibéis e vibração de corpo inteiro (VCI), fatores decisivos e relevantes para a fadiga durante longos períodos operacionais. Vinte e cinco pilotos do sexo masculino em Angola foram selecionados para a recolha de dados, por meio de amostragem não probabilística, incluindo voos em helicópteros dos modelos AW139 e AW189, operados pelas empresas SonAir e Bestfly. As medições obtidas durante voos comerciais utilizaram acelerómetros para medir vibração e microfones para medir som. Os participantes tinham, em média, mais de 45 anos, mediam 1,75 metros de altura e pesavam mais de 85 kg. O presente estudo conclui que a exposição a vibrações e ruído é substancial e prejudicial, indicando uma exposição cumulativa significativa ao ruído e às vibrações durante voos diários superiores a 4 horas, levando a recomendações de limites diários de voo. Como solução para a gestão do risco de fadiga dos tripulantes, apresenta-se uma metodologia de gestão que confirma a seleção ideal de uma escala ON/OFF. Essa abordagem será crucial para a manutenção dos sistemas de gestão da segurança operacional da aviação e para a promoção da melhoria contínua do safety. No entanto, a generalização é limitada devido à representação inadequada dos dados entre as regiões e à ausência de participantes do sexo feminino. Fatores externos que possam afetar a fadiga dos pilotos não foram considerados neste estudo.

Palavras-Chave: *Fadiga do Piloto de Helicóptero Offshore, Vibração de Corpo Inteiro Offshore, Fadiga do Ruído no Cockpit Offshore, FRMS em Helicóptero Offshore.*

Abstract

In the oil and gas sector, workers travel by helicopter between onshore and offshore locations. Flight durations range from 45 to 90 minutes per flight leg, with many flight crew members routinely exceeding 10 hours of flight duty time (FDT) and being limited to 8 hours of flight time (FT) daily. While airborne, pilots face conditions that contribute to physical and mental fatigue. This study assesses helicopter pilots exposure to high-decibel noise levels and whole-body vibration (WBV), significant contributors to fatigue during long operational periods. Twenty-five male pilots in Angola were selected for data collection, utilising non-probabilistic sampling and including flight tests conducted by SonAir and Bestfly on the AW139 and AW189 helicopter models. Measurements obtained during commercial flights utilised accelerometers for vibration measurements and microphones for sound recordings. Participants averaged over 45 years of age, measured 1.75 meters tall, and weighed over 85 kg. The present study concluded that exposure to vibrations and noise is substantial and harmful. This indicates substantial cumulative exposure to noise and vibrations during daily flights exceeding 4 hours, leading to suggestions for recommendations for maximum daily flight limits. As a solution to manage the risk of crew fatigue, a management methodology is presented that supports the optimal selection of an ON/OFF scale. This approach will be crucial for maintaining aviation safety management systems and promoting continuous safety improvement. However, generalizability is limited by inadequate data representation across regions and a lack of female participants. External factors affecting pilot fatigue were not examined in this study.

Keywords: Offshore Helicopter Pilot Fatigue, Offshore Whole-body Vibration, Offshore Cockpit Noise Fatigue, Offshore Helicopter FRMS

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List of Abbreviations and Acronyms

AD-HOC	The Latin word thar means “*for this*” or "*for this situation*". In aviation, an AD-HOC Flight refers to a charter flight or air taxi, which is a non-scheduled flight not included in regular airline routes. This type of flight is booked as needed, customised to meet a specific client's requirement and itinerary instead of following a set schedule.
ALARP	As Low As Reasonably Practicable
ANAC	*Autoridade Nacional de Aviação Civil,* (NCAA in inglês)
AFRP	Aramid Fibre Reinforced Polymer
ATPL H/A	Airline Transport Pilot License (H- Helicopter, A- Airplanes)
AVCS	Active Vibration Control Systems
BMI	Body Mass Index
BRI	Body Roundness Index
BROP	Best Ratio Operator-Pilot
BVI	Blade Vortex Interaction
CAA	Civilian Aviation Authority
CFIT	Controlled Flight Into Terrain
CFRP	Carbon Fibre-Reinforced Polymer
CPL H/A	Commercial Pilot License (H- Helicopter, A- Airplanes)
CRM	Crew Resource Management
CPT	Captain or Pilot in Command
DFTL	Daily Flight Time Limit
EASA	European Aeronautical Safety Agency
EPNL	Effective Perceived Noise Level
FADEC	Full Authority Digital Engine Control
FDM	Flight Data Monitoring
FDT	Flight Duty Time
FO	First Officer or Co-Pilot or Second in Command
FRMS	Fatigue Risk Management System
FT	Flight Time

GRFP	Glass Fibre Reinforced Polymer
GSO	*Gabinete de Segurança Operacional* (Flight Safety Office)
HAV	Hand-Arm Vibration
HEMS	Helicopter Emergency Medical Services
HL	Hearing Loss
HMFT	Helicopter Maximum Flight Time
HOGE	Hover out-of-ground effect
HUMS	Health and Usage Monitoring System
ICAO	International Civilian Aviation Organisation
IFTL	Ideal Flight Time Limit
ILFN	Infrasound and Low-Frequency Noise
IMC	Instrument Meteorological Conditions
IOGP	International Oil and Gas Producers
ISO	International Organization for Standardization
LDP	Landing Decision Point
MCC	Multi-Crew Coordination
MDFT	Maximum Daily Flight Time
Medevac	Medical Evacuation
MR	Main rotor
MTOW	Maximum takeoff weight
NCAA	National Civilian Aviation Authority
NDT	Non-Destructive Testing
NTA	*Normativo Técnico Aeronáutico*
NIHL	Noise-Induced Hearing Loss
OFF	OFF is a period of rest or off-duty work
ON	On is a period of on-duty work or being scheduled to work.
OSHA	Occupational Safety and Health Administration
PIC	Pilot in Command or Captain
PF	Pilot Flying

PM	Pilot Monitoring
PPE	Personal Protective Equipment
PSV	*Período Serviço de Voo*
QM	Quality Management
Sanevac	Sanitary Evacuation
SAR	Search and Rescue
SIC	Second in Command or Co-Pilot
SMS	Safety Management System
SN	Sound Noise
SPSS	Statistical Package for the Social Sciences
SV	*Serviço de Voo*
TCDSN	Type Certificate Data Sheet for Noise
TDP	Takeoff Decision Point
TR	Tail Rotor
VAD	VibroAcoustic Disease
WBV	Whole-Body Vibration

List of Units

BMI	Body Mass Index (kg/m^2)
dB	Decibel
dBA	A-weighted decibel
HNVED	Helicopter Noise Vibration Estimated Exposure Dose (dB)
HNVmfED	Helicopter Noise and Vibration Manufacturer Estimated Exposure Dose (dB)
HNVrfED	Helicopter Noise and Vibration Real Flight Estimated Exposure Dose (dB)
Hz	hertz
IAS	Indicated Airspeed
KIAS	Knots of Indicated Airspeed
kg	kilograms
log	logarithm
m	metre
m/s^2	Metre per second squared
PANVrfED	Propeller Airplane Noise and Whole-Body Vibration Real Flight Estimated Exposure Dose (dB)
s	seconds

Chapter I Introduction

The human body is a unique “machine” from an engineering perspective, harbouring mysteries that have not yet been fully revealed or characterised. Nevertheless, individuals continually try to deceive their “systems” (body and mind) by systematically pushing the limits, yet failure may persist even when full knowledge is reached.

The aviation industry has been rapidly developing since the 19th century, and additional operational safety measures are essential to ensure its growth over the next two decades. Surprisingly, the systems (both hardware and software) are developing relatively faster than humans (liveware). Workers across generations in the industry are experiencing significant knowledge and experience gaps, leading some to struggle to keep pace. Within these groups, potential risks related to human factors and fatigue levels are sometimes overlooked. Among these individuals, helicopter pilots pose a notable concern in the realm of human factors.

In helicopter accidents, aircrew human error remains the leading cause. It is imperative to study and continuously improve the relationship between man-machine-other, being 'other' elements, such as the environment, in both work and everyday life. In aviation, the constant goal is to minimise latent hazards, risks, and conflicts arising from the relationship between man, machine, and other factors by employing well-established systems or procedures. This promotes harmony within the overall system, resulting in improved operational safety. Identifying one's IKIGAI[1] and KAIZEN[2] daily while drawing knowledge from various industries represents the holy grail of life and work. The lack of achievement in aviation ultimately leads to an imperfect system that harbours latent hazards or risks, which will persist and cause accidents stemming from their root cause, primarily human error (Doc 9859 Safety Management Manual (SMM) Fourth Edition, 2018; Shappell & Wiegmann, 2000).

Helicopter operational characteristics have a natural tendency for higher fatigue levels than those experienced by fixed-wing aircraft pilots. Crews operating fixed-wing aircraft experience reduced equipment vibration; however, they are subjected to increased engine noise levels. The offshore industry discussed in this topic is underdeveloped despite significant industry interest and international recognition.

The shortage of helicopter pilots worldwide raises concerns about the accumulation of fatigue and related health issues. Numerous side effects, extensively studied in helicopter pilots, have revealed several pre-existing work-related conditions. Today, pilots are less exposed to hand-arm vibration due to automation. However, they mainly encounter excessive whole-body vibration and noise, which can lead to physical and health problems associated with prolonged exposure to high levels of vibration and noise over time.

[1] IKIGAI, Japanese term for philosophy of life regarding one's purpose, ability, vocation and work.
[2] KAIZEN, Japanese term for philosophy of life or work management regarding quality and organisation.

Offshore helicopter daily activities include transportation to/from an onshore heliport or airport to offshore rigs, vessels, associated installations, and sleeping facilities. The silence received from industry operators and helicopter manufacturers from previous studies has revealed valuable information about the several side effects widely studied in helicopter pilots. Previously, little attention seemed to be given to these elements, resulting in the overall efficiency of the crew-helicopter system often not being achieved (E.J. Lovesey, 1979). Nonetheless, limited progress has been made towards enhancing the welfare conditions of the crew management. The aeronautical industry has exhibited a lack of clarity and a markedly delayed acknowledgment of the detrimental effects experienced by pilots and their quality of life, which consequently impacts the well-being of their family units. Several relevant established correlations have been published in scientific research studies in medical, science and aeronautical journals, as well as pre-existing work-related illnesses or sicknesses associated with exposure to vibration and noise conditions in helicopter pilots.

The significantly elevated values between 91 - 110 dB, which surpass the recommended standards for international safety and health occupations, raise considerable concern. Although the author has identified a gap in the relevant studies, there is a pressing need to gather additional information to achieve a comprehensive understanding and elucidate safer methodologies. The research suggests that the direct measurement of pilot exposure to vibration and noise is an effective method that may help determine fatigue parameters, which are crucial for assessing pilot fitness and readiness for occupational flying duties and responsibilities. This additionally results in better pilot ratios and rostering schemes by mitigating latent risks.

A mixed-methods approach combining quantitative and qualitative research was proposed to gather data through measurements in actual flight. An additional correlational study with a cross-sectional design was conducted to gather data through Google Forms, which compiled 21 questions.

The study is therefore focused on human factors, including fatigue, rest periods, rotation schemes, and physical and psychological awareness of operational fitness to fly. Out of a population of approximately 80 active helicopter pilots in Angola working in an offshore environment within the oil and gas industry, more than 50% are based at a state-owned helicopter company called SonAir, while private companies, including BestFly and Heli Malongo, employ the rest.

1.1 Motivation of the Study

The author, an active helicopter pilot operating the AW189 in this industry, is a member of the working group and is keenly interested in researching and acquiring further knowledge regarding the health effects. Furthermore, the author is dedicated to identifying solutions backed by scientific proof that can be aimed at mitigating and creating solutions to the exposure of crews engaged in this field of activity. Most available studies originate from observers or authors outside the aeronautical industry with limited or no flying experience and with assumed limited knowledge in the field of human factors and its interaction in the operational environment.

1.2 Purpose and Contribution

The author aims to measure helicopter pilots' estimated actual flight vibration and sound noise exposure levels during flight. Furthermore, it enriches society’s knowledge of the risks associated with fatigue directly related to vibration and sound noise exposure, providing direct information for management’s decision-making regarding the best rostering scheme that augments the mitigating levels of fatigue.

The collected data clearly indicate a hidden hazard or risk in the helicopter transportation sector when pilots operate beyond 4 hours. This is particularly significant given that the recommended maximum daily limit is between 5 hours 30 minutes and 6 hours 15 minutes. (Teixeira, C., 2020). Although it is known that the maximum daily regulation limit of 8 hours may be the primary cause of accumulated fatigue in pilots due to excessive exposure to vibration, noise, and ultraviolet (UV) radiation (mainly in fixed-wing pilots who conduct intercontinental flights exceeding the average value recommended by health organisations). Furthermore, while crews have a specific period of rest, ranging from 20 to 45 minutes between flights, it is also advised that the same rest period be observed after 4 hours of flying (Teixeira, C., 2020) to break the cycle of what the author assumes to be the period of acute cumulative exposure after 4 hours without this rest. The author acknowledges that less than 45 minutes is sometimes granted between service flights, depending on the commercial pressure and time frame between each service. Additionally, there is a time frame of approximately 20 to 30 minutes between regular refuelling (engines off) for the outbound and inbound legs of flights.

The author means to prove that the measurements and benefits of Data collection will be of great use in:

i. Studies in whole-body vibration (WBV) and sound noise (SN) exposure in helicopter activities.
ii. Update or revise the “Safety Risk Analysis Matrix towards WBV and Hearing Loss (HL) in Helicopter Pilots” and the “Performance Risk Chart for HL & WBV Daily Exposure” presented in (Teixeira, C., 2020).
iii. Scientific data collection and numerical analyses are expected to associate pilots’ fatigue levels and determine their Operational Fitness To Fly (OFTF) during the on-duty (ON) rotation period.

1.3 Research Questions and Objectives

The author intends to address the existing gaps in the literature and scientific facts by responding to the investigation questions:

- Is the fatigue experienced by helicopter pilots predominantly attributable to exposure to whole-body vibrations and elevated noise levels produced by the rotor blades and engines, which jointly contribute to the overall impact?
- How can the daily exposure doses of pilot vibration and noise be measured and quantified to identify trends in fatigue?
- What is the exact exposure of WBV and SN of pilots performing flights with AW139 and AW189?
- Can the Flight Data Monitoring (FDM) of the aircraft be correlated with the acquired data by direct measurement equipment on the pilot?
- If so, could a trustworthy pilot fatigue characterisation be made solely by the FDM?
- Are measurements sufficient to identify and select the best rotation scheme ON/OFF scheme (21, 28 or 35) independently of the crew responsibility across flight exposure?

The author intends to improve safety standards related to pilot fatigue in the global offshore oil and gas sector by engaging the following objectives:

- Identify offshore helicopter pilots' daily exposure to vibration and sound noise exposure during a full day of work, up to a maximum of 8 hours of flights.
- Identify the average daily flying time limit when WBV and SN exposure exceed international health standards and recommendations.
- Analytical data relating to the Fatigue Risk Management System (FRMS) will help offshore helicopter operators better understand the correct rostering schemes based on intensity to implement in each business activity.
- Develop and create a simplified mechanism, system or tool to add to Helicopter Flight Data Monitoring (HFDM), which enables operators to control the exposure of vibration and sound noise values.
- Develop a Helicopter Pilot Fatigue Risk Matrix as a quick risk-mitigating tool during the ON rotation period.
- Lastly, contribute to developing and creating a simplified mechanism, system, or tool to add to the operator's Safety Management System (SMS), which enables operators to control the exposure to vibration and sound noise values.

1.4 Thesis Outline

The current research study is organised and divided into the following eight chapters:

Chapter I, a brief introduction, explains the project, the motivation of the study, followed by the Purpose and Contributions, Research Objectives and Questions, and finally, the thesis outline.

Chapter II, Theoretical Contextualization, explains Pilots' Psychological and Physiological Normal States. It introduces offshore helicopter pilots' activities and daily stress and explains the three most noticeable contributors to pilot fatigue.

Chapter III, Literature Review, focuses on Vibration, Noise, and Signal Analysis and Composite Materials in the Aerospace Industry.

Chapter IV, Research Questions, contains questions that require further clarification to establish any potential correlation with associated fatigue during flight. Relevant insight from surveys, measurements, and data analysis can be used to create mitigating tools and further research studies.

Chapter V, Methodology, outlines the experimental and analytical methodology employed in the present research study, including the study design, participants and sampling, data collection, survey, measurements, and data analysis.

Chapter VI, Results, is divided into two parts: Part I addresses the survey data, while Part II discusses the data obtained from in-flight measurements and their analysis.

Chapter VII, "Research Contributions and Discussion," presents revised and recreated equations and operator tools that help clarify the discussion by comparing the collected data. Additionally, direct operational feedback from rotor and fixed-wing pilots supports the research results and highlights pertinent facts.

Chapter VIII, Conclusion, clarifies the authors' ability to achieve some of the initially proposed objectives, their contribution to the literature on the diminished gap, and their ability to answer the research questions and hypotheses. It comprehensively summarises the research study's conclusions, discusses its limitations, and recommends future studies.

Appendices provide relevant information to support the research study, including the pre-notice letter, questionnaire, conversion table from acceleration to decibels, and in-flight data.

Chapter II Theoretical Contextualization

This chapter contextualises every important concept surrounding Human Factors in pilots for the present thesis research objectives. It begins with the daily activities of a helicopter pilot in the offshore oil and gas industry. It establishes the 'normal' pilot's psychological and physiological state. Afterwards, the chapter establishes the pilot's daily stress and the three most noticeable side effects contributing to pilot fatigue: **WBV, Sound Noise** resulting in Hearing loss (HL) **and Age.**

2.1 Pilots' Psychological and Physiological Normal States

Pilots must present themselves before a flight in well-rested and well-prepared circumstances. Pilots' vitality depends on their circadian rhythms: Sleep is as vital as food, water, and air, and disruption leads to serious fatigue-related risks (Gregory et al., 2010; Teixeira, C., 2020). Apart from the stated, the National Civil Aviation Authority regulations require an outstanding Aeronautical Class 1 medical record to be maintained annually.

Offshore flight activity worldwide typically ranges in time between 30 and 45 minutes. In Angola, support flights for offshore oil rigs primarily depart from Luanda's old International Airport, 4 de Fevereiro, to industrial sites over 100 nautical miles away, extending beyond the usual range and duration. Flights may soon shift to the new International Airport Dr. António Agostinho Neto, potentially resulting in longer transit times.

Several stressful conditions reduce the normal state of awareness and readiness, ultimately affecting the safety performance of associated helicopter pilots. "*A helicopter pilot´s psychomotor performance may be affected by several factors, involving (but not limited to) fatigue, time on the job, workload, environmental conditions, and operational stressors*" (McMahon & Newman, 2018). In addition to the above, pilots must genuinely feel healthy and fit to fly while on daily duty. This also includes understanding how to cope with routine changes that have an unusually significant impact on psychological and physiological well-being.

Landing on an oil rig facility or vessel with a fixed helideck or a moving elevated helipad demands that helicopter pilots push their skills to the extreme. Flying out of ground effect (OGE) entails variables, factors, and threats that can influence approach flight stability. OBSTACLES: rig cranes, antennas, flares, nearby ships or vessels. WEATHER: variable wind direction and intensity, reduced visibility due to fog, mist, and clouds, and atmospheric pressure. HELIDECK: dimensions, position, markings, lights, entry and exit points, and height (CAP 437, 2023; CAP 1145, 2014)

2.2 Pilot's Daily Stress

The energy that an individual possesses internally is restricted on a daily basis by the rest acquired each night. Consequently, a heightened level of concentration on flight activities results in an augmented daily depletion of energy, leading to stress or fatigue that adversely impacts the body with cumulative fatigue. "*Continuous helicopter operations in hostile environments might produce high levels of cognitive fatigue for the reason of time on duty, prevailing environmental conditions, the nature of the job, high cognitive workloads, operational or individual stressors, and reduced quality and amount of sleep*" (Rabinowitz et al., 2009). Scientific research has demonstrated that cognitive fatigue impacts cognitive and psychomotor performance (Kato et al., 2009; Lorist et al., 2002; Teixeira, C., 2020). Helicopter pilots are affected by several side effects resulting from the principles of vertical lift and aerodynamics. Additionally, when flying without a washroom, the delay in fulfilling the pilot's physiological needs may also cause internal unseen damage over time (Seidel et al., 1980), in the long run, may lead to potential health issues related to accumulated sickness resulting from vibration (Pope et al., 1985) and noise exposure (Lowson & Ollerhead, 1969) .

Several health effects, reported in various studies since late 60´s and early 70´s (Hawkes & Worsham, 1970; Lowson & Ollerhead, 1969), have been **attributed to exposure to noise and vibration** in the following body systems: the nervous system, Muscular and Skeletal system, Reproductive System, Endocrine system, Gastrointestinal system, Cardiovascular system, Respiratory System, and Urinary system. Affecting the body organs: Brain, spinal cord (Bongers et al., 1990; Dupuis & Zerlett, 1987; E.J. Lovesey, 1979; Pope et al., 1985), nerves and sensory organs; Muscle, tendons, smooth muscle, cardiac muscle and Joints, cartilage, and ligaments directly (E.J. Lovesey, 1979; Gradwell & Rainford, 2015; Seidel et al., 1980) ; Ovaries/ Testicles; Intestines, Stomach and Pancreas; Heart arteries, veins, blood vessels and lungs; liver; urinary tract (Gradwell & Rainford, 2015; Seidel et al., 1980). **Causing several side effects and disorders on pilots**: **Temperament swings, depression, irritability, aggressiveness, absence of energy, difficulties with concentration, panic attacks and anxiety, touch sensitivity, vision distorting** (E.J. Lovesey, 1979; Gradwell & Rainford, 2015), **and hearing momentary and permanent impairment (often reported), nervous break downs, stress-related symptoms**; **fatigue (reported when flying above 4 to 6 hours per day), loss of situation awareness; bones, joints (knees, elbows, lower back, neck) swelling, tension, diminished bone density, stiffness in the shoulders and back pain (most commonly reported**) (Panjabi et al., 1986; Pope et al., 1985) and sciatica pain (Bongers et al., 1990) ; and degenerative variations in the spinal, including lumbar inter-vertebral disc disorders (Dupuis & Zerlett, 1987; Panjabi et al., 1986); dormant muscle and cramps; declines testosterone and estrogen production, dropping fertility and sexual appetite, menstrual deregulation(Gradwell & Rainford, 2015; Seidel et al., 1980); nutrient absorption reduction and decreased metabolism (Panjabi et al., 1986), constipation, rises the risk of inflammatory bowel diseases (esophagitis, gastritis, colonitis, ileitis, and proctitis), cuts enzyme activity and diabetes; stomach ache or discomfort, nerve ulcers, gastric ulcers, irritable bowel syndrome, food allergies, stomach pains, reflux, nausea and weight oscillations; high insulin secretion that can lead to diabetes, harm to arteries and obesity; rise blood pressure, fast heart rate, higher risk of heart attack and stroke, rise “harmful” cholesterol; hormone fluctuations, calcium absorption, water retention, kidney stones, protein production, urinary tract infections (Cornelius et al., 1994; E.J. Lovesey, 1979; Gradwell & Rainford, 2015; Seidel et al., 1980). **All the above side effects and disorders have age as a significant negative factor towards accelerating the body’s correct function and recovery periods. These result in high fatigue levels and reduce operational fitness to fly, which are related to pilot response in normal and abnormal situations and reduced situational awareness.** Furthermore, a summary is presented on the general literature overview.

2.3 Three most noticeable contributors to pilot's fatigue

In this experimental and numerical research, the author acknowledges several contributors to pilot fatigue, such as body temperature, work location, ambient temperature (mainly in countries with tropical or subtropical climates), seating position, tightness of 5-point seatbelt, year of manufacture of the helicopter, number of helicopter fuselage and engine hours, psychological updated daily mental health and physiological daily body fitness. The author focuses this research study on explaining how fatigue may be affected by what he assumes are two main causal factors, with a third possibly varying**.**

First, Whole-Body Vibrations (WBV) are transferred to the entire body through a support surface. In this research study, vibrations are felt in areas such as the feet, buttocks, and the back of a seated person, as indicated by the pink dots in **Figures 1 and 2**. This is particularly relevant for helicopter pilots during flight, as shown in **Figure 3**. In other words, medically speaking, vibration transmitted through contact surfaces primarily affects the human body's muscles, tendons, and bones, although other organs have also been reported to be affected and which are discussed further in this chapter. It is characterised by three variables: frequency measured in Hertz (Hz), the acceleration experienced by the body (m/s^2), and the direction in which vibrations propagate, affecting the levels received by humans' axes—the longitudinal (*x*), lateral (*y*), and vertical (*z*) axes (**Figure 2**).

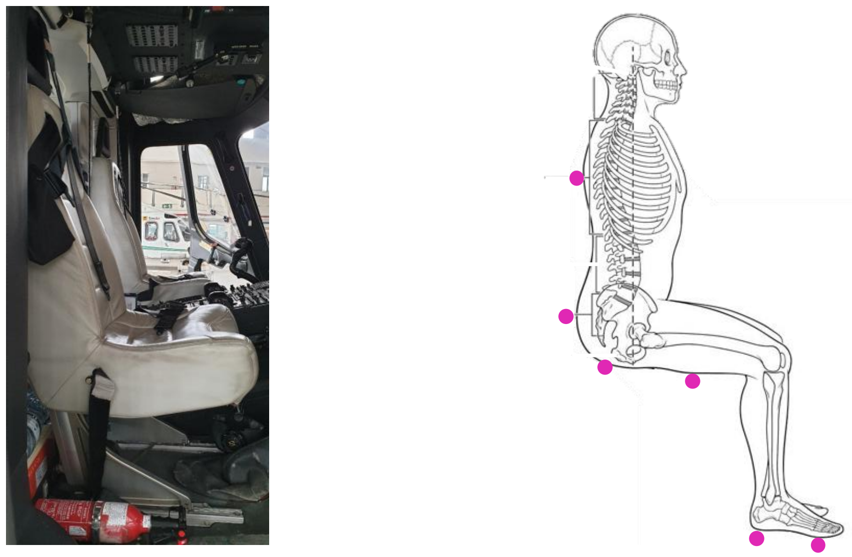


Figure 1 – AW189 Seating position for Pilots Monitoring and contact points

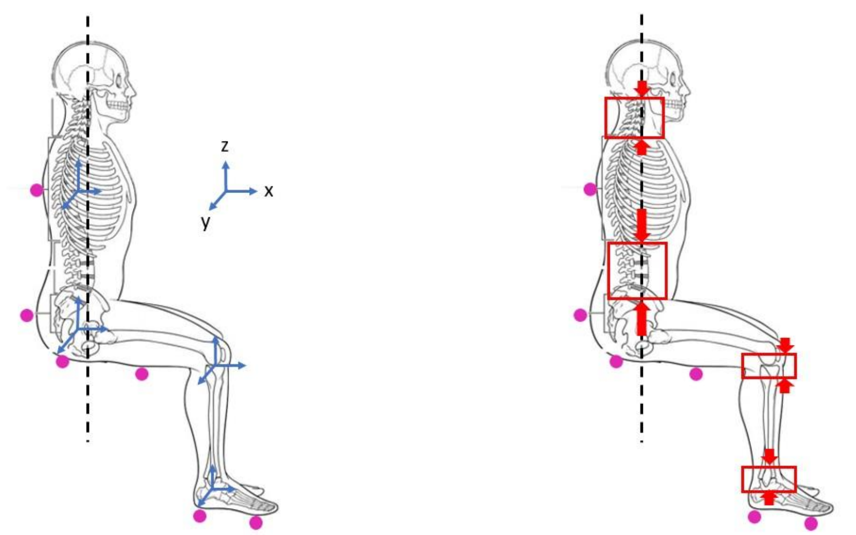


Figure 2 – AW139 and AW189 three axes, the Longitudinal (x), Lateral (y) and Vertical (z) and Pilots discomfort zones and sensational Compression Points

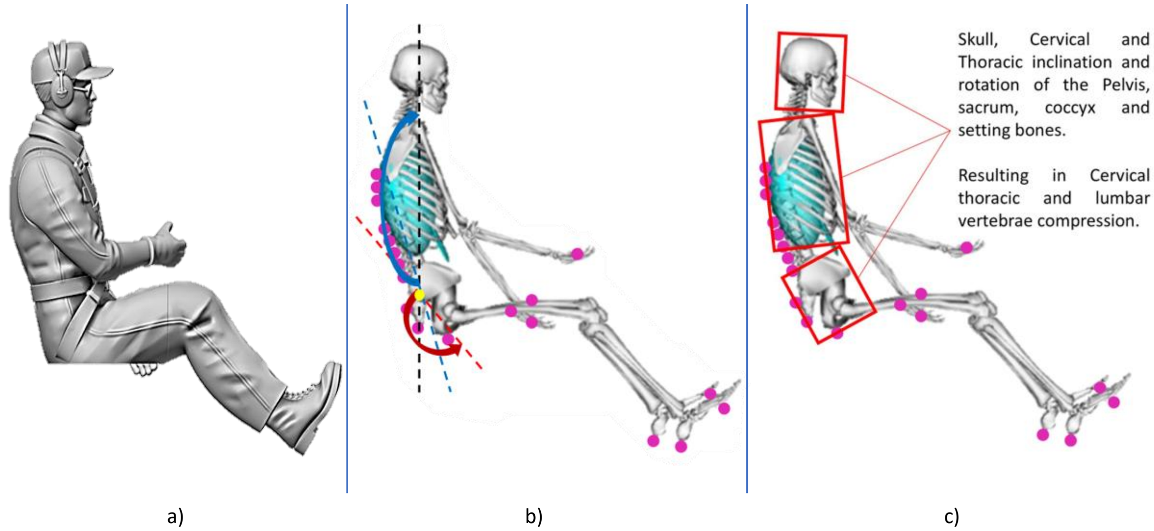


Figure 3 – Seating position for Pilots Flying on AW139 (hands-on controls), contact points and body Inclination and Rotation. See Appendix 5

Regarding helicopter pilots, the focus is on the contact interface among crews and the cockpit floor, seats, flight controls, and the cockpit centre console during various operating conditions. Pilots have experienced significant pain within hours of flying, and such cases have been documented for over 50 years. (Silva, 2018). The majority of the time, camouflaged by the desire to fly and complete the mission or job, is often overlooked by crews. These conditions subject pilots to intense vibrational accelerations that affect their bodies, increasing the risk of various health issues that may be latent, unobserved or unidentified internally. For nearly 40 years of WBV and HAV studies have documented "*Low back pain (LBP) is a common issue within a flight*"(Pope et al., 1985), considerable pain in the lower back or lumbar region and buttocks (Panjabi et al., 1986), described a general description as dull or achy (Bongers et al., 1990), extended exposure to WBV can lead to lasting physical harm affecting the lower spine the most harmful frequencies align with the spinal column's resonance, typically ranging from 10 to 12 Hz (Harrer, 2005), Low Back Pain (LBP) or discomfort may affect health and performance (Halmai et al., 2024).

Research indicates that reducing the monthly and daily hours is essential, as pilots can be impacted by as little as 1 hour and have health concerns when exceeding 4 hours per day. "*Approximately four hours into a seven hour mission, both pilots experienced severe middle and lower back pain, which progressed to numbness and tingling sensations in their feet……….Another HAZREP released by HC-5 on 25 January 2005 formally reported that back and leg pain began two to four hours into flight and increased with time. Pilots reported that they were distracted and constantly shifting in their seats trying to get comfortable. Crews reported that after flying a full day, approximately ten hours, the pain took several hours to subside or in some cases lasted one to two days after landing" (Harrer, 2005; A. S. Phillips, 2011).* According to Smith et al., study*, "…. Potencial for health risk, and even likely health risk in less than 8 hous, the pilot* *being exposed to potencial health risk in 1 to 3 hours of daily occupational exposure and exposed to likely health risks in 3 to 7 hours at higher airspeeds" (S. C. S. C. J. Smith, 2019).* **Tables 1 and 2** provide a summary of the literature review on **commonly reported pathologies related to the effects of fatigue caused by WBV**, as extensively examined in various studies.

Table 1 - Commonly Reported Pathologies Caused by WBV

Commonly Reported Pathologies due WBV	**BODY ORGAN**	**SIDE AFFECT** (Frequency range 2 - 20 Hz)	**Sources**
Low Back Pain; Low back/lumbar region and or buttocks pain; Muscles, tendons, ligaments and spinal nerves disorder; herniated nucleus; spine, neck and shoulder pain; pain in both pilots' legs and backs begins 2 to 4 hours into the flight and increases with time.	Muscle and Joints (Knees, elbows, lower back, shoulder, neck)	Pain, inflammation, tension, decreased bone density, stiffness in the shoulders and back, and reduced blood flow to lumbar muscles. *(Age is a significant factor)*	(Ballard et al., 2020; Blackman, 2019; Bongers et al., 1990; Boshuizen et al., 1989; Bovenzi, 1996; Chen et al., 2011; Cunningham et al., 2010; Gaydos, 2012; Gradwell & Rainford, 2015; Halmai et al., 2024; Harrer, 2005; Kåsin et al., 2011; Malmivaara & Hakkinen, 1995; Okunribido et al., 2008; Panjabi et al., 1986; J. Phillips et al., 1996; Pope et al., 1987; Savage et al., 2015; Seidel et al., 1980; Silva, 2018; D. Smith & Leggat, 2005)
Circulatory system; peripheral disorders and cardiovascular disorders, vascular diseases	Heart (Arteries, veins, blood vessels and lungs)	Increased blood pressure, fast heart rate, increased risk of heart attack and stroke, increased "bad" cholesterol. *(Age is a significant factor)*	(Ballard et al., 2020; Chen et al., 2011; Gradwell & Rainford, 2015; Krajnak, 2018; Savage et al., 2015; Seidel et al., 1980; D. Smith & Leggat, 2005)
Nervous system; Cognition; depression-dejection; decreased concentration and situational awareness; Neurophysiological stress; anxiety syndromes; cognitive inefficiency; emotional disorganisation	Brain, spinal cord and nerves.	Mood swings, depression, irritability, aggressiveness, lack of energy, problems with concentration, panic attacks and anxiety.	(Abbate et al., 2004; Ballard et al., 2020; Chen et al., 2011; E.J. Lovesey, 1979; Gradwell & Rainford, 2015; Halmai et al., 2024; Krajnak, 2018; Seidel et al., 1980; D. Smith & Leggat, 2005)

Table 2 – Commonly Reported Pathologies Caused by WBV (cont.)

Commonly Reported Pathologies due WBV	BODY ORGAN	SIDE AFFECT	Sources
Endocrine system; sexual appetite, infertility	Ovaries/ Testicles	Decreases testosterone and estrogen production, reducing fertility and sexual desire.	(Gradwell & Rainford, 2015; Seidel et al., 1980)
Gastrointestinal System disorders; Metabolism	Intestines Stomach Pancreas	Decreases nutrient absorption, reduces metabolism, causes constipation, increases the risk of inflammatory bowel diseases (esophagitis, gastritis, colonitis, ileitis, and proctitis), decreases enzyme activity and increases the risk of diabetes. Can cause ulcers, irritable bowel syndrome, food allergies, stomach cramps, reflux, nausea and weight fluctuations. It has elevated insulin secretion that can lead to diabetes, as well as damage to arteries and obesity.	(Ballard et al., 2020; Gradwell & Rainford, 2015; Krajnak, 2018; Savage et al., 2015; Seidel et al., 1980)
Various Illnesses or side effects from several organs that can be affected		Oxygen consumption, hyperventilation; Metabolic response increase; Neuromuscular responses; Physiology and biomechanics (limited to spinal stability and balance) Headache; Loss of balance; Blurred vision, affects perception; Decreases testosterone and estrogen production, reducing fertility and sexual desire.	(Abbate et al., 2004; Arora & Grenier, 2013; Auffret et al., 1980; Baig et al., 2014; Blackman, 2019; Bongers et al., 1990; Boshuizen et al., 1989; Bovenzi, 1996; Cunningham et al., 2010; Curry et al., 2002; De Oliveira et al., 2001; Gaydos, 2012; Griffin, 1977; Harrison et al., 2009; Ishimatsu et al., 2016; ISO 2631-5, 2018; Kåsin et al., 2011; Krajnak, 2018;

			Malmivaara & Hakkinen, 1995; Mansfield, 2004; Okunribido et al., 2008; Panjabi et al., 1986; J. Phillips et al., 1996; Pope et al., 1985, 1987; B. R. Santos et al., 2008; Silva, 2018; D. Smith & Leggat, 2005)

Safety and operational effectiveness during emergencies may be linked to the aforementioned pathologies, illnesses, and the impacts of cumulative fatigue resulting from excessive flying on a daily, weekly, monthly, and yearly basis. *"Indirect effects on motivation, mood and arousal may moderate the direct effects of WBV"* (Ishimatsu et al., 2016), which may result in reduced situational awareness and performance. Ishimatsu et al., concluded that WBV exposure at helicopter working frequencies increases errors and action slips, indicating impulsiveness and failures in response inhibition. Similarly, Chen et al. stated, "*Vibration can cause discomfort and interfere with aircrew situational awareness and decision-making during missions."* (Chen et al., 2011). Effective visual cues are essential for manually flying a helicopter during the day, but they are even more critical at night, especially for MEDEVAC (Medical Evacuation) and SANEVAC (Sanitary Evacuation) operations. These flights often take place under instrument flight rules (IFR) or in instrument meteorological conditions (IMC), where external visual references are unavailable due to poor weather, necessitating reliance on instrument indications for navigation (E.J. Lovesey, 1979). All the above align with Teixeira's research linking situational awareness to fatigue caused by WBV, noise, and age (Chen et al., 2011; Harrer, 2005; Ishimatsu et al., 2016; Teixeira, 2020)

Low Back Pain is sometimes only felt a few hours after the flight. Several exercises can help relieve pain aerobic activities, such as Walking, Biking, or Swimming, Stretching or Back-Extension Exercises (Ladner, 1997; Malmivaara & Hakkinen, 1995; J. Phillips et al., 1996; Silva, 2018).

The author finds that practising Karate three times a week, combined with Body Relaxing Massage and Chiropractic Treatment every 15 days, is very helpful in reducing stress and enhancing both physical and mental health. However, it is agreed that various factors contributing to LBP, including age, height, weight, Body Mass Index (BMI), and seating posture, may influence pain levels. The author suggests that longer daily flight hours, exceeding 4 hours per day and more than 70 hours per month, could lead to accumulated acute pain. Silva et al., concluded in their research that *"asymmetrical in-flight posture; cockpit design/geometry; seat design; WBV; static posture; prolonged sitting; and flight duration as mainly risk* *factors and a higher prevalence of LBP among helicopter pilots as well as a significant influence of flight activity on pain features when compared to office workers"*

Human biodynamics exhibits multiple resonance frequencies at which the body responds maximally to vibration, which a single resonance frequency cannot explain. The frequencies vary between individuals and with posture **Figure 3a**. Vibration causes the body to exhibit two mechanical responses: transmissibility and impedance. These responses are transmitted from the pilot's seat to the head, from the feet to the knees, and from the knees to the spinal cord through radiation**,** as shown in the pink dots in **Figures 3b and c.** The body's mechanical transmissibility depends on the vibration frequency, axis, and body posture (B. R. Santos et al.., 2008; Smith & Leggat, 2005) The body's mechanical impedance can demonstrate the force required to move the body at each frequency, even though impedance varies with body mass (Kåsin et al., 2011; Mansfield, 2004). It is an unequivocal fact that helicopter aircrews are subjected to vibrations and various sources of acoustic sounds that are both perceptible and felt physically on the body. Although the set boundaries in ISO 2631 or the European Directive EU 2002/44/EC, they do not mention the accumulation of vibration doses, nor do they provide any information on the combination of sources of acoustic exposure.

Secondly, exposure to sound noise (SN) results in hearing loss (HL). Sound Noise is often accepted as a necessary professional work-related risk, a part of the pilot's flying profession, and an unavoidable part of the aeronautical industry. A key reason for the control is pilots' annual medical exams, which include audiograms. The noise exposure helicopter pilots have, between climb, cruise and descent flight conditions, exposes pilots to variations between 80 – 100 dB of EPNL (Effective Perceived Noise Level) (Agustawestland, 2012; Corporation, 2016b, 2016a; EASA Type Certificate DATA SHEET AW189, 2020; Helicopters, 2014; Holder et al., 2016; Leonardo Helicopters, 2016; McReynolds, 2005) and low frequency at or below 500 Hz of noise with frequency variations between 315 – 8000 Hz (Hawkes & Worsham, 1970; Lowson & Ollerhead, 1969; McReynolds, 2005; Odilyn et al., 1999; OSHA, 2020; Yin et al., 2008). Such exposure causes pilots to experience temporary hearing loss, which decreases their hearing sensitivity during the workday and typically gets better overnight. "*The noise level in the cockpit depends not only on the aircraft type, but also on the engine power settings required in different flight conditions as well as on aerodynamic noise" (Kuronen et al., 2004).* Sound-induced noise exposure during flight can cause insidious hearing loss as it gradually builds up over time, often remaining unseen and undervalued due to the absence of visible effects and, in most cases, a lack of pain. This is not detected until pilots are caught by annual audiogram exams with results indicating unfitness to fly.

Hearing loss is undoubtedly the most well-known and probably the most serious adverse effect of noise exposure, often affecting Pilots and Maintenance personnel. Gradual deterioration in hearing ability results in Hearing loss (Kuronen et al., 2004; McReynolds, 2005), which naturally accompanies the ageing process and worsens as the individual with noise-induced hearing loss ages (Kuronen et al., 2004). Noise-induced hearing loss is generally considered an occupational disease or illness because its progression is typically gradual and progressive (Kuronen et al., 2004; McReynolds, 2005) . Therefore, the higher the noise level of exposure over a given period, the more pronounced the susceptibility to damage caused to pilots (Fitzpatrick, 1988; Jaruchinda, 2005; Kuronen et al., 2004; McReynolds, 2005; Owen, 1995).

The auditory consequences of noise are greatly acknowledged, and there is scarcely an argument about the amount of direct continuous noise, intermittent noise, and continuous background noise that causes varying degrees of hearing loss. The amount of hearing loss destruction will differ mainly with the intensity and duration of the impulse, and there is evidence that high-frequency impulsive noise sources are more damaging than those composed of lower frequencies (En–tong et al., 2008; Fitzpatrick, 1988; Hamernik et al., 1991; Jaruchinda, 2005; Kuronen et al., 2004; McReynolds, 2005; Owen, 1995; Snecma et al., 2015). Unfortunately, no medical treatment for hearing loss has been identified, so one can only take preventive measures by limiting exposure. Fitzpatrick & Daniel T, stated that *"The relative contbutions of age, total flight hours. type of aircraft. and type of hearing protection to observed changes in hearing thresholds were evaluated …..it becomes progressively worse as age and flight hours increase…..Analysis by Pearson correlation again shows the strong relationship of both age and total flight hours to hearing loss"* (Fitzpatrick & Daniel T, 1988; Jaruchinda, 2005).

Disruptions in both speech and non-speech communications, such as auditory warning signals, can affect flight safety and operational effectiveness. Factors like cumulative flying hours, years of flying service, aircraft type, and military service years contribute to the risk of noise-induced hearing loss (NIHL) among aircrew personnel (Lang & Harrigan, 2012).

Table 3 provides a summary of the literature review on commonly reported pathologies related to Noise exposure, as extensively examined in various studies. Further research may uncover additional pathologies; however, most medical diagnostic tests rely on biochemical rather than biomechanical data, leaving little information in the existing literature.

Table 3 - Commonly Reported Pathologies Related to Noise Exposure

Commonly Reported Pathologies Related to Noise Exposure	Side Effects of Infrasound (0–20 Hz) and Low-Frequency Noise (20–500 Hz).	Sources
Auditory System disorder, Tinnitus (ringing in the ears); Damage to the sensory hair cells located in the cochlea; Rupture the eardrum and possibly dislodge the ossicular chain; Hearing Loss; Noise-Induced Hearing Loss; Vibro Acoustic Disease (VAD) Vibroacoustic Syndrome	Temporary and permanent losses in hearing sensitivity, Impairment, Loss of sensitivity to environmental sounds, Unfit to fly or Loss of workdays, Impaired perception of warning signals, Annoyance, Fatigue, Interference with speech and nonspeech communications or the reception of other wanted sounds.	(Alves-Pereira & Castelo Branco, 2006; En–tong et al., 2008; Fitzpatrick & Daniel T, 1988; Gradwell & Rainford, 2015; Hubbard et al., 1971; Lang & Harrigan, 2012; McReynolds, 2005; Piňosová et al., 2018; U.S. DHEW, 1972)
Nervous & Cognitive Disorders	Psychological disorders. Interference with speech communication, Poor decision-making, misjudgment, Timely reactions, situational awareness and performance, Fatigue, frustration, stress, and depression, mental health effects.	(Alves-Pereira & Castelo Branco, 2006; Campos et al., 2018; Hawkes & Worsham, 1970; Jaruchinda, 2005; Kuronen et al., 2004; Owen, 1995; Piňosová et al., 2018; U.S. DHEW, 1972)
Circulatory Disorder,	Hypertension, disturbance of the circadian rhythm, sleep disturbances, cardiovascular disease, ischemic heart disease.	(Alves-Pereira & Castelo Branco, 2006; Jaruchinda, 2005; McReynolds, 2005; U.S. DHEW, 1972)

Lastly, Age and its natural progression are variable predictors (Bovenzi, 1996; Campos et al., 2018; Jaruchinda, 2005; Ladner, 1997). Age is a measure determined by science, linked to the body's self-degeneration. Humans are affected in various ways. Science shows that individual body cells degrade at different rates. Accelerating time makes the effects on these cells more noticeable, similar to travelling at the speed of sound in a jet. If human cells are accelerated, their normal vibration cycles may cause change or damage, altering our well-being and affecting the typical state of self-degeneration over time. Age, gender, and various other factors, in conjunction with noise level and exposure period, may contribute to variations in susceptibility to noise (Jaruchinda, 2005; Kuronen et al., 2004; Lang & Harrigan, 2012). Likewise, the model ISO 1999 utilises three essential factors: age, noise exposure, and gender to determine exposure by applying the equal-energy principle (ISO 1999, 2013).

Seidel and Boshuizen et al, concluded in their study that exceeding the daily work limit exposure should be avoided, particularly depending on the age, health state and capacity for higher tolerance of average exposure (Boshuizen et al., 1989; Seidel et al., 1980). The Jaruchinda study stated in the results, "*There appeared to be no association between hearing loss and age groups and no significant dependency to flight hours or working hours was found*" (Jaruchinda, 2005).

A correlation in some of several measurable subjective variables like weight, height and body mass index (Bongers et al., 1990; Ladner, 1997), body muscle and exercise activity frequency may be foreseeable, others may be harder to identify, like the number of blades on the helicopter's main rotor and type of operation (Training, Search and Rescue, Fire Fighting, Commercial Transportation), among others that can be identified although for this research study the author focused only on the following four quantifiable individual variables; the sum of hours flown and the quantity of hours or days of rest between flights, the type of helicopter flown, and if the headphones used by pilots were equipped with Active Noise Cancellation.

The author will explain how the number of hours a helicopter pilot flies affects these three main predictors and provide a possible correlation between the measurable subjective variables, as identified through the literature review and numerical and experimental research. Furthermore, it will show a clear correlation towards the importance of having a reduced number of hours per day flown to a new limit of 5 hours and 20 minutes to 6 hours versus the 8 hours currently instated by the NCAA´s around the world in helicopter activities, or the recommendation in Teixeira research, which referred to the limit of 6 hours and 15 minutes. This results in an additional reduction in the daily flying time limit, from minus 15 minutes to, ideally, minus 55 minutes. Rest periods between flights and rostering schemes of ON/OFF and the advantages of using Active Noise Cancellation headsets or headphones due to high doses of noise exposure during flight activities, mainly in helicopters since accumulated exposure is above 110 dBA´s (Hawkes & Worsham, 1970)

Chapter III Literature Review

This chapter provides an overview of vibration, noise, and signal analysis, as well as the use of three-axis smartphone sensors to acquire such data. Additionally, an overview of composite materials in aircrafts is made, taking vibration propagation into account. It also provides a brief introduction to manufacturing processes in the aviation industry, particularly regarding helicopters and composites. The author seeks to elucidate the potential link between psychological and physiological fatigue in pilots and the observable side effects that contribute to their fatigue. Teixeira's research investigates the impact of Whole-Body Vibration, Noise, and age on fatigue in helicopter pilots. Finally, the author intends to explain how these materials can influence vibration and sound insulation in different types of helicopters utilised by offshore oil and gas pilots.

3.1 Vibration, Noise and Signal Analysis

A review was conducted of several epidemiological studies involving whole-body vibration among helicopter operators, construction equipment operators, tractor drivers, and forklift drivers.

3.1.1 Vibration Base Concepts

Vibration is defined as a movement in any of an object's or system's around its resting position or equilibrium position, which is the position where the object or system would remain still if no external forces were ever acted upon it. For instance, the vibration of a specific system, structure, or machine can be categorised as either forced or free vibration. Forced vibration, which is the focus of this study, includes imposed oscillations from an engine or the oscillations generated by the main and tail rotors of a helicopter. Thus, mechanical vibration refers to the oscillations within the system during operation. These vibrations are characterised by their frequency (or frequencies) and corresponding amplitude. Oscillations can be quantified in terms of displacement, velocity, or acceleration. By observing oscillation, we can gauge its frequency based on the number of complete oscillations or cycles per unit time (seconds), expressed in Hertz (Hz). The oscillation can indicate displacement, which is the distance or amplitude from its resting position. When measuring distance, we can derive velocity, which is the time taken to alter movement during the oscillation, measured in meters per second (m/s). Consequently, acceleration magnitude can be understood as the rate of change of velocity over a specific time period, measured in meters per second squared (m/s^2). In this study, we can also assess sound in terms of acceleration (9,81 m/s^2) and the human ear's hearing threshold, set at 120, expressed in decibels (dB).

Several types of Vibration can be identified, but only four, in the author's opinion, were relevant to this research study, as shown in **Table 4**.

Table 4 – Some Types of Vibration

Type of Vibration	Description
Forced Vibration	Occurs when an object is subjected to a continuous external force, causing it to vibrate at the frequency of the driving force.
Linear Vibration	Vibration where the restoring force is proportional to the displacement, resulting in simple harmonic motion. (x-axis)
Longitudinal Vibration	Vibration, where the movement is along the length of the object. (y-axis)
Transverse Vibration	Vibration where the movement is perpendicular to the length of the object. (z-axis)

Vibration Analysis systematically examines vibration patterns and characteristics to identify their underlying causes and subsequent effects. This analysis can be conducted in both the time domain, where the vibration signal is analysed directly, and the frequency domain, which entails examining the frequency spectrum using techniques such as the Fourier Transform. The aviation industry utilises it in various fields, including mechanical, structural, and acoustic engineering, for mechanical components like engines and rotors; structural metallic and composite components like fuselages and blades; structural health monitoring and diagnosis; and noise reduction.

Vibration Sensitivity varies from person to person, with some individuals more sensitive than others. The threshold intensity limit is typically between 0.5 and 1.15 m/s^2, equivalent to the action exposure value (DIRECTIVE 2002/44/EC, 2002; Halmai et al., 2024; ISO-2631-1, 1997; Mansfield, 2004). Peak value or impulsive noise, with durations ranging from 0.25 to 0.1 seconds, respectively, has a working environmental noise level threshold between 35 and 65 dB. Additionally, limits are set between 80 and 90 dB for 8 hours, as prescribed by several entities (Fitzpatrick & Daniel T, 1988; ISO 1999-2013, 2013; ISO 9612, 2009; Noise-Occupational Exposure Limits in Canada, 2023; Occupational Noise Exposure, Revised Criteria 1998 (NIOSH Publication No. 98-126), 1998; Owen, 1995; U.S. DHEW, 1972).

Vibration Transmissibility through the body depends on various factors, including the frequency and direction of input motion. It varies by individual (weight, height, age) and contact surface characteristics. In this case study, the seat and cockpit floor panel inside the helicopter are considered. Vibration below 12 Hz affects the whole body, while vibration above 12 Hz has a local effect (Hostens & Ramon, 2003). Pilots endure vibrations during flight that cause discomfort or pain. Baig et al. stated in their results, *"This study found that the peak transmissibility of the lumbar (2–4 Hz) and thoracic (2–4 Hz) spinal regions occur at similar frequencies for the seated human regardless of the direction of the imposed vibration"* (Baig et al., 2014). Anh & Griffin, stated "…..*greatest sensitivity from 4 to 12.5 Hz"* (Ahn & Griffin, 2007). However, assessing precise vibration levels is challenging, and these body vibrations can weaken the spine and skeletal muscle systems due to cumulative damage. "*There can be large variations between subjects with respect to biological effects. Whole-body vibration may cause sensations (e.g. discomfort or annoyance),* *influence human performance capability or present a health and safety risk (e.g. pathological damage or physiological change). The presence of oscillatory force with little motion may cause similar effects" (ISO-2631-1, 1997).* Blackman´s study stated that *"Different frequency ranges have different effects on different parts of the body. Frequencies 4-8 Hz are most effective for vertical vibrations. Frequencies 2.5-5 Hz generate strong resonance in neck vertebra and the lumbar region that can cause an amplification of up to 240%. Frequencies 4-6 Hz generate resonance in the trunk with an amplification of up to 200%. Finally, frequencies 20-30 Hz generate resonance between the head and the shoulders with an amplification of up to 350%" (Blackman, 2019).*

The International Standard Organization, through its ISO 2631-2018, states in its introduction, *"The purpose of this document is to define a method of quantifying whole-body vibration containing multiple shocks concerning human health in the seated posture. In biodynamics, the term "shock" is used to describe a wide range of short-time, high-magnitude exposures. It covers the range of severity, starting at mild shocks and resulting only in annoyance and brief discomfort up to magnitudes of shock sufficient to cause pain, injury, or substantial physiological distress. The methods described in this document can be appropriate for assessing the risk of chronic injury from exposure to repeated shock, which can be experienced in military, commercial, or recreational off-road vehicles, including agricultural vehicles, heavy plant equipment, and high-speed marine craft. The methods are not intended to assess the probability of acute damage from a single impact.*

This document solely addresses lumbar spine response based on studies indicating that the lumbar spine can be adversely affected by exposures to whole-body vibration, which also contain multiple shocks. Other adverse health effects of exposure to repeated shock, such as damage to parts of the body other than the lumbar spine, or types of short or long term health effects other than damage to the vertebral end plates, are not specifically considered by this document.

A standardised approach to the prediction of injury for non-vertical or combined axes shocks is complicated by the range of different postures and body restraint systems that can be employed in different vehicles and the limitations of current capabilities for predicting injury from non-vertical shock. Shocks involving horizontal, rotational or multi-axial motion are known to occur in practice and can present a significant risk of injury.

The risk of injury in the lumbar spine depends on an exposure dose, which is a combination of an exposure quantity and a duration. A manifest injury can take several years to develop. Due to the complexity of the measurement of multiple shocks, it is at the moment not possible to measure the exposure of the lifetime dose directly. Instead, the exposure is measured in representative situations and the dose is extrapolated from this measurement to a recorded exposure duration in the past or an anticipated exposure duration in the future. To monitor constantly the lifetime dose at a workplace, alternative measurement equipment will need to be developed, e.g. dosemeters.

Section 5.1.2 Measurement location and specific hardware requirements also state, **"***The vertical acceleration az(t) should be measured at the interface between the seat and the ischial tuberosities. During data collection, the subject should remain seated and should not rise from the seat. The location of measurements on the seat and the design of the accelerometer disk on the seat pad"* (ISO 2631-5, 2018).

The European Parliament and the Council of the European Union, through its Directive 2002/44/EC, states the following prior to the beginning of section 1:

" (3)……it is considered necessary to introduce measures protecting workers from the risks arising from vibrations owing to their effects on the health and safety of workers, in particular muscular/bone structure, neurological and vascular disorders.

(6) The level of exposure to vibration can be more effectively reduced by incorporating preventive measures into the design of work stations and places of work and by selecting work equipment, procedures and methods so as to give priority to reducing the risks at source. Provisions relating to work equipment and methods thus contribute to the protection of the workers involved.

(7) Employers should make adjustments in the light of technical progress and scientific knowledge regarding risks related to exposure to vibration, with a view to improving the safety and health protection of workers.

(8) In the case of sea and air transport, given the current state of the art it is not possible to comply in all circumstances with the exposure limit values for whole-body vibration; provision should therefore be made for duly justified exemptions in some cases.

Article 2 Definitions

(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.

Article 3 Exposure limit values and action values

1. For hand-arm vibration:

(a) the daily exposure limit value standardised to an eight-hour reference period shall be 5 m/s^2;

(b) the daily exposure action value standardised to an eight-hour reference period shall be 2,5 m/s^2.

2. For whole-body vibration:

(a) the daily exposure limit value standardised to an eight-hour reference period shall be 1,15 m/s^2 or, at the choice of the Member State concerned, a vibration dose value of 21 $m/s^{1.75}$;

(b) the daily exposure action value standardised to an eight-hour reference period shall be 0,5 m/s^2 or, at the choice of the Member State concerned, a vibration dose value of 9,1 $m/s^{1.75}$.

Article 4 Determination and assessment of risks

2. The level of exposure to mechanical vibration may be assessed by means of observation of specific working practices and reference to relevant information on the probable magnitude of the vibration corresponding to the equipment or the types of equipment used in the particular conditions of use, including such information provided by the manufacturer of the equipment. That operation shall be distinguished from measurement, which requires the use of specific apparatus and appropriate methodology.

Article 5 Provisions aimed at avoiding or reducing exposure

1. Taking account of technical progress and of the availability of measures to control the risk at source, the risks arising from exposure to mechanical vibration shall be eliminated at their source or reduced to a minimum.

2. On the basis of the risk assessment referred to in Article 4, once the exposure action values laid down in Article 3(1)(b) and (2)(b) are exceeded, the employer shall establish and implement a programme of technical and/or organisational measures intended to reduce to a minimum exposure to mechanical vibration and the attendant risks, taking into account in particular:

(a) other working methods that require less exposure to mechanical vibration;

(c) the provision of auxiliary equipment that reduces the risk of injuries caused by vibration, such as seats that effectively reduce whole-body vibration and handles which reduce the vibration transmitted to the hand-arm system;

(g) limitation of the duration and intensity of the exposure;

(h) appropriate work schedules with adequate rest periods;

3. In any event, workers shall not be exposed above the exposure limit value.

Annex B WHOLE-BODY VIBRATION

1. *Assessment of exposure*

The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes (1,4awx, 1,4awy, awz for a seated or standing worker) in accordance with Chapters 5, 6 and 7, Annex A and Annex B to ISO standard 2631-1(1997). 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, and based on observation of specific work practices or on measurement.

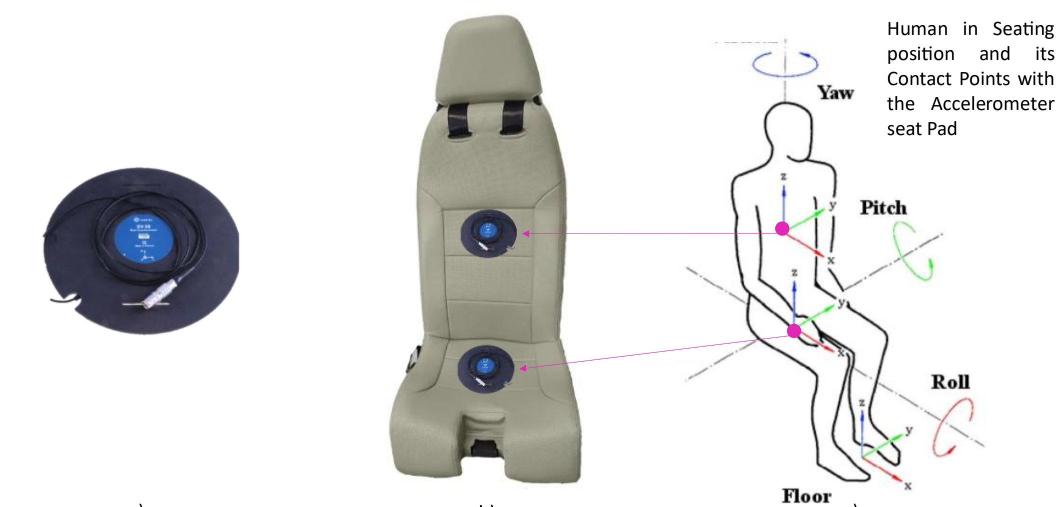
2. *Measurement*

When measurement is employed in accordance with Article 4(1), the methods used may include sampling, which must be representative of the personal exposure of a worker to the mechanical vibration in question. The methods used must be adapted to the particular characteristics of the mechanical vibration to be measured, to ambient factors and to the characteristics of the measuring apparatus" (DIRECTIVE 2002/44/EC, 2002).

The guidelines for measuring and quantifying human exposure to whole-body vibration (WBV) have been presented in international standards (ISO 2631, 1997); however, these standards do not establish straightforward limits for vibration duration exposure and are often misinterpreted.

Furthermore, ISO 2631 offers comprehensive guidance on WBV measurement and analysis. According to ISO 2631-1, vibration frequencies recorded from various locations (e.g., seatback) and in diverse directions (*X, Y*, or *Z*) are assigned differing weightings based on the analytical purpose (e.g., health, comfort, perception, or motion sickness) (ISO-2631-1, 1997). The use of varying weightings is necessitated by the fact that the transmissibility of vibration through the human body and its resultant effect on the individual can vary with different inputs.

From a seated position, WBV measurements were taken. Blackman´s research stated *"Vibration data collected, using tri-axial seat pad accelerometers, showed that 89% of the flying events that were evaluated exceeded the American Conference of Governmental Industrial Hygienist (ACGIH) action level, defined as half of the threshold limit value, with 22% of the events exceeding the threshold limit value. …. Per the ISO 2631-1 standard, since each of the flying events had crest values greater than nine, the vibration dose value was calculated for this study. After calculating the vibration dose value for each of the flying events it was found that all 18 (100%) of the flying events exceeded the action limit and of those 44% of the flying events exceeded the limit value" (Blackman, 2019)*. **Figure 4** shows a triaxial accelerometer housed in a flexible disk, which measures whole-body vibration and is typically placed between the seat cushion and the working occupant. **Figure 4a** represents the Seat pad accelerometer used for seating measurements, **Figure 4b** is an example of the location of the pads on an AW139 seat, and **Figure 4c** shows the location of the body where the Pilot would be in contact with the Whole-Body Seat Pad accelerometer.



a) Castle KD1009 Whole Body MEMS Seat pad Accelerometer

b) AW139 Pilot Seat with measuring Pads

c) Seating Position

Figure 4 – Castle KD1009 Whole Body MEMS Seat Pad Accelerometer – Measuring Locations

Measuring Hand-Arm Vibration (HAV) requires performing measurements with sensors on the hands and arms. Larson Davis, one of several global manufacturers and suppliers, is shown in **Figure 5**. It details equipment used for measuring Whole-Body Vibration (WBV), Hand-Arm Vibration (HAV), and General Vibration. The illustration includes cables, accelerometer sensors, related adapters, and their typical uses, categorised by adapter type such as Handle, "T", Clamp, Palm, and Seat adapters.

	HAND-ARM VIBRATION				WHOLE-BODY VIBRATION	GENERAL VIBRATION
Adapter Type	Handle Adapter	"T" Adapter	Clamp Adapter	Palm Adapter	Seat Adapter	
Cable	CBL217-01(incl)	CBL217-01(incl)	CBL217-05	CBL216	Included with SEN027	CBL217-05
Sensor	SEN040F	SEN040F	SEN040F	SEN026	SEN027	SEN020
	S = 0.1 mV/(m/s²)	S = 0.1 mV/(m/s²)	S = 0.1 mV/(m/s²)	S = 1 mV/(m/s²)	S = 10 mV/(m/s²)	S = 0.1 mV/(m/s²)
	1.0* to 49k m/s²	1.0* to 49k m/s²	1.0* to 49k m/s²	0.1* to 49k m/s²	0.02* to 98 m/s²	0.1* to 14.7k m/s²
Adapter	ADP081A	ADP080A	ADP082A	ADP063	Included	Included stud mount
Typical Use	Accelerometer held to the side of the hand	Accelerometer held between fingers	Clamp to handle of a machine	Measure at the palm under a glove	Measure from a sitting or standing position	General purpose

Figure 5 – Manufacture Larson Davis Measuring Equipment Summary

Source: https://www.larsondavis.com/Products/human-vibration-meter-hvm200/sensor-selection (Online accessed 03/04/2025)

Several **questionable aspects can be highlighted from the ISO 2631 standards**. It provides guidance on "*a method*", **there is no obligation to use only one method**, **it does not prove it is the best method for the specific activity in this research**, **it is clear on lack of research data in concerning maters of air and sea activities**, its main focus is "*experienced in military, commercial, or recreational off-road vehicles, agricultural vehicles, heavy plant equipment, and high-speed marine craft"(ISO 2631-5, 2018).* It is clear that ISO 2631 is focused on vibration containing multiple shocks in the range of short-time, high-magnitude exposures for the above line of activity, which differs from air and sea. **Prediction of injury mainly focuses on non-vertical or combined-axis shocks.** (ISO 2631-5, 2018). Therefore, the **standard does not provide a clear analysis or adaptation for aviation**, where the **environment can be significantly different**. As the results will prove in **the present study. In the aviation sector, there is both a constant and significant WBV, as well as multiple high-amplitude shock vibrations of short time spans**. Kasin et al. stated, *"Although the EU Directive states that the design and layout of workspaces should be considered, there is no guidance or criteria for posture assessment either in the Directive or ISO 2631-1. Furthermore, no standard test protocol exists for measuring helicopters using ISO 2631-1, and there* *are no known publicly available data sets of vibration exposure, thus making it difficult to estimate exposures as part of a vibration risk assessment"* (Kåsin et al., 2011)**.**

The author acknowledges that the locations of measurement for seating position are mandatory, and that the equipment used, particularly the disk pad, is also mandatory, as it is used for measurements between the seat and the ischial tuberosities of subjects. However, this is all related to non-air activities. Furthermore, the in-flight use of disk pads in commercial flights may raise safety concerns; therefore, research would need to be conducted in non-normal day-to-day activities and non-commercial flights, with a greater emphasis on research flights. This would render this study highly costly and infeasible for supporting the gathering of relevant information on the basis of safety and human factor awareness for fatigue risk management systems.

Additionally, Directive 2002/44/EC highlights several points that need clarification or further reference. It specifies key measures to protect workers, which the European Union, employers, or employees should implement as minimum mandatory standards for safety and mitigation. Moreover, it underscores the absence of research data regarding air and maritime activities. The observation assessment does not clarify who can perform the observations or how frequently these assessments should occur. While it addresses the probable magnitude of vibrations, it does not specify which measurement scale to use, whether the Richter or Mercalli scale, allowing either to be applied. Furthermore, it fails to outline which types of equipment can be referenced, enabling the use of any accelerometer or seismometer for vibration measurement, both of which are commonly used in scientific studies. Information from manufacturers about the equipment can be used for calculations that serve as data references in the equipment's datasheet for noise or vibration.

Building on the previous statements, a logical conclusion can be extrapolated: the standards and directives for WBV do not support air or sea activities as per this study, and alternative methods shall need to be applied. An alternative idea indicates that innovative solutions can be advantageous for industries. Drawing from ISO 2631, which advises to "….*constantly monitor the lifetime dose at workplaces and develop alternative measuring equipment….*" it **highlights the necessity for practical tools that are accessible to everyone, regardless of gender or background, thus ensuring user-friendliness and minimal interference with daily work tasks.** The author acknowledges the complexity of measuring multiple shocks, especially when evaluating lifetime dose exposure; however, current research seeks to provide daily and monthly forecasts. This data will support the calculation of an average career lifetime based on standard exposure values and typical annual working hours. Furthermore, it aligns with the European Union's strategy to access efforts aimed at reducing vibration exposure through preventative actions. This involves implementing robust policies and strategies to mitigate risks, grounded in a scientific understanding of the threats associated with vibration exposure, thereby enhancing the health and safety of workers in their daily activities. In Chapter V, the author presents alternative measuring solutions based on the identified gaps.

3.1.2 Noise-Based Concepts

Noise is defined as any sound audible to humans that they may consider (subjectively) as unwanted and/or annoying or that may in some way interfere with communication between two or more people.

Humans have hearing perceptions defined by the number of decibels by which the threshold of audibility for an ear can withstand a band of frequencies. *Humans are considered to perceive sound between 20 and 20,000 Hz, but non-uniformly, i.e., there is an acoustical window where the human ear is most susceptible: 500 – 8,000 Hz. It is within these frequency bands that hearing impairment occurs—legal deafness is assessed at 4,000 Hz. Humans ignore all acoustical energy below 20 Hz* (Alves-Pereira & Castelo Branco, 2006).

Sensitivity varies from person to person as some individuals may be more sensitive than others. Usually, the threshold **intensity limit is between 120-140 dB peak value or impulsive noise**, ranging from a duration of 0.25 to 0.1 seconds, respectively, and the working environmental noise level threshold is between 35 and 65 dB (Piňosová et al., 2018), and **limits are between 80 and 90 dB for 8 hours** as **prescribed by several entities** (DIRECTIVE 2003/10/EC, 2003; ISO 1999, 2013; ISO 9612, 2009; Noise-Occupational Exposure Limits in Canada CCOHS Noise Noise-Occupational Exposure Limits in Canada, 1990; Occupational Noise Exposure, Revised Criteria 1998 (NIOSH Publication No. 98-126), 1998; U.S. DHEW, 1972). **Table 5** summarises the Average Daily Noise Exposure Limit per Reporting Organisation.

Table 5 - Average Daily Noise Exposure Per Reporting Organisation

Reporting Organization	Average Daily Noise Exposure (dBA) as an 8-hour time-weighted average 3 dB exchange Rate (conservative)	Average Daily Noise Exposure (dBA) as an 8-hour time-weighted average 5 dB exchange Rate (under protective) **	Maximum Peak Pressure Level (dB)	Sources
European Parlement	87 Exposure Limit 85 Upper Exposure Action Value 80 Lower Exposure Action Value		140 137 135	Directive 2003/10/EC European Parliament and of the Council on the minimum health and safety requirements risks arising from physical agents (noise). (EU)
International Standard Organization (ISO)	90 **85** 80			(ISO 1999-2013) Acoustics - Estimation of noise-induced hearing loss.
				(ISO 9612:2009) Acoustics – Determination of Occupational Noise Exposure – Engineering Method.
National Institute for Occupational Safety and Health (NIOSH)	90 (Permissible Exposure Limit (PEL)) **85** (Recommended Exposure Limit (REL)) 80	115 peak sound pressure is the Ceiling Limit for less than 28 sec 140 allowable exposure time, less than 1 sec, ceiling limit for impulsive noise	140	NOTE: NIOSH communicates with the Occupational Safety and Health Administration (OSHA). NIOSH 98-126 Occupational Noise Exposure Revised Criteria 1998 (USA)
Canadian Centre for Occupational Health and Safety (CCOHS)	**85 (8h)** 88 (4h) 91 (2h) 94 (1h) 97 (0.5h) 100 (0.25h)	**85 (8h)** 90 (4h) 95 (2h) 100 (1h) 105 (0.5h) 110 (0.25h)	140	**Ontario** Occupational Health and Safety Act [R.S.O. 1990, c.1] Noise (O. Reg. 381/15) Canada Labour Code, Part II, (R.S.C. 1985, c. L-2) Canada Occupational Safety and Health Regulations, (SOR/86-304) Section 7.4(1)(b)

**NOTE: Generally, the regulations in which the exchange rate is 5 dB permit 10,000 impulses at a peak pressure level of 120 dB, 1,000 impulses at 130 dB, 100 impulses at 140 dB, and none above 140 dB.

*** All Canadian provinces have the same values under different regulations; only the federal one is different.

The International Standard Organization, through its ISO 1999-2013, states in its introduction chapter: "*This International Standard can be applied to the calculation of the risk of sustaining hearing loss due to regular occupational noise exposure or due to any daily repeated noise exposure*. *Consequently, this International Standard does not stipulate a specific formula for assessment of the risk of impairment, but specifies uniform methods for the prediction of hearing loss, which can be used for the assessment of impairment according to the formula desired or stipulated in a specific country. The results obtained by this International Standard may also be used for estimating the permanent effects of noise on the perception of everyday acoustic signals, the appreciation of music, or the effect of one specific frequency not necessarily stipulated by a hearing impairment formula"* (ISO 1999, 2013).

Furthermore, it states the following: "*For reasons given above, this International Standard, by itself, does not comprise a complete guide for risk assessment and protection requirements, and for practical use, it has to be complemented by national standards or codes of practice delineating the factors which are here left open*" (ISO 1999, 2013).

In its scope section it also states in two notes the following "*NOTE 1 This International Standard does not specify frequencies, frequency combinations, or weighted combinations to be used for the evaluation of hearing disability; nor does it specify a hearing threshold level (fence) which it is necessary to exceed for hearing disability to exist. Quantitative selection of these parameters is left to the user. All sound pressure levels stated in this International Standard do not consider the effect of hearing protectors which would reduce effective exposure levels and modify the spectrum at the ear."* and *"NOTE 3 The prediction method presented is based primarily on data collected with essentially broadband, steady, non-tonal noise"* and *"This International Standard is based on statistical data and therefore cannot be applied to the prediction or assessment of the hearing loss of individual persons except in terms of statistical probabilities"* (ISO 1999, 2013).

The International Standard Organisation, through its ISO 9612-2009, states in its introduction chapter: "*This International Standard provides a stepwise approach to the determination of occupational noise exposure from noise level measurements. The procedure contains the following major steps: work analysis, selection of measurement strategy, measurements, error handling and uncertainty evaluations, calculations, and presentation of results. This International Standard specifies three different measurement strategies: task-based measurement; job-based measurement; and full-day measurement. This International Standard gives guidance on selecting an appropriate measurement strategy for a particular work situation and purpose of investigation. This International Standard recognizes the use of hand-held sound level meters as well as personal sound exposure meters"* (ISO 9612, 2009).

Its scope section also states in two notes: "*This International Standard specifies an engineering method for measuring workers' exposure to noise in a working environment and calculating the noise* *exposure level. The measuring process requires observation and analysis of the noise exposure conditions so that the quality of the measurements can be controlled"* (ISO 9612, 2009).

Section 7.2 Defining homogeneous noise exposure groups also states, "*Measurement efforts can be reduced by defining homogeneous noise exposure groups. These are groups of workers that are performing the same job and are expected to have similar noise exposures during the working day. If used, the homogeneous noise exposure group shall be clearly identified and can consist of one or more workers. Homogeneous noise exposure groups can be defined in a number of ways. For example, it may be possible to define such groups according to job title, function, work area or profession. Alternatively, the groups can be defined by analysing the work according to production, process or work activity criteria. Measurements shall be planned to ensure that all significant noise events are included. For each of the events, it shall be recorded when it occurred, its nature, duration and daily frequency. In some cases, the work and consequently the noise exposure, vary from day to day so that there is no typical daily exposure. If the purpose of measurements is to estimate the long-term risk of hearing impairment of workers, then the nominal day chosen shall be representative of the average exposure over the period under consideration, in accordance with ISO 1999"* (ISO 9612, 2009).

In section 8.2 Measurement strategies it also states the following *Three measurement strategies for the determination of workplace noise exposure are offered by this International Standard. These are:*
a) task-based measurement: the work performed during the day is analysed and split up into a number of representative tasks, and for each task separate measurements of sound pressure level are taken
b) job-based measurement: a number of random samples of sound pressure level are taken during the performance of particular jobs" (ISO 9612, 2009).

The European Parliament and the Council of the European Union, through its Directive 2003/10/EC, states the following:

"Article 1: ….lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to noise and in particular the risk to hearing" and " shall apply to activities in which workers are or are likely to be exposed to risks from noise as a result of their work"

Article 3: For the purposes of this Directive the exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

(a) exposure limit values: LEX,8h = 87 dB(A) and Ppeak = 140 dB;

(b) upper exposure action values: LEX,8h 85 dB(A) and Ppeak = 137 dB;

(c) lower exposure action values: LEX,8h = 80 dB(A) and Ppeak = 135 dB.

Article 4: 1) …the employer shall assess and, if necessary, measure the levels of noise to which workers are exposed. 2) The methods and apparatus used shall be adapted to the prevailing conditions particularly in the light of the characteristics of the noise to be measured, the length of exposure, ambient factors and the characteristics of the measuring apparatus. These methods and this apparatus shall make *it possible to determine the parameters defined in Article 2 and to decide whether, in a given case, the values fixed in Article 3 have been exceeded. 6)….. the employer shall give particular attention, when carrying out the risk assessment, to the following:*

(a) the level, type and duration of exposure, including any exposure to impulsive noise;

(b) the exposure limit values and the exposure action values laid down in Article 3 of this Directive;

(c) any effects concerning the health and safety of workers belonging to particularly sensitive risk groups;

(e) any indirect effects on workers' health and safety resulting from interactions between noise and warning signals or other sounds that need to be observed in order to reduce the risk of accidents

Article 5:

1. Taking account of technical progress and of the availability of measures to control the risk at source, the risks arising from exposure to noise shall be eliminated at their source or reduced to a minimum. The reduction of such risks shall be based on the general principles of prevention set out in Article 6(2) of Directive 89/391/EEC, and take into account in particular:

(a) other working methods that require less exposure to noise;

(g) organisation of work to reduce noise:

(i) limitation of the duration and intensity of the exposure;

(ii) appropriate work schedules with adequate rest periods.

2. On the basis of the risk assessment referred to in Article 4, if the upper exposure action values are exceeded, the employer shall establish and implement a programme of technical and/or organisational measures intended to reduce the exposure to noise taking into account in particular the measures referred to in paragraph 1" (EU DIRECTIVE 2003/10/EC, 2003).

NIOSH 1998 and CCOHS could also have been referred to in this chapter, but it is deemed unnecessary since all the regulations run around the same values. Some will discuss the exchange rate of 3 dB, which is primarily used for scientific purposes due to its more precise definition, in contrast to 5 dB, a less stringent standard, which also examines the count of impulses exceeding 120 dB within the context of the 5 dB exchange rate (NIOSH, 1998; Noise-Occupational Exposure Limits in Canada, 2023).

Piňosová research study on hearing impairment risk in long-term exposure to noise, presents a risk probability and severity matrixes and stated that any noise above 95 dB imposed during 8 hour shift with 30 minute break for lunch was valued in a 1 to 5 scale by author as Almost Certain, with a description of "*the danger or risk occurrence is highly probable"* and in the severity matrix level 5 corresponded to catastrophic, with a description of "*Catastrophic consequences, excessive increase in the risk of hearing damage and occurrence of occupational"* disease which meant that with time 3 Stage Illnesses would be guaranteed, referred in **Table 6**.

Table 6 – Three-Stage Noise Illnesses and Health Impact

Stage 1 Illness	Stage 2 Illness	Stage 3 Illness	Source
Fatigue, psychological stress, concentration difficulties, decreased cognitive capacities, stress on reflex muscles, tinnitus, and mild difficulties in conversation.	Problems mentioned in 1st stage + temporary hearing impairment, Disturbances in the circulatory system through the nervous system, heart diseases, and severe problems in communication	Problems mentioned in 1st and 2nd stages + hearing loss, ultimate deafness, severe sleeping disturbances	(Piňosová et al., 2018)
Slight mood swings, indigestion and heartburn, mouth or throat infections, bronchitis	Chest pain, definite mood swings, back pain, fatigue, fungal, viral and parasitic skin infections, inflammation of stomach lining, pain and blood in urine, conjunctivitis, allergies	Psychiatric disturbances, haemorrhages of the nasal, digestive and conjunctive mucosa, varicose veins and haemorrhoids, duodenal ulcers, spastic colitis, decrease in visual acuity, headaches, severe joint pain, intense muscular pain, and neurological disturbances.	(Alves-Pereira & Castelo Branco, 2006)

Similarly, other research studies have also reported the same and additional health issues when exposed to noise for prolonged periods (En–tong et al., 2008; Fitzpatrick & Daniel T, 1988; James, 2005; Jaruchinda, 2005; Kuronen et al., 2004; McReynolds, 2005; Stave, 1973). Hearing loss eventually appears over time due to degenerative cells in the human body.

When considering the types of noises to which one can be exposed, they can be categorised into five types: Environmental, Continuous or Constant, Intermittent or Occasional, Impact or Impulsive, and Occupational, as shown in **Table 7**. *"A variety of noise sources are associated, mainly external, from main and tail rotors, which include steady, periodic, and random loads on the rotor blades, as well as volume displacement and nonlinear aerodynamic effects at high blade Mach numbers and which either main or tail rotor can be the dominant noise sources at various frequencies which include main rotor high-order harmonics, main rotor random loadings, tail rotor low-order loading harmonics, and harmonics of main and tail rotor impulsive noise due to blade vortex interactions and high Mach number effects" (George, 1978).*

Table 7 – Categorisation of Types of Noises

Types of Noise	Description and Example
Environmental	External sources, such as traffic, factories, people talking, recreational activities, etc
Continuous or Constant	It remains constant and stable for an extended period, like a Generator or car engine at idle speed.
Intermittent or Occasional	Varies in intensity and duration, such as the noise of engines turning on and off or speeding up and down
Impact or Impulsive	Rapid, short-term impacts, such as the sound of a lightning strike or gunfire, can cause it.
Occupational	Work environments that negatively impact workers' health, such as those of helicopter pilots and agricultural truck drivers, etc.

Noise is measured in decibels (dB). ISO 1999-2013 and ISO 9612-2009 have the following information towards measurement and control:

A-weighted Noise Exposure Level Normalized to a Nominal 8 h Working Day or Daily Noise Exposure Level.

$$\boldsymbol{L_{EX,8h} = L_{p\mathrm{Aeq},Te} + 10 \times \log\left(T_{\mathrm{e}} / T_0\right) \mathrm{dB}} \quad (0.1)$$

Where:

***LpAeq,Te** is the A-weighted equivalent continuous sound pressure level for **Te**;*

***Te** is the effective duration of the working day in hours;*

***T0** is the reference duration (**T0** = 8 h).*

*If the exposure averaged over n days is desired, for example if noise exposure levels normalized to a nominal 8 h working day for weekly exposures are considered, the average value of **LEX,8h,** in decibels, over the whole period may be determined from the values of **(LEX,8h)i** for each day using*

$$\boldsymbol{L_{EX,8h} = 10 \times \log\left[\frac{1}{c}\sum_{i=1}^{n} 10^{0,1\left(L_{EX,8h}\right)i}\right] \mathrm{dB}} \quad (0.2)$$

The value of c is chosen according to the purpose of the averaging process: it will be equal to n if an average value is desired; it will be a conventional fixed number if the exposure is to be normalized to a nominal number of days (for example, when n = 7, c = 5 will lead to a daily noise exposure level normalized to a nominal week of 5 eight-hour working days). For consideration of irregular exposures over an extended time period, see ISO 9612" (ISO 1999-2013, 2013; ISO 9612, 2009).

Helicopters produce noise through mechanical and aerodynamic processes. Cockpit noise features distinct tones alongside harmonics, set against a low-level broadband background. Furthermore, noise from avionics systems and cooling fans can contribute to the overall internal environment. Aerodynamic noise originates from the main and tail rotors, incorporating design interactions and the angle of attack relative to the main fuselage during level flight. (e.g., AW139, AW189, EC225 or S76C++). It also arises from interactions among rotors, engines, fuselage, and the type of structural materials used, such as composite versus metal. Mechanical noise originates from rotor-associated systems, such as gearboxes, transmission shafts, APUS, and drive shafts. Every helicopter has a distinctive acoustic signature, influenced by differences in rotor configurations and gearbox ratios (James, 2005).

The helicopter frequency spectrum range is between 90 to 1000 Hz (George, 1978; Pope et al., 1985; Teixeira, 2020). However, the primary concern pertains to the lower infrasound frequencies ranging from 1 to 20 Hz, which may exert vibrations on the eardrum, ossicles, and semicircular canals, thereby impacting the outer, middle, and inner ear (Teixeira, 2020). The author acknowledges that pilot´s poor ear care or high noise exposure with social activities like positioning near speakers in concerts, nightclubs, bars or parties, use of high-volume earphones, the use of earbuds commonly connected to smartphones via bluetooth, lack of earplugs at the tarmac on airport and even cleaning ears with cotton swabs which may result in clogged ear canals may also affect the ear and therefore cause higher fatigue levels and hearing loss (HL).

A slight attenuation from noise exposure may be present due to wearing different headset models of different brands, qualities, or equipped with active noise reduction (ANR). Mckinley states that "Typically *ANR headsets improve attenuation 10-15 dB in the noise frequencies below 800 Hz and in sound pressure levels below 135 dB. While providing a significant gain in hearing protection, ANR headsets fall short for protecting the hearing of personnel working in noise above 135 dB. The consensus of these articles was that once 43-45 dB attenuation is achieved, bone and tissue noise pathways predominate at 2 kHz. Bone and tissue conduction were a factor at other frequencies but at greater attenuations."* (Mckinley et al., n.d.). It's important to note that in the Mckinley study, two measures were employed: a passive method using deep-inserted earplugs or custom earplugs and an active method involving headsets or earmuffs equipped with active noise reduction systems. This approach is not typically observed in flight decks or cockpits. The noise frequency range that most impacts helicopters is between 0 and 500 Hz, while the study also demonstrated effects in higher frequency regions above 500 Hz. Burgess, however, stated "……*during cruise in the cockpit of the Cessna 172 was found to be around 95 dB. For the tests using the cockpit sound, the overall noise reduction achieved by the three aviation headsets (with active noise cancellation if a feature) ranged from 19 to 25 dB.* ***……..****The results demonstrate the benefit of the active noise cancellation feature to improve the noise reduction achieved at the low frequencies"* (Burgess & Molesworth, 2016). "*Attenuation provided by standard ear-muffs and earplugs is in the range 10–30dB*. The efficacy of protectors varies over different frequencies." (Kuronen et al., 2004). Although this value was identified in laboratory conditions using crew helmets and ear muffs. It is not the case for helicopters operating in the offshore oil and gas industry during crew changes. The use of helmets is primarily found in air forces and search and rescue (SAR) or helicopter emergency medical services (HEMS).

In the capacity of a pilot, the author acknowledges and concurs that, on average, **an attenuation of up to 9 dB with normal headphones is attainable at frequencies below 300 Hz**, **potentially reaching as high as 12 dB with normal headphones for frequencies exceeding 300 Hz**, since at this frequency, ±200, the noise level is most intense in the one-third octave bands. Other studies suggest that a reduction of 15-30 dB can be achieved effectively. (FAA - Nonmilitary Helicopter Urban Noise Study, 2004; Fitzpatrick & Daniel T, 1988; George, 1978; King et al., 1996). The above statement regarding attenuation is also supported by Kuronen's results, which stated, *"Noise exposure during actual flights depends on many variables. In these measurements, the equivalent noise levels in the cabin were somewhat above and below 100 dB, and roughly 10 dB lower at the ear canal entrance. To evaluate the attenuation of aircraft noise provided by the helmet, the noise level at the ear canal entrance was calculated using the coherent output spectrum……. The number of hours of flight of the pilots increased rapidly at the beginning of their career, but this increase levelled off with age*" (Kuronen et al., 2004). Additionally, the author highlights that wearing helmets provides better coverage for pilots' heads, which helps diminish sound absorption in their surroundings, especially when compared to just using headphones during their daily activities.

The Author acknowledges the information laid down in ISO 1999-2013, Directive 2003/10/EC, NIOSH, and CCOHS. Numerous **uncertain aspects can be highlighted from all**, **none clarify the mandatory obligation to comply with only the evaluation criteria laid down, nor do they present an evaluation method for two types of combined sources in the spectrum of infrasound** between 0–20 Hz for **vibration**, **and the low-frequency noise** of 20–500 Hz (Alves-Pereira & Castelo Branco, 2006), **nor does it state that it is impossible to perform measures in only one specific way, nor does it state that it is impossible to perform measurements with specific equipment(s).**

Additionally, it states that the **lack of information is clearly noticeable in marine and air transportation**. The author also wants to emphasize that atmospheric conditions vary between sea level and the air. For instance, the speed of sound differs at the surface and at altitudes like 1000 feet or 5000 feet when flying, such as in a helicopter. Likewise, reference temperature, humidity, and atmospheric pressure all play significant parts in the outcome.

Building on the previous statements, a logical conclusion can be drawn that the standards and directives for noise cannot support air or sea activities as per this study, and alternative methods shall need to be applied. An alternative idea indicates that innovative solutions can be advantageous for industries. The research method presented in Chapter V aims to provide a simpler, quicker, more straightforward, and practical daily measurement method. It can be evaluated immediately by any worker, measuring sound and vibration exposure, and can collect data with the accuracy and feasibility of a simple observer, regardless of their level of knowledge in the field. This allows workers or observers to easily determine if the measurements are within safety and health levels or not.

3.1.3 Smartphone Three-Axial Acceleration Sensors for Vibration Acquisition

Smartphones have undergone unprecedented advancements over the last two decades. The smartphone assumes a crucial role in contemporary society, providing services such as health monitoring, disease detection, sports analysis, fitness tracking, and behaviour analysis (Javed et al., 2020). Each year, the top manufacturers of smartphone devices compete for client share in the market, and each year, the market becomes more and more diverse, growing more sophisticated and presenting unique gadgets, pocket-sized computers (Grouios et al., 2023; Wannenburg & Malekian, 2017) simultaneously contributing to or eliminating older industries (e.g., photography machines, scanners, Portable Navigation Devices (Pei et al., 2010), fax, etc). The integration of sensors that serve various purposes, from accelerometers, gyroscopes, magnetometers, and environmental sensors like ambient light and temperature sensors (Andersson et al., 2024; Grouios et al., 2023; Majumder & Deen, 2019; Pei et al., 2010), has opened the market in smartphone applications, contributing to the support to several sensors and applications in multiple fields, including Human Activity (Wannenburg & Malekian, 2017), Medical, Automotive, Educational, geographical, engineering, architectural, marketing, fashion, Environmental, Aviation industries, and you name it (Andersson et al., 2024; Grouios et al., 2023). The interesting point is that users and manufacturers have also benefited from the data collection and processing capabilities, helping to meet users' needs and benefiting from users' contributions that support the backbone for further application developments.

Human activity recognition is a vital area of research that holds great promise for applications in healthcare, smart environments, and safety. Extracting physical features plays a crucial role in understanding context and monitoring activities, as it can enhance predictions and decision-making processes (Wannenburg & Malekian, 2017).

Accelerometers, in particular, are widely favoured in the scientific research community and find diverse applications in fields like biomedicine and for tremor analysis both directly related in some point in this study (Wannenburg & Malekian, 2017). These **accelerometers are provided with three-axial sensors that acquire the acceleration along the *X*, *Y*, and *Z* axes equivalent to the roll (ϕ), pitch (θ), and yaw (ψ) axes**, as shown in **Figure 6** (Andersson et al., 2024; Majumder & Deen, 2019; Pei et al., 2010; Wannenburg & Malekian, 2017). Modern smartphones come equipped with microelectromechanical sensors (MEMS) that gather data on location, movement, surroundings, biometrics, and health. Current mobile devices utilise compact, cost-effective sensors that consume minimal energy while providing exceptional performance, enhancing their sophistication and advancement (Grouios et al., 2023).

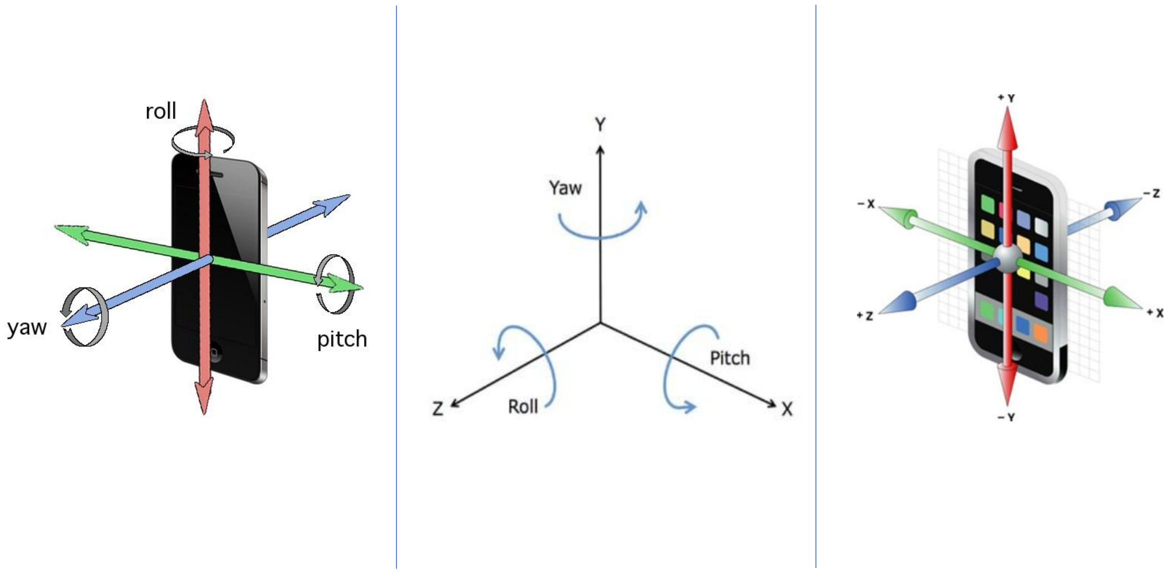


Figure 6 – Smartphone Three-axial sensors that capture acceleration

One reason the Author assumes smartphone sensors are capable of being used for this study is the diversity of their use in health monitoring within the healthcare industry, as shown in **Table 8**. Majumder and Deen's research clarifies the use of several sensors to monitor sound with the microphone and motion with the accelerometers, explaining several studies using older and inferior phones that provided the necessary accuracy compared to the ones used in this research (Majumder & Deen, 2019).

Furthermore, Grouios et al, stated in their study regarding the accuracy of data provided from smartphones the following *“Results demonstrated that (a) the tested smartphone accelerometers are valid and reliable devices for estimating accelerations and (b) there were not significant differences among the three current generation smartphones and the Vicon MX motion capture system’s mean acceleration data. This evidence indicates how well recent generation smartphone accelerometer sensors are capable of measuring human body motion* (Grouios et al., 2023), Ibrahim et al. concluded in their study that “linear estimation accuracy is close to the best achievable estimation accuracy determined by the Cramer-Rao lower bound (CRLB)” (Ibrahim et al., 2020), which relates to the estimation of a deterministic parameter. Javed et al. stated in their research study, *“Android-based smartphones have a built-in motion sensor that provides accurate and precise acceleration readings against physical activities”*, using only the smartphone accelerometer's y and z axes, the accuracy for recognising physical activities reached 93% (Javed et al., 2020).

Table 8 – Smartphone Sensors used for Health Monitoring.

Monitored Health Issues	Typically Used Smartphone Sensors
Cardiovascular activity, e.g., heart rate (HR) and HR variability (HRV)	Image sensor (camera), microphone
Eye health	Image sensor (camera)
Respiratory and lung health	Image sensor (camera), microphone
Skin health	Image sensor (camera)
Daily activity and fall	Motion sensors (accelerometer, gyroscope, proximity sensor), Global positioning system (GPS)
Sleep	Motion sensors (accelerometer, gyroscope)
Ear health	Microphone
Cognitive function and mental health	Motion sensors (accelerometer, gyroscope), camera, light sensor, GPS

Source: (Majumder & Deen, 2019)

The well-documented studies on WBV and Sound illnesses (**Table 9**) related to it and its expected and adverse effects on the demographic group studied in this research and associated concerns with their healthcare and well-being can be quickly and adequately managed through continuous monitoring. To enable continuous health monitoring, affordable, non-invasive, and easy-to-use healthcare solutions are crucial. Smartphones make this possible because they have become a must-have item in today's society. It is light, portable, relatively low-cost technology, private and capable of continuous self-monitoring of users' health and wellbeing, pending the app used with negligible additional costs.

The difference between high-quality smartphone brands and accelerometers exists, assuming that the error margin is between 0.3% and 0.5% of the measuring unit, which is therefore considered negligible.

There is a need for immediate evaluation of workers' sound and vibration exposure information, which can be retrieved using the accuracy and feasibility of smartphone sensors that work similarly to the Flight Data Monitoring (FDM). This information may be relevant not only to their health but also to on-site maintenance technicians.

3.1.4 Summary of Health Effects from Whole Body Vibration and Noise Exposure

Table 9 - Summary of Health Effects from Whole Body Vibration and Noise Exposure

Title	Noise Level (dB)	Vibration Frequency (Hz)	Health Effects	Body organs affected by Vibration and Noise	Summary Conclusion
Vibration Exposure in Helicopter Pilots		0.01 - 50	Motion sickness, musculoskeletal issues like back pain and herniated discs, and cognitive fatigue can impair flight safety by slowing reaction times and causing tunnel vision, distraction, and reduced situational awareness, attention, vigilance, and alertness. All of these factors decrease concentration and psychomotor skills. Conditions such as muscular fatigue, tissue microtrauma, metabolic and microvascular damage, degenerative changes, and tissue failure contribute to these problems. Low back pain, which varies in location and severity, may interfere with flight operations, especially during emergencies. Factors influencing LBP include age, height, weight, BMI, and seating posture.	The circulatory systems, In general, affects the kidneys, digestive system, and cardiovascular system (elevated to high blood pressure), liver, urinary system and neurological (stress-related symptoms).	Vibration exposure significantly **impacts a pilot's health, leading to musculoskeletal and neurological symptoms**, and it involves accumulated muscular irritation and inflammation in the lumbar region. Low back pain, characterised by dull or achy discomfort, may affect flight performance, **safety and operational effectiveness in emergencies.** This includes herniated nuclear material and varying pain in diverse areas, such as muscles, tendons, ligaments, **and spinal nerves.** Suffering occurs in the Z-axis of the lumbar vertebrae, both horizontally and vertically, and involves a flexion-extension rotational component. **Tunnel vision**, muscular fatigue, microtrauma, tissue failure, **metabolic compromise, microvascular damage**, degenerative changes or combinations of these issues can be significant contributors. Several factors may contribute to low back pain, including age, height, weight, body mass index and seating posture. **Neurocognitive impairments** that affect cognitive fatigue can reduce pilot performance, particularly at levels related to **situational awareness** (attention, vigilance, and alertness). This can **lead to distraction,** lower vigilance, concentration issues, and a **decline in psychomotor performance,** potentially jeopardising flight safety. Additionally, **cognitive fatigue can increase anxiety and slow processing, decision-making and situational awareness.**

Noise Exposure in Helicopter Pilots	80.2 and 99.5 (>90)	≤ 500	Hearing loss, tinnitus, Vibro Acoustic Disease; reduced or declining monaural and binaural sound localisation cues; impaired self-motion perception, compromised environmental spatial orientation, and diminished awareness of auditory objects. Also includes difficulty with postural adjustments, maintaining spatial orientation, and responding promptly to environmental changes.	Hearing and balance organs (affected by tinnitus and sound localisation issues), as well as neurological effects (caused by stress and fatigue).	Noise exposure **significantly affects hearing, leading to hearing loss, tinnitus, and vibroacoustic disease.** It also causes **deficits in monaural and binaural cues vital for sound localisation, self-motion perception, environmental spatial orientation, and awareness of auditory objects and events.** These impairments **hinder the ability to respond appropriately and promptly to environmental changes**. **Neurocognitive impairments can lead to memory loss, attention problems, headaches, slower reaction times, fatigue, heightened stress levels, anxiety, diminished cognitive performance, delayed decision-making, and reduced alertness.**
Musculoskeletal Disorders in Helicopter Pilots due to Noise and Vibration	80-100	20-50	Musculoskeletal disorders include neck, lower back pain, long-term spinal issues, and disc herniation. Neurocognitive impairments encompass memory loss, attention issues, headaches, slower reactions, fatigue, stress, anxiety, reduced cognition, slower decisions, and diminished alertness.	Musculoskeletal system (neck, back, spine), cardiovascular system (high blood pressure), and neurological system (cognitive fatigue and stress).	**Chronic exposure to noise and vibration in helicopters is associated with musculoskeletal pain, particularly in the neck and lower back. This exposure can impair cognitive function and reduce overall flight performance, while stress factors contribute to fatigue and slower reaction times. In summary, helicopter noise and vibration negatively affect both cognitive and physical health.**

The following Sources support **Table 9** (above):

Vibration Exposure in Helicopter Pilots

(Ahn & Griffin, 2007; Auffret et al., 1980; Baig et al., 2014; Ballard et al., 2020; Bongers et al., 1990; Boshuizen et al., 1989; Bovenzi, 1996; Cunningham et al., 2010; De Oliveira et al., 2001; Dupuis & Zerlett, 1987; Fletcher & Dawson, 2001; Gaydos, 2012; Gradwell & Rainford, 2015; Griffin, 1977; Hubbard et al., 1971; Kåsin et al., 2011; Kittusamy &

Buchholz, 2004; Ladner, 1997; Mansfield, 2004; McMahon & Newman, 2018; Panjabi et al., 1986; Pope et al., 1985, 1987; Seidel et al., 1980)

Noise Exposure in Helicopter Pilots

(Alves-Pereira & Castelo Branco, 2006; En–tong et al., 2008; Gradwell & Rainford, 2015; Kuronen et al., 2004; McReynolds, 2005; Reinhart, 2008)

Musculoskeletal Disorders in Helicopter Pilots due to Noise and Vibration

(Gradwell & Rainford, 2015; Kato et al., 2009; Sirevaag et al., 1993; Sneddon et al., 2013)

3.2 Composite Materials in the Aerospace Industry

Composites are in all industries: electrical equipment, aerospace structures, Infrastructure, pipes, and tanks. Several reasons have given humans an unmistakable understanding of why composites have become an integral part of our day-to-day lives, and one of the most important reasons is their ongoing study, improvement, and development.

Carbon fibre is the most widely used composite fibre in aerospace applications.

- Carbon fibre**,** as shown in **Figure 7,** is a highly versatile material consisting of thin, strong crystalline filaments of carbon, fundamentally carbon atoms connected in long chains. The fibres are incredibly stiff, strong, and light and are used in several processes to create excellent structural materials. Carbon fibre's high strength and low weight help to improve speed and engine efficiency in aviation designs.

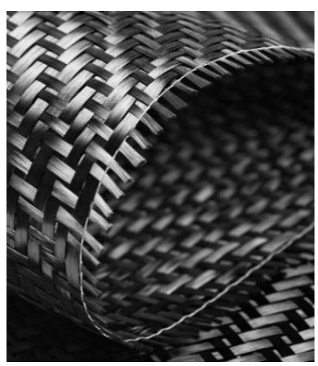


Figure 7 – Carbon Fibre

Typical Composite Applications in Helicopters

- Main and Tail Rotor blades
- Rotor hub
- Glazing bars
- Seats and interiors
- Engine/body fairings/access panels
- Main and Cargo doors
- Landing Gear Panels
- Horizontal stabilisers
- Fuselage panels
- Fuselage

A helicopter manufacturer may elect to use graphite fibre. Graphite fibre starts as carbon fibre, although it is processed at considerably higher temperatures to graphitise the carbon. This additional processing enables structures to achieve higher strength-to-weight or stiffness-to-weight ratios than those of carbon fibre, for example, in rotor blades, as presented in **Figure 8**. While Carbon Fiber generally has a higher modulus or is stiffer than fibreglass, it comes in various strength and stiffness combinations, making it suitable for many applications. Being stiffer and lighter than fibreglass, it is more likely to be used in a helicopter's fuselage or tail boom, although its stiffness makes it an ideal candidate for the spar in a main rotor blade.

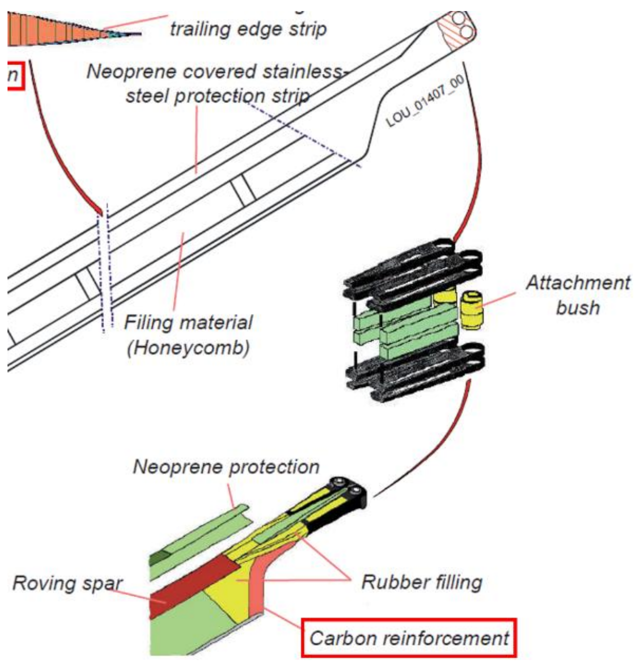


Figure 8 – Airbus H225 (EC225) Main Rotor Blade Structure (Source: Airbus H225 Training Helicopter Manual)

- Fiberglass has a high strength-to-weight ratio, good environmental resistance, and is quite flexible (low modulus). These properties make it an excellent material for making main and tail rotor blades, as shown in **Figure 9.**

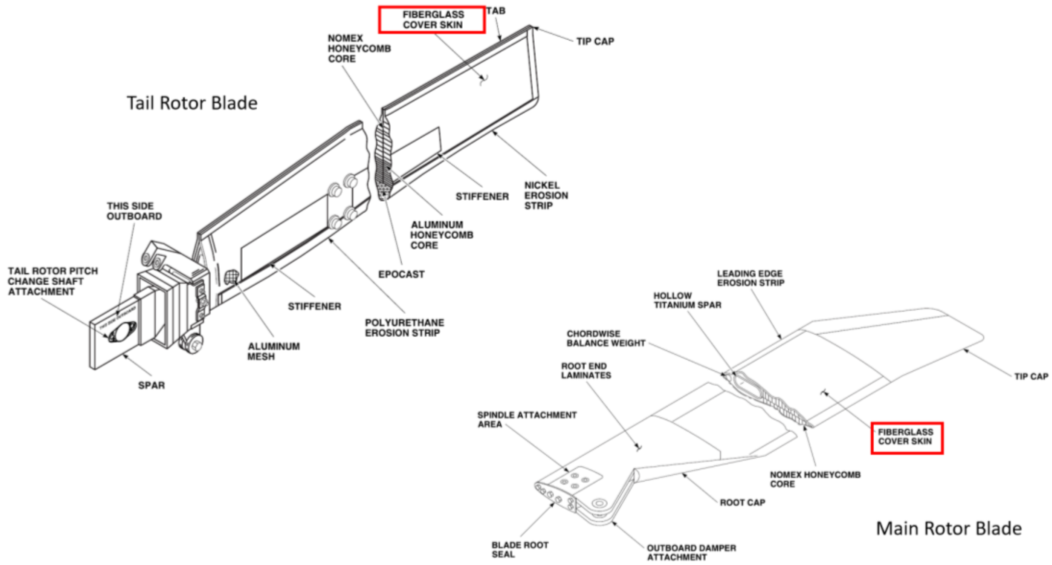


Figure 9 – Sikorsky S76 Tail and Main Rotor Blade Structure (Source: Sikorsky76 Composite Materials Manual)

- Kevlar fibre, known as Aramid fibre, is the lightest of the advanced composite materials and is extensively used throughout the helicopter industry. This combination of unique properties is particularly desirable in the design of transmission and engine cowlings, driveshaft covers, landing gear doors, and, for example, on the main cabin canopy of the AW189, as shown in Figure 10. It is an extremely tough, durable fibre with a very high tensile strength. Unfortunately, the lightweight and durability come at a cost. The Kevlar fibre tends to absorb moisture and other liquids to which it is exposed, such as fuel, oil, or water. Therefore, the composite structures may become compromised by intrusion. Given that many composite repairs are heated to cure the resin system, the problem becomes significantly more pronounced. Drying the structure before such a repair requires additional steps, as engine oil, hydraulic fluid, fuel, or water cannot be dried or adequately cleaned by flushing with solvents on contaminated Kevlar skins or Nomex honeycomb cores. It must be treated as damage and removed. One clear example is water entrained in a honeycomb sandwich structure. During an elevated-temperature cure, the water will flash to steam, generating enough pressure to rupture the skin off the core surrounding the repair.

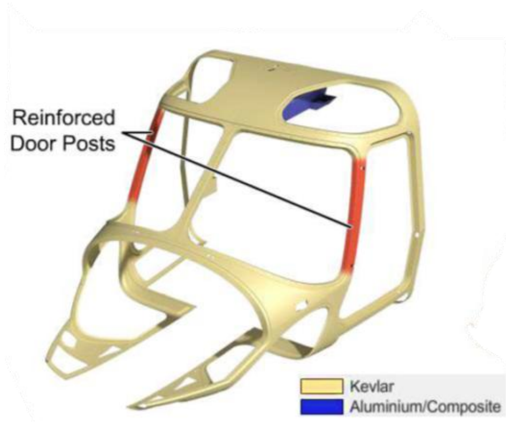


Figure 10 – AW189 Main Cabin Canopy Structure (Source: AgustaWestland Training Academy)

3.2.1 Advantage of Composites in Aviation

The significant benefits of composite materials in aviation are becoming increasingly evident, thanks to recent advancements in the aeronautical industry. These materials enable the creation of structures with smooth shapes and aerodynamic curves, substantially reducing drag. Other advantages include:

- Flexibility in Designs
- High Impact Strength
- Strength-to-weight ratio
- Durability
- Electrical insulation
- Thermal resistance
- Corrosion Resistance (to a large range of chemical agents)
- Good Insulator (in general)
- Low Maintenance Costs
- Chemical resistance
- Adaptable properties
- Low Production time
- Low Production Costs* (compared to metals)
- Reduced Maintenance

*It depends on the manufacturing processes used.

In the past, engineers used a complex lay-up process to manufacture composites, which was time-consuming and restricted the design geometry. New Technologies, manufacturing processes, and 3D printing have resulted in zero manual labour and lower production costs. These advantages save production time and reduce maintenance costs over the lifespan of helicopters, aeroplanes, and their components. Composites have revolutionised the market, both locally and globally, across all industries, and they will continue to replace traditional materials like steel and aluminium in aviation due to their advantages (**Table 10**).

Table 10 – General Composite and Metal Differences

Aspect	Composite	Metal
Composite Production Process	Tailorable	Standardised
Corrosion[3]	Corrosion Resistant	Corrosion Prone
Directional Property	Anisotropy	Isotropy
Propensity to Cyclic Loading	Low	High
Properties of Material	Process Dependent	Fixed
Stiffness	Tailorable	Fixed
Stiffness-to-Weight Ratio	High	**Low**
Strength-to-Weight Ratio	High	Medium
Stress-Strain Behavior	Elastic	Elastic-Plastic

Weight is crucial to overall performance in the helicopter industry as it significantly impacts the aircraft's fuel efficiency. NASA notes that a significant challenge in creating efficient, lightweight aircraft engines is the high cycle fatigue (HCF) limitations on high-performance rotating blades, contributing to 56% of significant engine failures and limiting the lifespan of crucial rotating components (Min et al., 2012). For this reason, composites have become an alternative material for manufacturing, and polymers, as vibration absorbers, are one of the leading composites used, although further investigation is required.

Fibre-reinforced polymer composite materials are increasingly used in primary aircraft structures due to their high strength, stiffness, and lightweight properties. Structural integrity is an essential requirement (Wan et al., 2021). Components made from laminated polymer matrix composites are susceptible to various defects resulting from impact (Morozov et al., 2003). The impact of projectiles, including stones or fragments, causes the formation of cracks, perforations, and micro-holes in composite components. Impacts on composite structures should be regarded as the most perilous initiators of damage, as they have the potential to initiate fracture processes that may culminate in catastrophic structural failure.

3.2.2 Primary Structures, Composites versus Metals

When comparing metals versus composites in primary structures, fatigue tests for metals reveal inferior fatigue performance compared to composites. The main reason is their ability to cease the growth of initial defects. On the other hand, their size and occurrence in composite materials are far greater than in metal components. While damage in metals is typically measured by the growth of an initial crack, fatigue damage in composite materials develops more gradually and in a nonlinear manner. Some failure mechanisms include matrix cracking, fibre breakage, debonding, delamination, and interface cracking, as well as complex interactions (Rivera et al., 2016). The high inconsistency of current manufacturing

[3] *Fretting corrosion is a particular problem in helicopters due to high-frequency vibratory loads, which cause micromotion caused by vibration and/or thermal expansion due to heating or cooling cycles (Davies et al., 2013).*

processes and other factors may lead to higher uncertainty in analysing long-term fatigue and failure behaviour, and composites must be carefully analysed more frequently than metals.

3.2.3 General View of Composites in Other Industries

The most common composite materials used for various industries include:

- **Ceramic matrix composite:** Ceramic is spread out in a ceramic matrix. It is superior to regular ceramics and becomes resistant to thermal, shock, and fracture.
- **Metal matrix composite:** A metal distributed throughout a matrix.
- **Reinforced concrete:** Concrete reinforced with high tensile strength material, such as steel reinforcing bars.
- **Glass fibre reinforced concrete**: Using High Zirconia, the concrete is reinforced with a glass fibre structure.
- **Translucent concrete:** Optical fibres encased with concrete
- **Engineered wood:** Manufactured wood linked with other cheap materials. Ex: particle board
- **Plywood:** Engineered wood by glueing several thin layers of wood together at diverse angles.
- **Engineered bamboo:** Strips of bamboo fibre are glued together to form a board. This composite is beneficial because it exhibits higher compressive, tensile, and flexural strength than wood.
- **Parquetry:** A square of various wood pieces set together, frequently out of hardwood. It can be sold as a decorative art piece.
- **Wood-plastic composite:** Either wood fibre or flour cast in plastic.
- **Cement-bonded wood fibre:** Mineralised wood pieces cast in cement. Resulting in insulating and acoustic properties.
- **Fibreglass:** Glass fibre combined with plastic, relatively inexpensive and flexible.
- **Carbon Fibre reinforced polymer:** Carbon fibre set in plastic, offering a high strength-to-weight ratio.
- **Sandwich panel:** Various composites that are layered on each other.
- **Composite honeycomb:** A selection of composites in many hexagons to form a honeycomb shape.
- **Papier-mache:** Paper bound with an adhesive.
- **Plastic-coated paper:** Paper coated with plastic to improve durability. This is often used in playing cards.
- **Syntactic foams:** Light materials created by filling metals, ceramics, or plastics with micro balloons. These balloons are made using either glass, carbon or plastic.

3.2.4 Mechanical structural response of composite materials in helicopters

3.2.4.1 Thick Laminates on Primary Structures

In aviation, thick laminates are used as primary structural parts and must be assembled and fastened to other structural parts using metallic fasteners, such as steel or aluminium bolts. These thick composite laminates are subjected to high-cycle fatigue loadings in service, and normal and shear stresses develop under the action of axial, flexural, and torsional loadings. As a result, delamination failure is primarily due to interlaminar shear stresses, with out-of-plane normal stress being more dominant. During manufacturing, significant thermally induced residual stresses are developed. Metallic fasteners in thick composite laminates lead to severe stress concentrations and contact stress distributions, altering the development and progression of failure.

These fractures generally involved the complete cross-section of the aluminium extrusion but had minimal progression into the composite laminate. In general, the crack in the metal spline induced either a short corresponding crack in the composite or a slight local delamination of the composite, both of which were limited in extent and non-propagating even after 5×10^6 cycles (Gilchrist, 2003). According to Gilchrist's research, composites exhibit fewer cracks when examined through micro holes. Using more composite materials may result in less vibration perception because there are fewer contact points between structural parts. Usually, composite structures are manufactured as large, single-piece mouldings rather than assembled from multiple metal panels, bolts, joints, rivets, and stringers. This reduction in the number of separate parts means fewer interfaces through which vibration can be transmitted or amplified, leading to a perception of lower vibration. Therefore, “fewer structural parts in contact” primarily refers to a reduction in mechanical joints and interfaces, not an inherent property of the material to have lower vibration.

3.2.4.2 Composite Fatigue Behaviour

Noise and vibration reduction remain fundamental to maintaining high performance and prolonging the useful life of structures, as well as the pilot's fitness to fly. A vast amount of literature is available regarding composite fatigue behaviour. The approaches developed and used to characterise and quantify the fatigue behaviour of composite materials and laminates can be grouped into three major categories: (i) Fatigue Life Modelling and Prediction, (ii) Phenomenological and Empirical Modelling, and (iii) Progressive Damage Modelling (Ganesan, 2020). Macroscopically speaking, fatigue-induced damage in composites can manifest in two fundamentally different ways: (1) by gradual degradation of material properties, slowly progressing through the structure by accumulating partial damage from different failure modes, leading to a continuous reduction in both strength and stiffness characteristics, or (2) by sudden failure, occurring when the instantaneous material stress exceeds corresponding strength characteristics, considering the gradual degradation of the latter (Rivera et al., 2016).

On the practical side, when composite materials reduce stiffness in a helicopter, for example, on the rotor blades, it may lead to increased flapping oscillations. Under turbulent wind conditions and aerodynamic loads, this can increase rotor vibrations during flight. A decrease in aerodynamic performance and a possible violation of minimum clearance requirements may result in a catastrophic event, ultimately leading to a fatal in-flight accident due to rotor blade contact with the tail boom. This is similar to strength reduction; when accumulated over time, it may lead to comparable catastrophic failure under extreme load conditions. It is important, therefore, to be able to anticipate accumulated fatigue and damage over the lifetime of severe vibratory structures. Be able to specify recommended repair or replacement activities, such as addressing pilot fatigue and rostering periods caused by excessive vibration and noise exposure, as well as the daily dose. (Teixeira, C., 2020).

3.2.4.3 What are the most effective composites for insulation or noise absorption?

Noise exposure has become one of the main reasons for pilot impairment and unfitness to fly by creating adverse effects on the Physiological process, such as hearing loss, cardiovascular disease, and human psychological health, causing sleep disorders; as a result, both causing stress and fatigue (S, 2009; Teixeira, C., 2020; Zhu et al., 2014). Noise may involve a single pure tone, but in most cases, such as when helicopters are involved, it is perceived by pilots and passengers as a combination of multiple tones at different frequencies and intensities (S, 2009; Teixeira, C., 2020). Noise is the third primary type of global pollution, mainly from modern technologies and industrial progress; studies on the sound absorption of porous materials have been ongoing since the 1970s (Peng et al., 2015). The air cavities are the main reason.

There are two main uses of acoustic materials:

1. *Sound Insulation*, in which noise from engines and rotors produced from the outside of the helicopter cabin is blocked from entering the inside of the cabine; and
2. *Sound Absorption*, which minimises sound generated inside the cabin space.

In commercial aviation, we are looking more into sound insulation, which can be affected by the material, size and shape of the structure's fuselage walls of aircraft since the acoustic energy that is incident on the wall is converted into reflected acoustic energy, energy loss, and transmission acoustic energy (Yan et al., n.d.). Acoustical materials, such as foams, fabrics, and metals, can be used to soundproof aircraft, improving occupants' protection and comfort levels by reducing the higher noise exposure often experienced outside the cabin structure. Polymeric materials are widely used for sound insulation and are well-recognised in the aviation industry. When analysing the weight ratio versus performance, one may consider using only foam or cork, as rubber tends to weigh significantly more. Foam is widely used in helicopter panels to insulate sound (**Figures 15a, 15b, and 15c**). Although existing varieties of acoustic absorptive materials are available, fibrous, porous, and other materials are often considered the most effective acoustic materials due to their high efficiency in reducing noise levels (Singh & Nath, 2021).

Research indicates that natural fibres offer several advantages over synthetic fibres, including lower weight, density, cost, and satisfactory properties. Importantly, they can be recycled or biodegraded and possess distinct sound and mechanical characteristics (S, 2009). This indicates that mineral fibres have the potential to serve as fillers or sound-absorbing materials. Natural Cork with carbon fibre in a sandwich structure has demonstrated improved sound and vibration performance. Other combinations of natural materials, such as cotton, bamboo, rice husk (**Figure 11a),** luffa, jute **(Figure 11b**), banana, and other natural fibres, have also been explored, along with combinations of wood, recycled rubber particles, and plastics (S, 2009; Zhu et al., 2014).

a)

b)

Figure 11 – Rice Husk & Jute

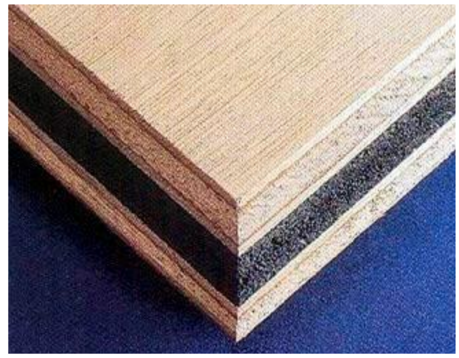
The **rice husks** shown in **Figure 11a** may be worth studying in depth due to some of their natural properties, which have significant safety and environmental implications. Rice Husk burns slowly with smoke but does not create flames, is highly resistant to moisture penetration and fungal decomposition, has thermodynamic properties with minimal heat transfer, is odourless, has gas-free emissions, and is non-corrosive when combined with metals like aluminium, copper, or steel, which are still widely used in aviation. In their raw and unprocessed state, rice hulls constitute a Class A or Class I insulation material, making them ideal for frequencies between 0 and 500 Hz, compared to wood shavings and recycled rubber (S, 2009).

Shen et al.'s study states that **jute fibres** (**Figure 11b**) used in composite with polypropylene improved the acoustical performance of the composite materials in the frequency range of 100−2500 Hz. His study identified that air in the pores would rub against the cavity walls, and the sound energy would be converted into heat energy and consumed. The study revealed that when the sound wave propagated inside the composite material and encountered the fibre, it was equivalent to encountering an obstacle, causing reflection, refraction, scattering, and diffraction within the composite material. The propagation path of the sound is also lengthened, resulting in the consumption of more sound energy (Shen et al., 2021).

Several research studies using diverse natural fibres for sound absorption have been successful in the low frequencies. However, adequate progress has not been made in the high frequencies, and further studies are needed to better understand how to reduce noise.

Medium-density fiberboard (MDF), **Figure 13a,** and rubber multilayer panels**, Figure 13b,** were studied in Liu et al., 2019 Sound reduction was gained by 28.0 dB for 6 mm MDF and 37.4 dB for 6 mm wood composite damping material. The primary concern is the weight gain on the structure; therefore, it is unlikely to be used in commercial aviation, except in private aviation.

a)



b)

Figure 12 – Medium Density Fiberboard & MDF and rubber multilayer panels

There are three different approaches to mitigating noise exposure in pilots: turning off the source (an impossible action), preventing the sound from entering the ears by using headphones, altering the noise propagation path, and impeding sound propagation using soundproof materials (Liu et al., 2019). Only a combination of the second and third options is possible in aviation. A reduction of 35 to 50 dB is desirable for pilots and passengers (Teixeira, 2020). Pilots are exposed to values exceeding 80 dB, reaching up to 115 dB or even higher, for instance, at peak levels. Using both types of material would return the exposure value to the 65-80 dB range, resulting in greater comfort and possibly reduced fatigue levels. Ideally, complete sound insulation would be the best solution. However, it comes at a high cost, as traditional methods of improving sound insulation performance involve increasing the material's surface density and thickness, which adds weight. This is neither convenient nor economical.

3.2.4.4 How does reduced vibration and noise exposure relate to composites?

Studies on reducing vibration and noise exposure have focused on mechanical properties, including tensile strength, stiffness, thermal insulation, and impact properties. However, composites used in engineering applications often suffer from dynamic loading, and vibration can cause undesirable noise with wide-ranging consequences, including a shortened lifespan of integral structures due to fatigue. Similarly, this same fatigue results in the Pilot's unfitness to fly (Teixeira, C., 2020). Challenges have arisen to enhance composites' vibration control capacity, increasing operational time and reducing maintenance costs. However, very few studies have been identified in this field, and further research is needed.

Some promising studies with foam and cork have shown progress. However, different mixtures and thicknesses require a comprehensive comparison with foam and cork to determine the optimal solution regarding weight added versus performance loss. With the results of these studies, a clear understanding is necessary to demonstrate the increase in the pilot's fitness. Assumed reduction in noise and vibration body absorption to diminish the fatigue levels that crews and passengers receive in prolonged periods will generally increase safety and comfort. Since vibration can also be viewed as a wave of sound, one can state that the same measures used for sound can also contribute to reducing vibration and noise exposure.

Medium-density fiberboard (MDF) and rubber multilayer panels can also significantly dampen sound waves caused by the stronger vibrations felt by helicopters. The thickness of the rubber increased the storage modulus, and the failure or loss factor of the composite increased accordingly. The greater the damping loss factor, the greater the energy loss, making the composite material more resistant. Since the loss modulus is a measure of the energy dissipation, the fibre orientation and stacking sequence influence a higher loss modulus of the multi-layered composite, and more acoustic energy would be dissipated during sound wave propagation in the material (Liu et al., 2019; Tang & Yan, 2020). Therefore, controlling the rubber thickness and type used can enhance the composites' sound insulation, thereby increasing the weight of the helicopter structure.

3.2.4.5 What are the best composites to reduce or absorb vibration?

The question raises several questions because it depends on its final understanding and purpose. Within the composite's family, as one can say, various types of viscoelastic materials are available for the absorption of vibrations, known as anti-vibration passive dampers (G.C. Mekalke; S.R. Basavarddi, 2019). Polymeric materials, such as rubber, plastic, Teflon, polyester, sugarcane, and wool, are widely used for sound and vibration damping. Viscoelastic materials hold mutually elastic and viscous properties within polymeric compounds. Despite certain disadvantages associated with viscoelastic materials, they are extensively utilised to produce composites that achieve advantageous trade-offs in maximum load-carrying capacity, sound insulation, compressive strength, and vibration displacement. These elements are critical in the aviation sector, particularly concerning helicopters.

Composite materials and structures are typically assembled with connections such as bolted, riveted, and bonded joints. These connections significantly influence the overall system's performance and damping characteristics. Damping is the capacity of a material to dissipate energy from mechanical vibrations. Given the intricate dynamic interactions between components, assessing damping can be complex, whether through analysis or empirical tests.

Aramid, Cork and Foam composites have good vibration-damping properties. Aramid is utilised in components, including helicopter engine casings, to mitigate the transmission of vibrations from the main rotor blades to the cabin. The vibration-damping loss factor is one of the characteristics that the composite must have for good damping. Several composites, such as aramid–epoxy and carbon–epoxy, have 10 to 200 times more loss decrement than aluminium, which is ideally used in aerospace materials.

Despite Aramid being lightweight with high stiffness and strength in tension, its material has poor compression strength, limiting its use in aircraft components subject to compression loads. Its fibres also absorb large amounts of water and are damaged by long-term exposure to ultraviolet radiation. Therefore, the surface of aramid composites must be protected to avoid environmental degradation ("Chap 14 - Manufacturing of Fibre–Polymer Composite Materials," 2012).

Agglomerated Cork (**Figure 13a**) is a good way to absorb vibration. Several composite mixtures can form when added to other fibres, such as carbon, aramid, glass, or metals like aluminium (**Figures 13b & 13c**).

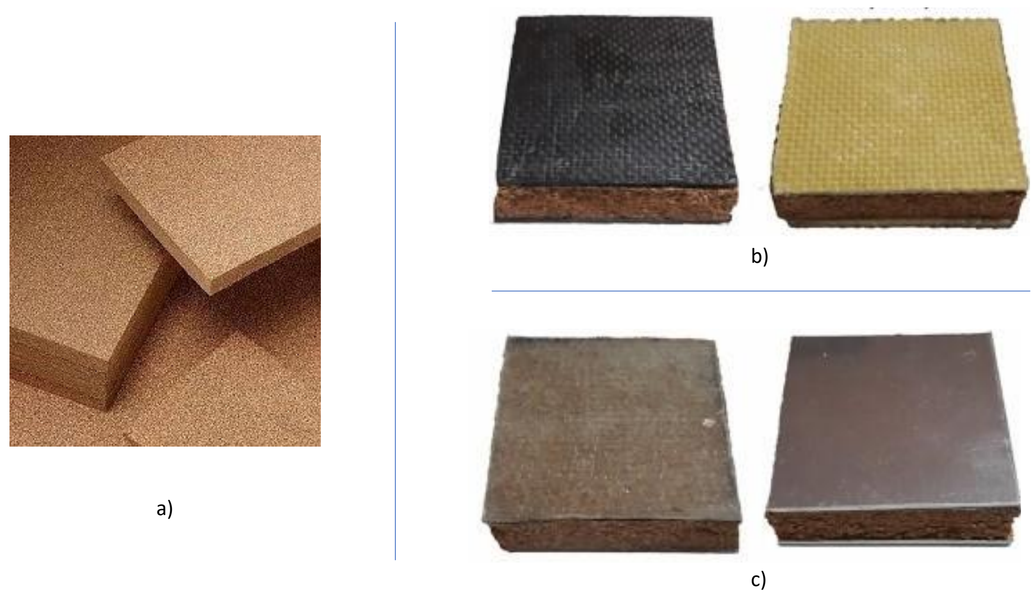
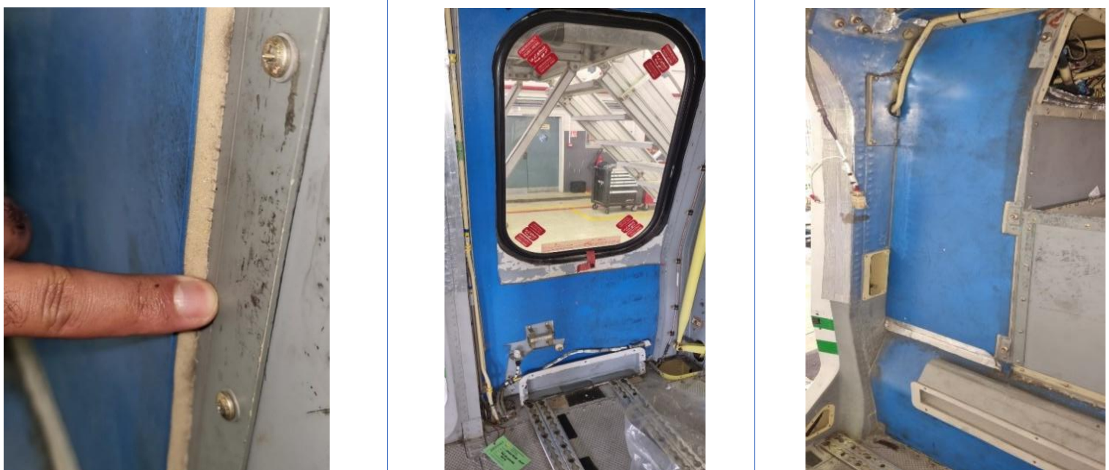


Figure 13 – Agglomerated Cork, Examples of CFRP/CORK/CFRP, AFRP/CORK/AFRP &GFRP/CORK/GFRP & Al 2024/CORK/Al 2024

Foam composites are good vibration-observant and soundproof barriers that contain at least one layer of acoustic-grade polyurethane foam, as shown in **Figures 14, 15a, 15b, and 15c**. Due to their weight, they are less resistant to the weight ratio for prolonged periods and, therefore, better suited for sound insulation in helicopters.

Figure 14 – Polyester Polyurethane Foam



a) b) c)

Figure 15 – Insulation Foam Thickness, Left-hand cabin panel &back panel of AW139 under Maintenance

3.2.5 Composites ratio in helicopters under 15 seats: AW139 vs S76

This subsection provides an overview of the AugustaWestland AW139 and Sikorsky S76 helicopters to help readers understand the quantity of composites used in both helicopters.

3.2.5.1 AgustaWestland AW139

The Airframe Structure of the AW139 (**Figure 16**) is made from a combination of metal and composite materials.

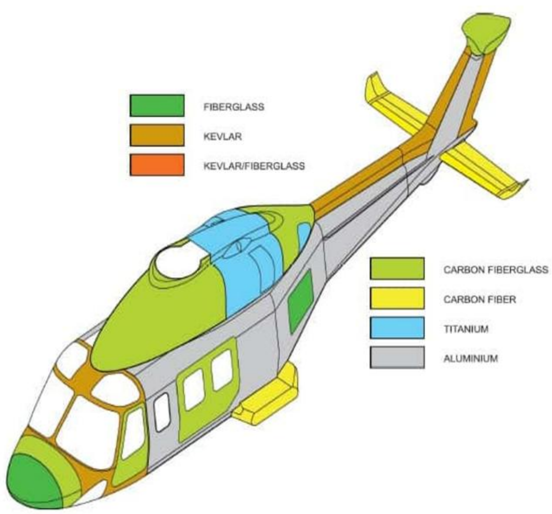


Figure 16 – AW139 Airframe Structure (Source: AW139 CAE Training Manual)

The Tail Rotor Blades **(Figure 17a)** are constructed from composite materials; the primary structural component is the fibreglass composite spar.

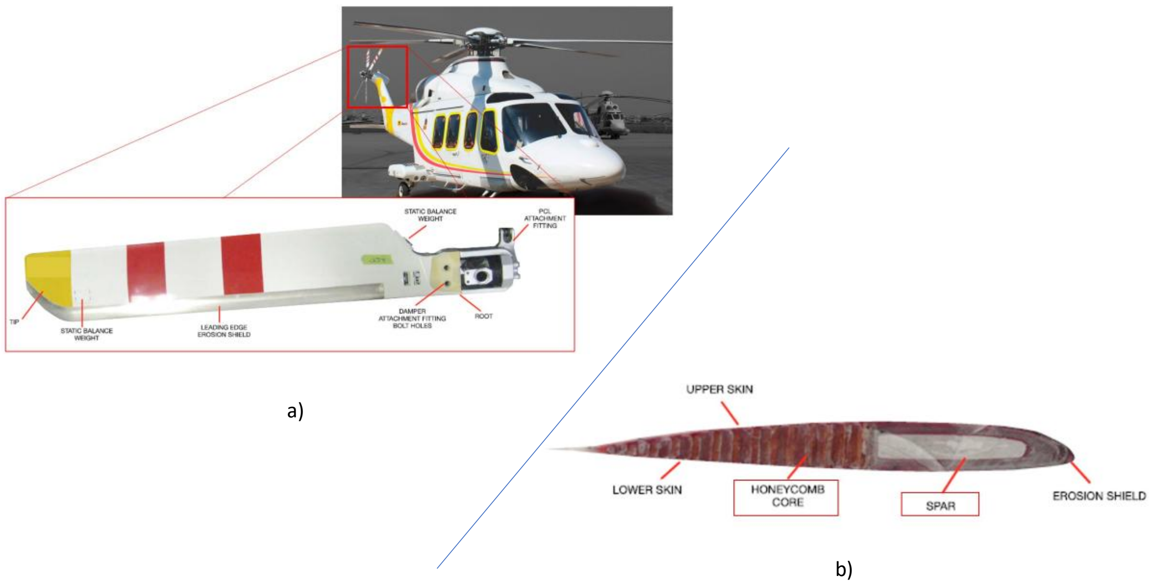


Figure 17 – Composite Material of the AW139 Tail Rotor Blades (Source: Authors' adaptation of CAE Training Manual)

A honeycomb core (**Figure 17b**) is merged to the flattened face of the spar, which extends aft to form a tapered trailing edge. Both are protected by fibreglass fabric skin, which is also bonded onto the spar's trailing edge.

The main rotor blades **(Figure 18a)** are constructed primarily of composite materials. The primary structural component is the composite spar, which is built from layers of fibreglass fabric and carbon fibre bonded around a foam layer to form an anti-torsional box. The trailing edge features a Nomex Honeycomb core (**Figure 18b**) between two carbon fibre skins, which on the aft end forms the trailing edge. The upper and lower skin is constructed from multilayered graphite tape (**Figure 18c**) covering an internal Nomex honeycomb core bonded to the blade spar to form the blade body.

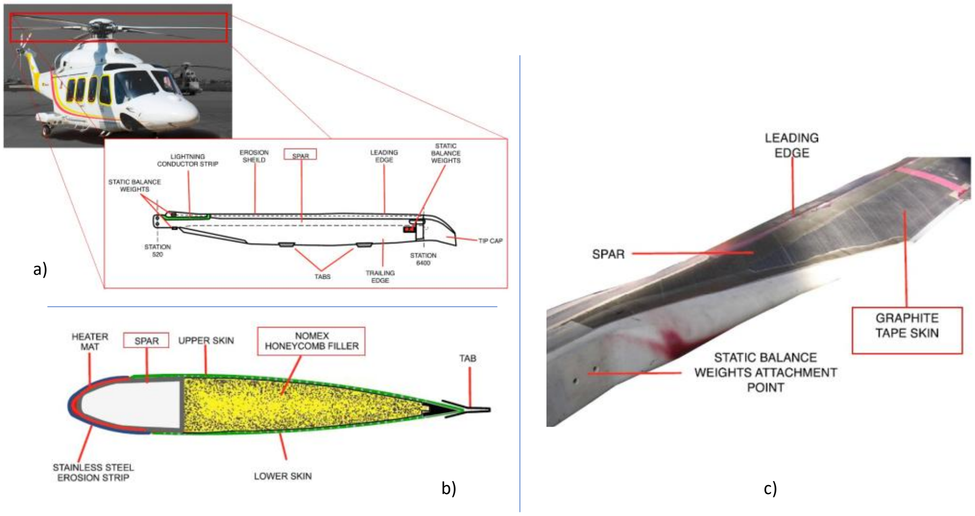


Figure 18 – Composite Material of the AW139 Main Rotor Blades (Source: Authors' adaptation of CAE Training Manual)

3.2.5.2 Sikorsky S76

The Sikorsky S76's airframe structure **(Figure 19)** comprises metal and composite materials.

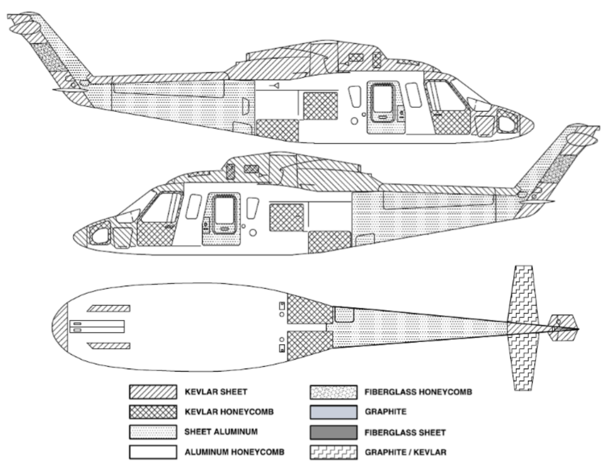


Figure 19 – Composite Material on the Sikorsky S76 Airframe Structure (Source: Authors' adaptation from Sikorsky S76 Composite Material Manual)

The Horizontal Stabilisers **(Figure 20a)** are made from composite materials. The main structural element is the composite spar, constructed from aluminium honeycomb, wrapped in Kevlar, and secured with a graphite epoxy strap. The upper side of the leading edge has a Rohacell core, while the lower side consists of a Kevlar honeycomb. Both sides are encased in a Kevlar outer layer.

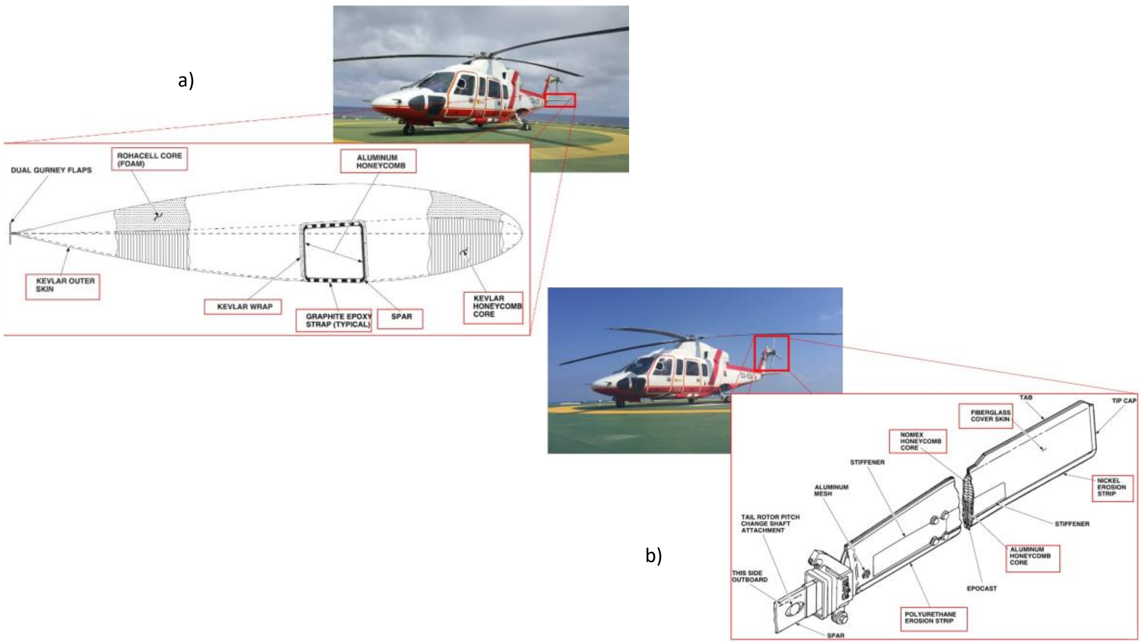


Figure 20 – Composite Material on the Sikorsky S76 Horizontal Stabiliser and tail rotor Blade (Source: Authors' adaptation of Sikorsky S76 Composite Material Manual)

Tail Rotor Blades **(Figure 20b)** are constructed from composite materials made in halves of graphite, fibreglass, Nomex, and aluminium honeycomb. A nickel erosion strip along the leading edge protects the outer portion of the blade's radius, and polyurethane shields exposed areas of the leading-edge skin. The main rotor blades **(Figure 21)** are primarily made from composite materials. The cover skin consists of cross-plied woven fibreglass with graphite trailing edge reinforcing strips. A Nomex honeycomb core supports the cover skin behind the spar. The balance weights are composed of fibreglass.

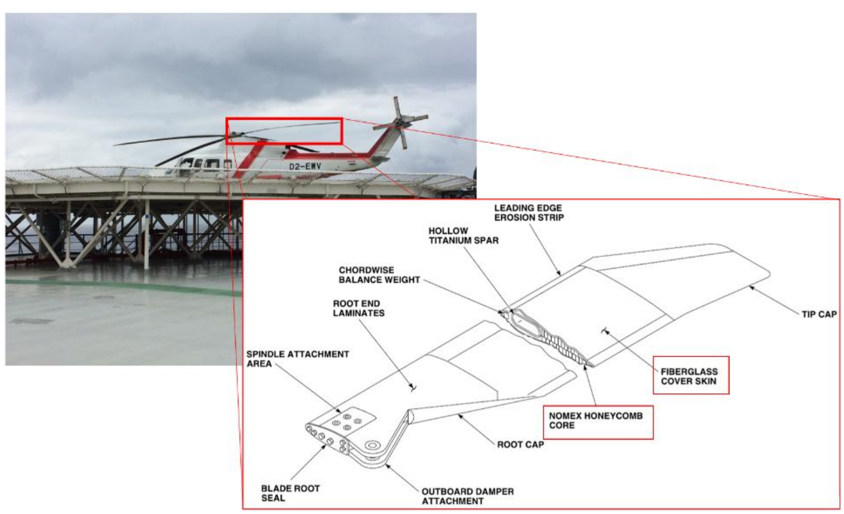


Figure 21 – Composite Material on the Sikorsky S76 Main Rotor Blades (Source: Authors' adaptation of Angola offshore Photography taken of SonAir helicopter and Sikorsky S76 Composite Material Manual)

3.2.6 Composites ratio in helicopters Over 15 seats: AW189 vs H225 or EC225

This subsection provides an overview of the AugustaWestland AW189 and Airbus Helicopters H225 or Eurocopter EC225 helicopters to help readers understand the quantity of composites used in both helicopters.

3.2.6.1 AgustaWestland AW189

The AW189's airframe is composed of both metal and composite materials **(Figure 22).** The main Cabin is constructed of aluminium alloy with machined main frames assembled in a join jig. Carbon fibre/Nomex-cored composite side panels are used.

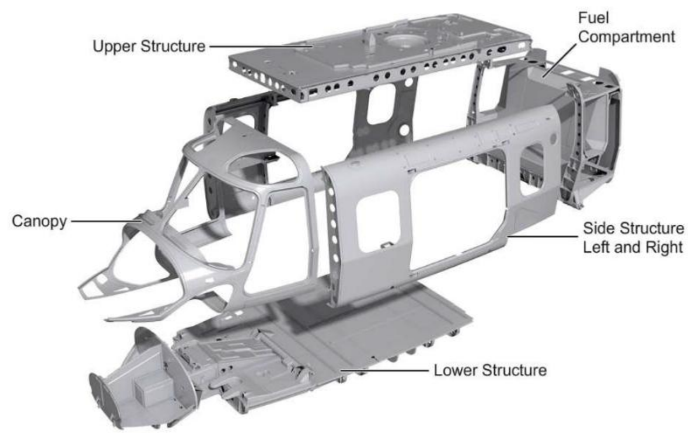


Figure 22 – AW189 Main Cabin Frame Airframe Structure (Source: AgustaWestland Training Academy)

The AW189 boasts a distinctive tail unit made entirely of composite materials, primarily carbon fibre, with the lower and upper sections comprised of fibreglass and carbon. To avoid moisture ingress, the outer Kevlar layers are overlaid with glass fabric (**Figure 23**). Copper mesh is incorporated into specific composite components to shield the structure from lightning strikes.

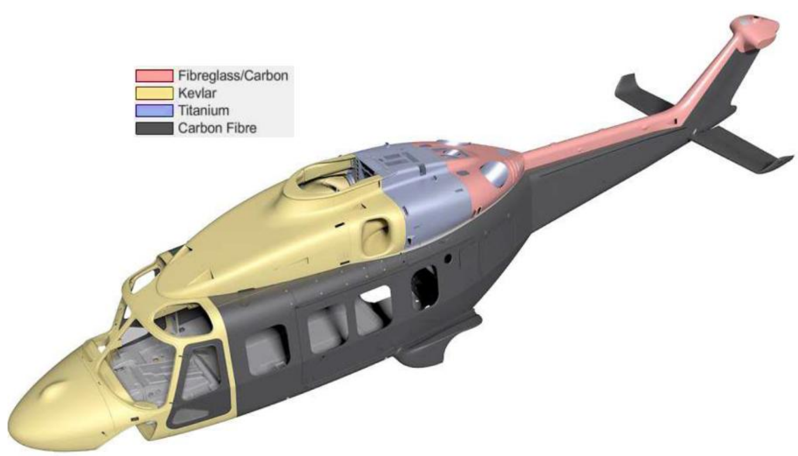


Figure 23 – AW189 Airframe Structure (Source: AgustaWestland Training Academy)

The composite parts are primarily carbon fibre. Kevlar Fabric is also used for the composite parts, which are subject to possible bird strikes, mainly the canopy and forward cowling (**Figure 24**).

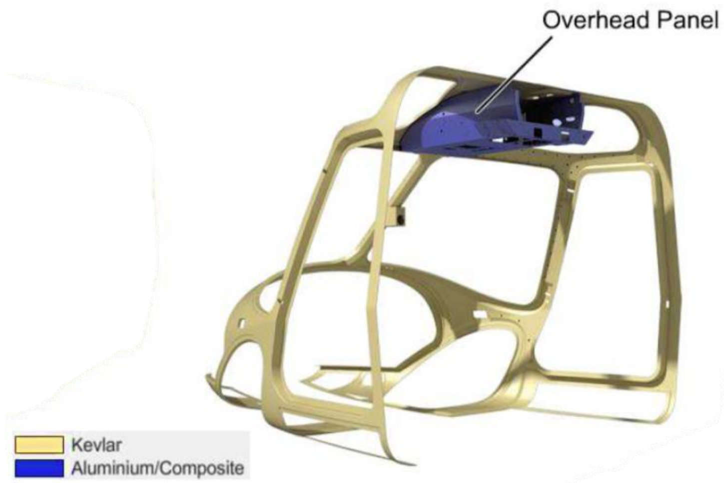


Figure 24 – AW189 Airframe Structure (Source: AgustaWestland Training Academy)

The canopy is of composite construction, utilising woven aramid fibre with Nomex honeycomb cores and carbon fibre tows to reinforce the pilot door posts. The canopy provides mounting provisions for the glazing and overhead console (aluminium/composite part fastened to the interior roof of the canopy).

The Radom Section (**Figure 25**) is made of composite sandwich panels and glass fibre composite. Kevlar is also used to seal the corner skin reinforcement, providing lightning protection to the Avionics Bay, located at the front of the helicopter.

Figure 25 – AW189 Radom (Source: AgustaWestland Training Academy)

Horizontal Stabilisers **(Figures 26, 27, and 28)** are constructed from composite materials; the primary structural component is the composite Carbon Fibre.

Figure 26 – Inside the lowered part of the Horizontal Stabiliser of AW189 under Maintenance

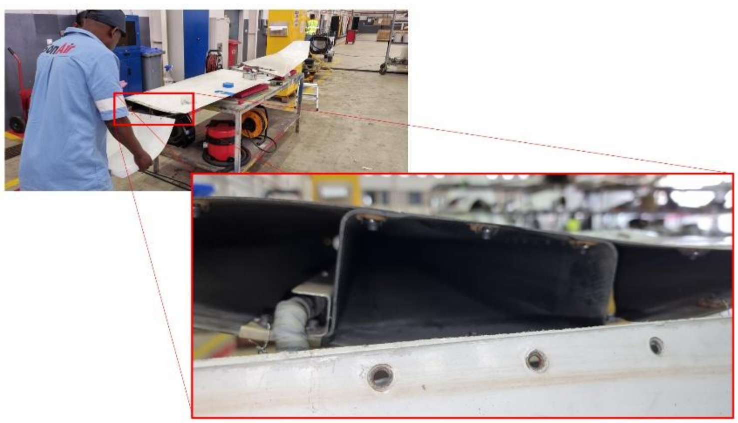


Figure 27 – Inside the Upper part of the Horizontal stabiliser of AW189 under Maintenance

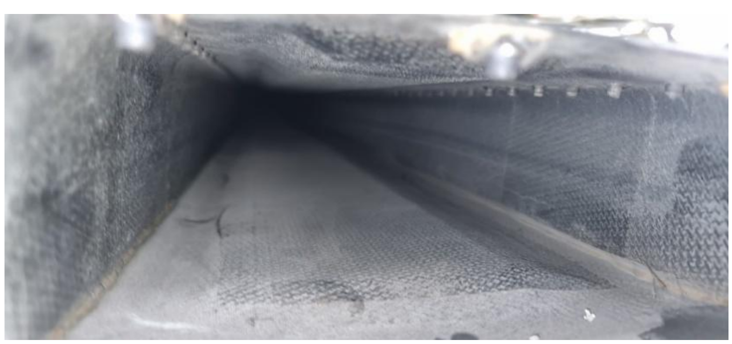


Figure 28 – Inside the middle section of the Horizontal Stabiliser of AW189 under Maintenance

Tail Rotor Blades **(Figure 29)** are constructed from composite materials; the root end lug region primarily consists of two split tape unidirectional glass fibre straps (top and bottom), which are wound to form a U-shaped lug. The skin is made of glass fibre plies, with a honeycomb material used to fill the void between the upper and lower surfaces at the rear of the spar, providing thorough thickness and stiffness. Each blade consists of three aerodynamic profiles distributed along the span of the blade.

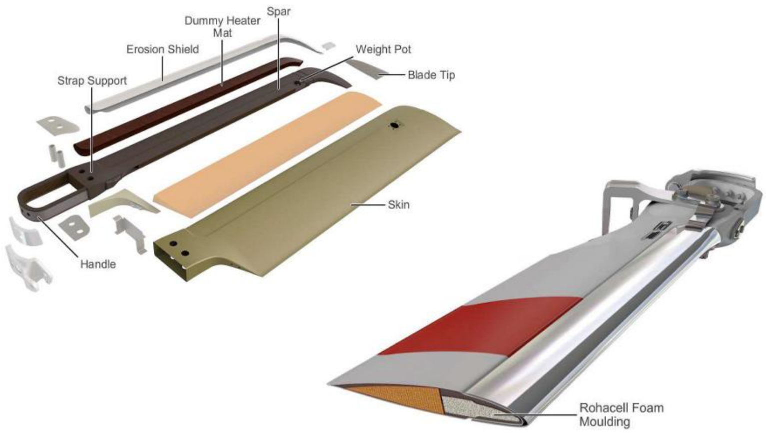


Figure 29 – Tail Rotor Blades of AW189 (Source: AgustaWestland Training Academy)

The blade spar is D-shaped and filled with a carbon-glass composition. The core of the spar is made from Rohacell foam moulding. The handle region of the blade consists of two split-tape unidirectional glass fibre straps separated by a piece of Epoxy Moulding Compound (EMC) filler. The main rotor blades are primarily constructed from composite materials. They have a complete composite structure with carbon and glass fibre epoxy spars. The trailing edge is a continuous element of carbon fibre/Nomex construction, and the blade is protected against lightning damage from root to tip.

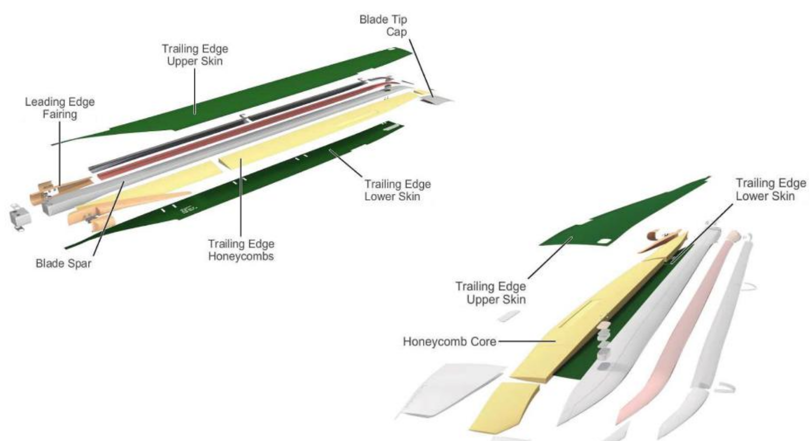


Figure 30 – Main Rotor Blades of AW189 (Source: AgustaWestland Training Academy)

The spar is D-shaped, consisting of Unidirectional (UD) carbon and glass laminate in the side walls and UD carbon and glass fibres in the nose. The spar plies are wrapped externally and internally by ±45° carbon fibres, and the spar's centre contains a foam core. Bonded to the rear wall of the spar are the upper and lower skins, which extend back to be joined together to form the trailing edge. The skins are made of ±45° carbon fibres, and the honeycomb core fills the space between the upper and lower skins.

3.2.6.2 Airbus Helicopters H225 or EC225

Figure 31 – EC225 (H225) at Soyo Airport

The H225's Helicopter **(Figure 31)** airframe comprises metal and composite materials (Figure 32). The main Cabin is constructed mainly of Light alloy. The composite parts are primarily carbon, Kevlar Honeycomb, and glass fibre. As in all the helicopters above, Titanium is used near the engines. **Table 11** is a legend that helps identify the structure of the EC225.

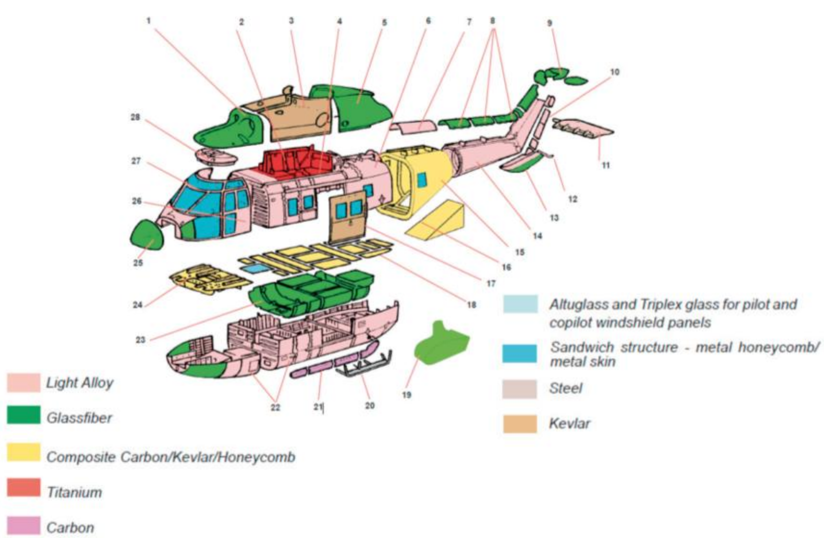


Figure 32 – EC225 or H225 Main Cabin Frame Airframe Structure (Source: Airbus Helicopter Ground Rescue Booklet)

Table 11 – EC225 or H225 Structure Legend (Source: Airbus Helicopter Ground Rescue Booklet)

1 - Air intake sliding cowling 2 - Engine firewall 3 - Engine cowling 4 - Transmission deck 5 – Main Gear Box sliding cowling 6 - Upper structure 7 - Tail rotor drive shaft fixed cowling 8 - Tail rotor drive shaft opening fairings 9 – Tail Gear Box fairing 10 - Pylon fairings	11 - Horizontal stabiliser 12 - Tail skid (steel) 13 - Lower fin 14 - Tail boom 15 - Intermediate structure 16 - Loading hatch 17 - Cabin door (RH door opposite hand) 18 - Cabin floor 19 - Landing gear fairing 20 – Footsteps	21 - Hydraulic line protective channel 22 - Bottom structure 23 - Fuel tank compartment trimming 24 - Cockpit floor 25 – Radome 26 - Copilot's door (Pilot's door opposite hand) 27 – Canopy 28 - Forward fixed fairing (cockpit roof)

Tail Rotor Blades (**Figure 33**) are constructed with composite materials, including fibreglass and foam filler, a fibreglass and carbon tissue skin structure, and a fibreglass trailing-edge stiffener.

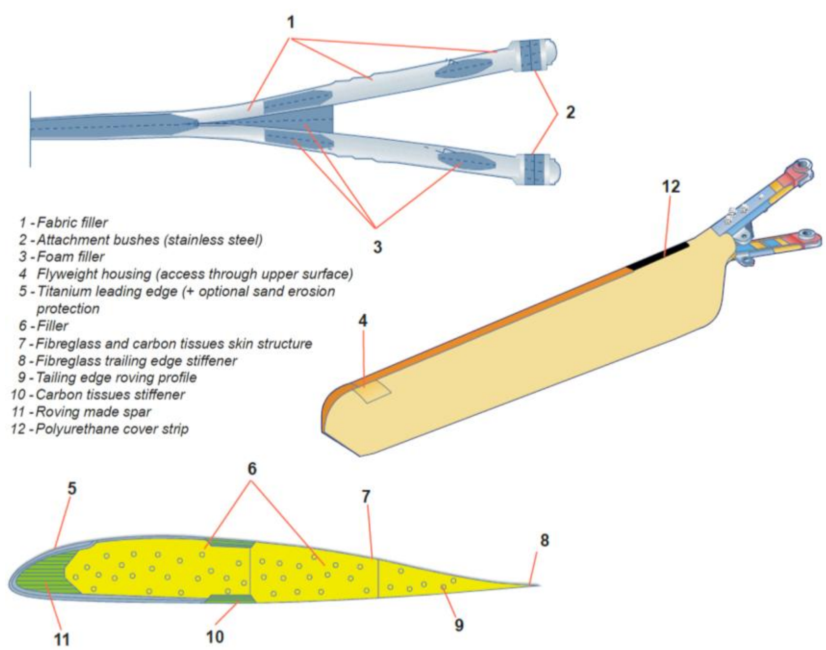


Figure 33 – EC225 or H225 Tail Rotor Blades (Source: Airbus Helicopter Training Helicopter Manual)

The main rotor blades **(Figure 34)** are constructed primarily of composite materials, mainly glass fibres impregnated with resin. Specific areas feature rigid foam composite or Nomex honeycomb. The skin comprises layers of fibreglass and carbon fibre.

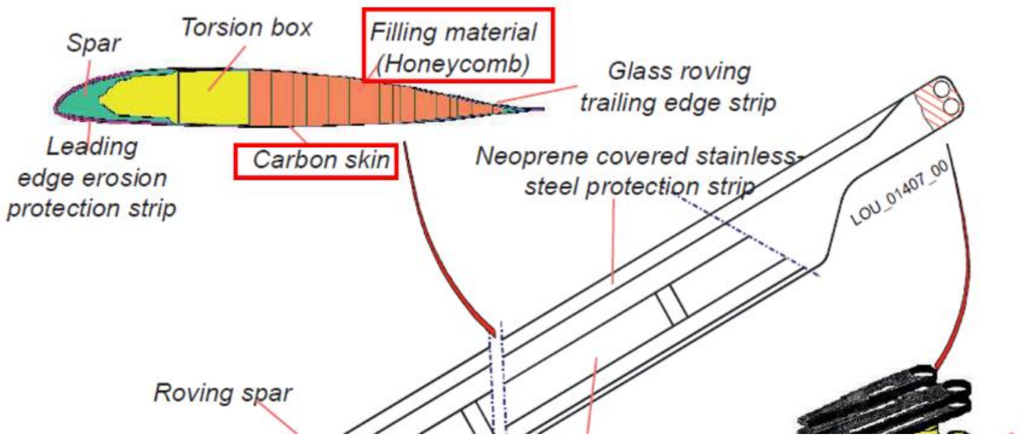


Figure 34 – EC225 or H225 Main Cabin Frame Airframe Structure (Source: Airbus Helicopter Ground Rescue Booklet)

3.2.7 Reliability analysis of helicopter maintenance with most composites.

Good maintenance analysis reliably determines the lifetime of composite structural components in helicopters. Qualified engineers or aircraft maintenance technicians must identify visible defects or barely visible damage (BVD) in the early stages, both in the design and maintenance phases (Das et al., 2020). Two of the most critical maintenance analyses in composites are fatigue cracks and delamination, which are very common and highly hazardous for aircraft composite structures, potentially leading to catastrophic failure in some cases. It becomes clear that damage identification is essential through mapping locations and precise size dimensions to avoid unexpected structural shortcomings.

Helicopters have different missions than aeroplanes, so they may be more prone to impact loads from foreign objects, such as debris from unprepared areas, runways, or during low-level flight. The detection of some of these damages is sometimes visually unidentified during inspections. Damages may occur internally in an impact event, and several damage types may occur, such as delamination, matrix cracking, or fibre fractures (Agrawal et al., 2014). The majority of damage is caused by impact. Low-velocity impact can quickly cause significant degradation of the mechanical properties (Diamanti & Soutis, 2010).

Several methods are used to detect defects within NDT (non-destructive testing), including visual inspection, optical methods, eddy current (electromagnetic testing), ultrasonic inspection, ultrasonic laser, acoustic emission, vibration analysis, radiography, thermography, and Lamb waves.

3.2.8 Comparison of Vibration: Metal vs. Composite Helicopters

A vast number of helicopters can be compared. However, the author will focus solely on helicopters that are or were widely used in the oil and gas industry, specifically on three manufacturers and four types of helicopters. The following manufacturers were selected: Airbus Helicopters (French), Sikorsky (American), and Leonardo (Italian). The types of helicopters chosen correspond to the manufacturers mentioned above: the H225, also known as the EC225, the S76, and the last two from the same manufacturer, the AW139 and AW189.

3.2.9 Effects of Vibrations on the Structural Integrity of Composite Materials in Helicopters

Helicopter and aeroplane manufacturers have adopted a new trend over the past 30 years: lighter structures, smaller and more powerful engines, and reduced fuel consumption. Due to the current approach, vibrations are presumed to rise due to their adverse effects on vibratory behaviour (Davies et al., 2013). It can potentially make structures more susceptible to vibration (Zaman et al., 2016). Vibrations are undesirable for structures because they affect stability, position control, durability against fatigue, performance, and noise reduction (D.D.L. CHUNG, 2001), and in the process, it is a critical problem for pilots and passengers if the vibration is not controlled to a level that does not impact the industry. Vibration is one of the most significant impacts that leads to pilot fatigue and hearing loss (Teixeira, C., 2020). Moreover, structural fatigue is due to vibratory loads.

The large blades on the main rotor (**Figure 35**) play a significant role in the vibration felt in the helicopter, which is filtered through the hub to the fuselage. This becomes the primary source of helicopter vibration. However, it is not the only source since the tail rotor and engine contribute to the overall noise and vibration its occupants feel due to the continuous rotational movement of blades and its reaction, while rotating movements like flapping, feathering and torsion (all three known as flap-bending/torsion couplings) significantly affect the rotor vibratory hub loads.

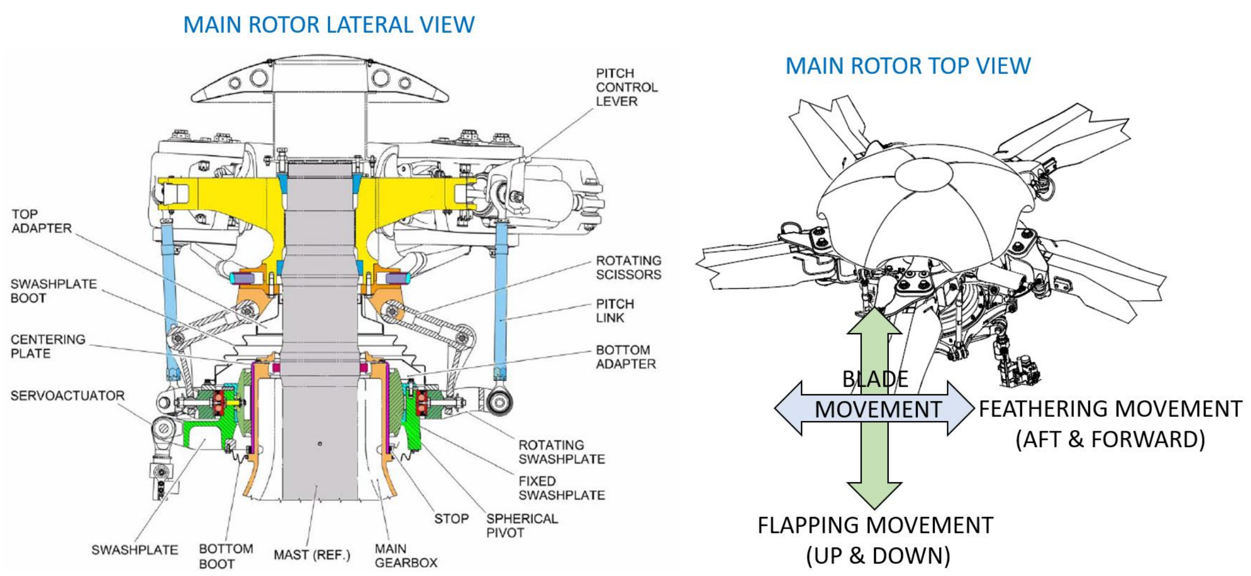


Figure 35 – AW139 Main Rotor (Source: Author's adaptation of CAE Training Manual)

*NOTE: Blade Feathering and Blade Flapping (***Figure 35***). Blade feathering is the term for hanging blade angle (pitch) and influences the blade's angle of attack. As a result, the change in the blade pitch will cause a change in the blade flapping behaviour. Flapping was revealed as a cure for rolling over when airspeed increased: a blade moving forward has additional lift than a blade moving aft. The flapping hinge allows the forward-moving blade to move up, effectively decreasing the Angle of Attack. Likewise, the aft-moving blade descends, increasing the angle of attack. The blade angle is adjusted by changing the control rod connected to the swashplate.*

High vibration levels limit helicopter performance, reduce the structural life of components, lead to pilot fatigue and poor ride quality, and increase operating costs. There are several classical approaches to reducing helicopter vibrations. Still, engineering practices have proven to have negative aspects, such as weight gain, increased power consumption, complexity, reduced reliability, and decreased maintainability, ultimately resulting in higher operational costs and higher consumer service prices. Since the early 1960s, advanced composite materials have opened a new field in aircraft construction due to their strength, lightweight nature, and ability to permit aeroelastic tailoring. The composite-tailored couplings result from the intentional distribution of fibre orientation and layup, which has been a new approach to helicopter vibration reduction. Promising future development in advanced composite approaches, combined with new research, may help achieve further reductions in vibration.

3.2.9.1 Main and Tail Rotor Blades

The helicopter's main and tail rotors operate in a highly dynamic and unsteady aerodynamic environment, which causes severe vibratory loads on the rotor system (Pawar & Ganguli, 2007). Blades play a central role in these severe vibration loads during flight, and they also significantly contribute to the noise experienced by crews and passengers. This results in pilot unfitness for flight due to degenerative side effects of whole-body vibration (WBV), hand-arm vibration (HAV) and hearing loss (HL) (Teixeira, C., 2020). The main and tail rotor blades experience different load conditions and aerodynamic forces in repetitive cycles at various points along each blade. Their failures can lead to loss of control and performance and, in worst-case scenarios, serious incidents or accidents. Continuous monitoring plays a crucial role in overseeing this type of structure throughout its lifetime (Pawar & Ganguli, 2007; dos Santos et al., 2016). Investigation results in Jin et al. have shown that elastic tailoring of the bearingless rotor blade is also an effective method for reducing vibration, as well as the effects of flap-bending/torsion couplings, rotor vibratory hub loads, and the distribution of these couplings. In some cases, the vibratory head moment has also experienced a considerable reduction. With suitable design optimisation, proper coupling strength, and correct spanwise distribution, the impact on rotor vibration characteristics can reduce vibratory hub loads without incurring weight penalties or extra power consumption. The research also provides beneficial theoretical support for subsequent experimental research of bearingless composite tailored model rotor blades (Jin et al., 2015).

Although advanced composites play a gigantic role in helicopter designs and construction, continuous and precise inspection for internal and external damage is crucial to maintain profiles at the construction level, helping to reduce vibration and, perhaps, noise. Though external defects may be observed visually when under maintenance, internal defects are challenging to spot, and issues such as delamination and lack of resin-rich and starved areas, minor breakage and matrix cracks, de-bonds or misalignments of fibres may be very challenging to detect (Balaskó et al., 2004). Balaskó et al. recommend radiography inspection of blades to adequately identify some of the issues above.

Identifying specific defects, such as cavities, holes, and cracks, is extremely important. The possibility of penetrating liquids into the interior of blades can cause severe damage. Liquids like water are commonly found and may freeze depending on altitude, temperature, humidity, and wind conditions. Freezing particles of the composite may damage the surrounding composite due to the volume expansion of ice (Balaskó et al., 2005). The difference in weight in the above condition, even in micrograms, may be present in this stage, resulting in unbalanced blades (F. L. M. dos Santos et al., 2016). This may result in added fatigue due to the differential micro vibrations felt by both the helicopter's structure and the crew and passengers. The differential wave of micro-accumulated vibrations, referred to above, due to the rotation of the main rotor, will cause an additional flapping phenomenon on the vertical axis of the main rotor hub and similarly on the tail rotor, but with an effect on the horizontal axis of the tail rotor hub. Both actions respond to the increase in vibration and noise exposure for crews and passengers, and once again, they result in fatigue due to WBV, HAV, and HL affecting both crews and structures. Davies et al.stated, "*The types of fatigue acting on the helicopter and its components comprise both high and low-frequency loads. In the case of the high cycle fatigue loads, these are primarily generated from the interaction between the main and tail rotor and through gear tooth interactions, whereas the causes of low cycle fatigue are largely due to aircraft manoeuvres, gust loading and through take-off and landing. As a result, both the high and low-frequency vibrational loads will be transmitted into the supporting structure, creating fatigue loading and possible damage"* (Davies et al., 2013). When observed externally, micro-holes or cracks may cause unstable laminar micro airflow, which can lead to micro-vortices at specific locations, and resulting in micro vibrations in the affected blade section.

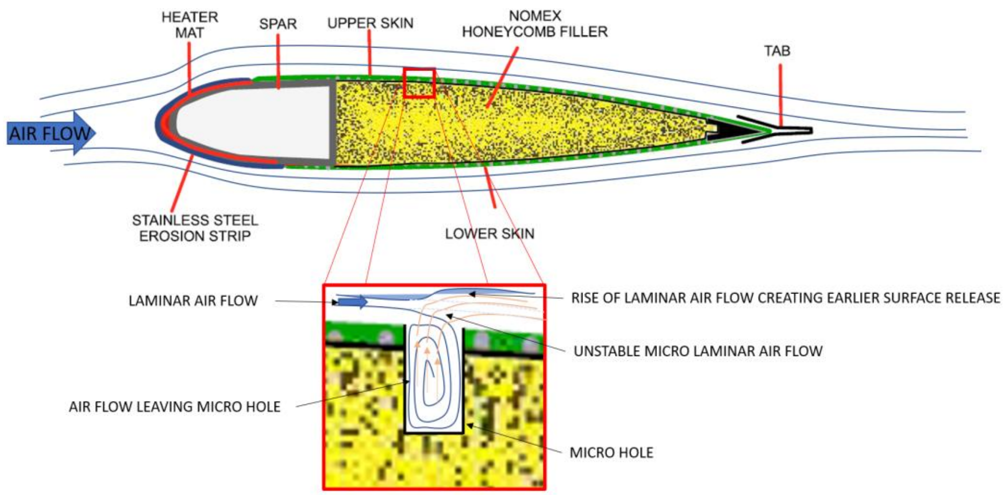


Figure 36 – AW139 Blade with Unstable Air Flow Due to Micro Hole (Source: Authors Creation and adaptation of CAE Training Manual)

The delay caused by the laminar flow will cause a laminar-turbulent transition, resulting in a second laminar flow with an upward force. This force raises airflow and creates earlier surface release, which results in vibrations. One can, therefore, conclude that microcavities or holes on surfaces may affect not only the second laminar wave flow but also the base flow due to the roughness effects. When examining the general overview of the helicopter structure, it can be observed that this may also be present.

Despite the increasing use of composites in the industry, helicopters continue to face challenges related to noise and vibration. Cabin noise and vibration are closely connected issues; both aerodynamic and mechanical sources can produce sound levels that often exceed 80 dB, sometimes reaching up to 115 dB. The rotation of the main rotor, tail rotor, engines, and their moving parts naturally generates vibration and noise. Furthermore, replacing small windows with larger escape exit windows, often driven by recommendations or requirements from the oil and gas sector, may have unintentionally caused the industry to overlook quieter, yet potentially more latent safety risks. Larger windows around the fuselage might have highlighted the subtle but significant dangers associated with long hours of flight and the exposure to vibration and noise that crews face daily in their work activities. Further research in this field must be conducted in the same industry.

Chapters IV and V raise relevant questions that the industry needs clarification on, and present an innovative approach backed by current aeronautical philosophy on safety and mitigation measures, supported by scientific assessment to identify possible solutions.

Chapter IV Research Questions

The following chapter contains questions that require further clarification to establish any potential correlation with associated fatigue during flight. Relevant insight from surveys, measurements, and data analysis can be used to create mitigation tools and further research studies.

4.1 Questions and Hypotheses

Several research questions were asked to gain a deeper understanding and fulfil the research study's purpose. For each question, a hypothesis was placed to obtain a clear view of the possible impact of fatigue on the pilot's fitness to fly. The questions and respective hypotheses are presented in **Table 12**. They aimed to clearly understand the possible impact of fatigue on a pilot's flight fitness.

Table 12 – Question and Hypothesis.

RQ 1: Does the helicopter pilot's fatigue mainly result from exposure to whole-body vibrations and above-average noise levels from blades and engines?	H1: Lengthy periods of whole-body vibration can result in higher fatigue impacts in pilots. H2: Prolonged periods of sound noise can result in pilot higher fatigue impacts due to hearing Loss.
RQ 2: What is the exact exposure of WBV and SN of pilots performing flights with AW139 and AW189?	H3: The average exposure range is within the recommended ISO 2631 and ISO 1999 standards. H4: The average exposure range exceeds the recommended ISO 2631 and ISO 1999 standards.
RQ 3: Can daily pilot vibration and noise exposure doses be measured to identify fatigue trends?	H5: Yes, trends of fatigue may be foreseeable with more data. H6: No, trends of fatigue are not foreseeable with more data.
RQ 4: Are measurements sufficient to identify and select the best rotation scheme ON/OFF scheme (21, 28 or 35) independently of the crew responsibility across flight exposure?	H7: Bearing the industry's best practices and the national Angolan Aviation laws, 21 ON 21 OFF is the best rotation for pilots. H8: Bearing the industry's best practices and the national Angolan Aviation laws, 28 ON 28 OFF is the best rotation for pilots.

	H9: Bearing the industry's best practices and the national Angolan Aviation laws, 35 ON 35 OFF is the best rotation for pilots.
RQ 5: Is there any direct or indirect correlation associated with current HUMS or FDM installed equipment to identify an average or correct exposure to avoid adding new physical hardware equipment to measure vibration and noise pilot exposure?	H10: The HUMS or FDM vibration data registered is comparably similar to data collected from crew exposure. H11: The HUMS or FDM data registered can predict foreseeable fatigue trends without adding additional hardware or software to aircraft compared to collected data from crew exposure. H12: Additional equipment must be added to aircraft to assure foreseeable fatigue trends to crews.

Chapter V Methodology

This chapter outlines the experimental and analytical methodology employed to fulfil the research study and answer the research questions in the previous chapter. It includes the study design, participants and sampling, data collection, survey, measurements, and data analysis.

5.1 Study Design

The general methodology followed in this research study is described in **Flow Chart 1 through Flow Chart 3**. The philosophy behind the methodology is based in part on the ICAO (International Civil Aviation Organization) 9854 SMS hazard identification using a proactive approach, safety risk mitigation strategies, categories of reduction or segregation and the author's adaptation towards the research (Doc 9859 Safety Management Manual (SMM) Fourth Edition, 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" (Doc 9859 Safety Management Manual (SMM) Fourth Edition, 2018).

The approach to safety risk mitigation strategies, category of reduction or segregation, is 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" (Doc 9859 Safety Management Manual (SMM) Fourth Edition, 2018).

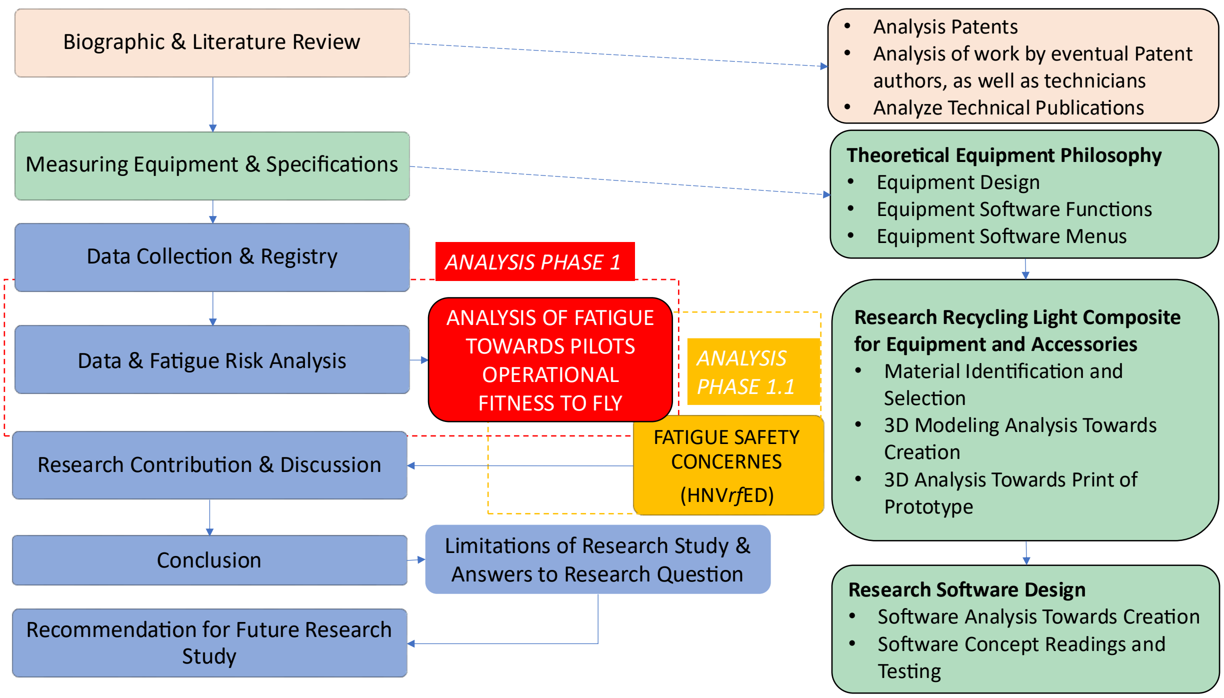
"Segregation: Action is taken to isolate the effects of the consequences of the safety risk or build in redundancy to protect against them" (Doc 9859 Safety Management Manual (SMM) Fourth Edition, 2018).

Based on the literature review, patent analysis and the aim of the research study, a set of questions was formulated for each subject prior to or after the commencement of flight testing. The reason was to prevent volunteers from having predetermined answers after discussing with one another. This ensures the participant's privacy and optimises the time required. A structured, individualised, quick self-survey approach was chosen as the most appropriate method. After data collection, flight data analysis was conducted. The scope of the discussion will centre on using the developed conceptual scheme of fatigue analysis concerning the pilot's operational fitness to fly, shown in **Flow Chart 2 - 6**.

The flow charts analyse and understand fatigue based on its direct or indirect influence on flight safety. Fatigue analysis is based on body exposure to WBV, HL, age, height, and body mass index, and it is compared to the number of flight hours and rest periods between flights. To fulfil the research scope objectives, the author recognised the relevance of conducting a correlational study with a cross-sectional design based on in-field measurements. Therefore, all voluntary pilot subjects completed a brief questionnaire that included several questions related to human factors, aiming to collect data on fatigue, sleep, rest periods, and rotation schemes before or after field measurements. The in-field measurement data collected aimed to provide an understanding of the conditions that may result in fatigue among the crew, which were recorded on personal smartphone apps by crew members. The study on the variables was conducted among offshore pilots working in the southern hemisphere of the African continent, specifically in the western African region of Angola.

The overall structure of the research presented here is illustrated in **Flow Chart 1**.

Flow Chart 1 – Research Methodology – Overall Concept



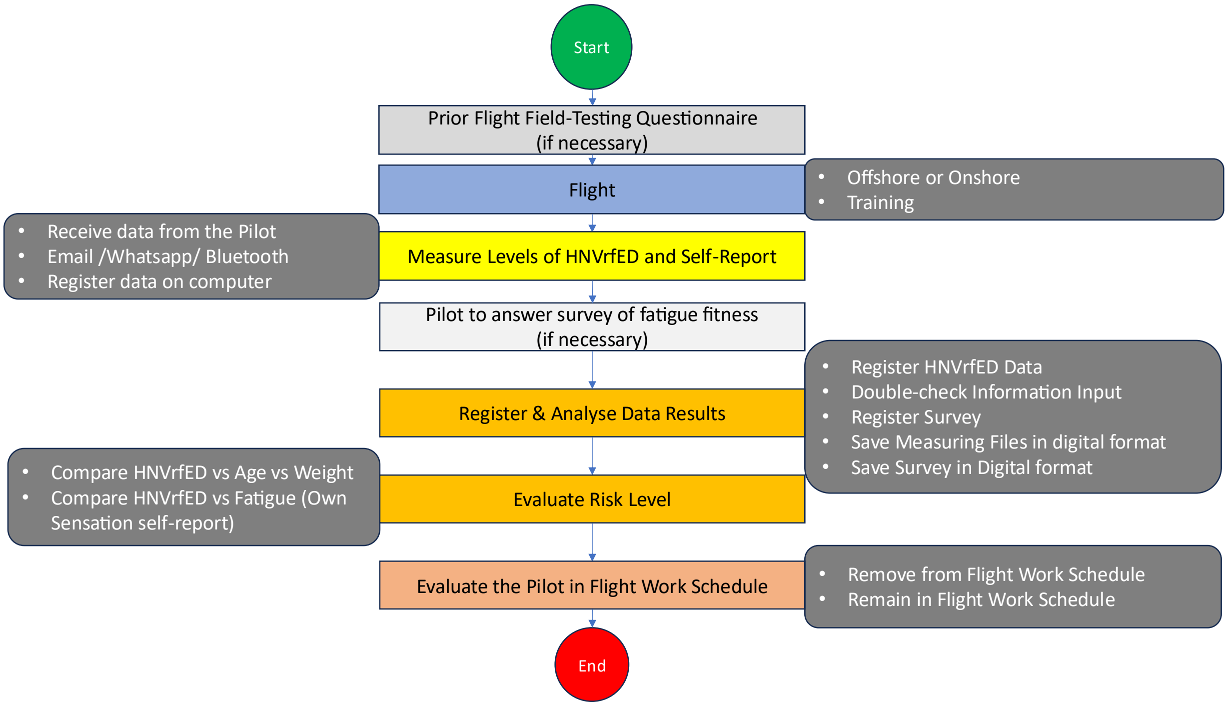
Taking into consideration **Flow Chart 1**, the study methodology is divided into sections, each with a respective Flow Chart detailing the conducted work:

- Data collection regarding WBV and Noise
    - General Field-Testing Process Overview (**Flow Chart 2**)
    - Field-Testing Data Analysis Process Overview (**Flow Chart 3**)
- Data analysis towards the characterisation of pilot fatigue analysis (see 5.5)
    - Analysis of Fatigues towards Pilots Operational Fitness to Fly (**Flow Chart 5**)
    - Fatigue Safety Concerns (**Flow Chart 6**)

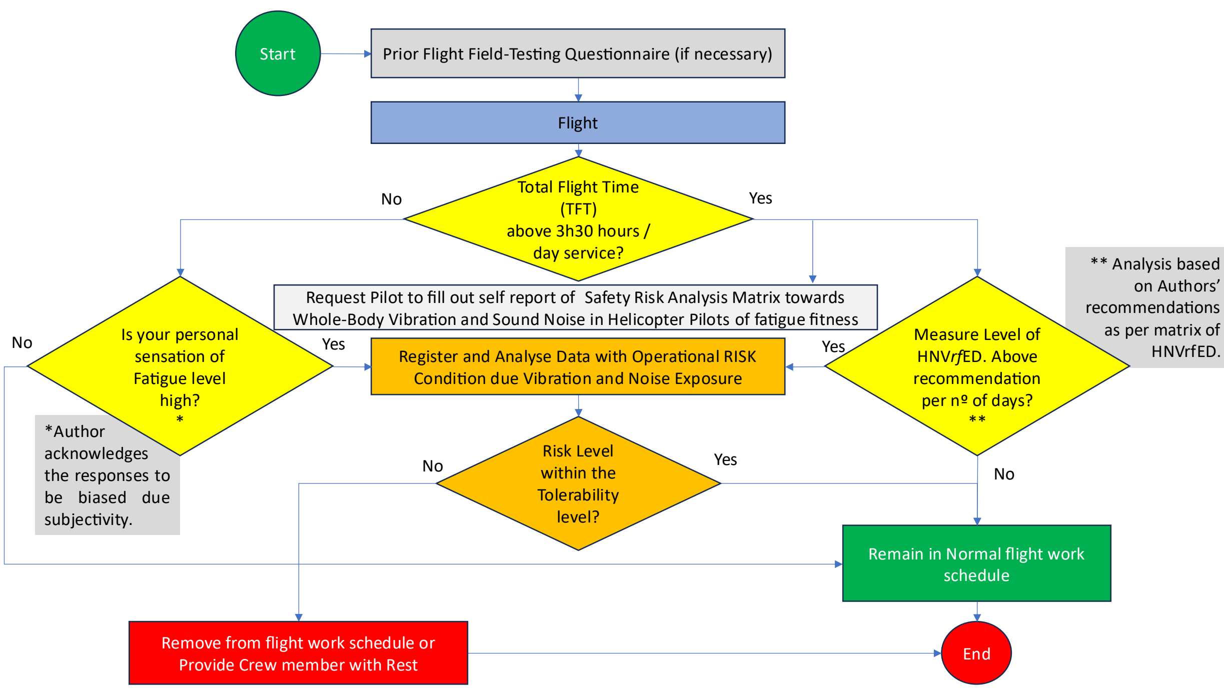
As previously described, Data collection followed the methodology outlined in two schemes:

- General Field-Testing Process Overview (**Flow Chart 2**)
- Field-Testing Data Analysis Process Overview (**Flow Chart 3**)

Flow Chart 2 – Research Methodology – General Field-Testing Process Overview



Flow Chart 3 – Research Methodology – Field-Testing Data Analysis Process Overview



5.2 Vibration and Sound Noise Measuring Equipment

In this sub-chapter, the evaluation of WBV, Noise, and the equipment used to collect data is presented.

5.2.1 Evaluation towards Vibration

Several criteria were used to select the equipment and software, ensuring the vibration measurement was approved. Primary Criteria:

- Capable of recording in dB, m/s^2 and other units
- Portable equipment
- Lightweight
- Easy data recovery
- Data readable
- 3 axes of recordings (Vibrations appearing on the fuselage's axes: *x* (roll), *y* (pitch) and *z* (yaw)

5.2.2 Evaluation towards Sound Noise

On the other hand, several criteria were used to select the equipment, ensuring that sound noise measurement was approved. Primary Criteria:

- Audio Class 1 Certified and Approved
- Capable of recording in dB, m/s^2 and other units
- Portable equipment
- Lightweight
- Easy data recovery
- Data readable

5.2.3 Equipment Used for the Research Study

After observing several equipment and software, the chosen ones were:

- Equipment: Cellphones with the following brands: Samsung S and iPhone 12 and above.
- *Sound Meter Pro (By: Tools Dev)* (for Android and IOS)
- *Vibration Meter (By: Smart Tools)* (for Android and IOS)
- *Vibration Meter (By: Cards)* (for Android and IOS)
- *Vibrometer (By: Exa Mobile)* (for Android and IOS)
- *Resonance – Vibration Analysis Tool* * (for Android and IOS)

*Vibration measurement in the three axes *z, x, y,* and Fast Fourier Transformation (FFT) frequency content analysis. Power spectral density results are calculated from the FFT.

The Sound Meter Pro (*By: Tools Dev) application* allows users to screen record, screen video record, and record and save files. *Vibration Meter (By: Smart Tools)*

The Vibrometer (*By: Exa Mobile*) application enables users to record, screen record, and save triaxial acceleration data on a smartphone device and export it in a CSV file.

The *Resonance – Vibration Analysis Tool also allows users* to screen record and save triaxial acceleration data on a smartphone device.
The *Vibration Meter (By: Smart Tools) and Vibration Meter (By: Cards) applications* allow users to screen record.

NOTE: Several vibration apps were used to identify possible measurement errors.

5.3 Field-Testing

To effectively create an alternative method, as mentioned in Chapter III, for measuring exposure to vibration and noise, it is essential to define the expected outcomes and leverage them for development. This method aims to accurately assess pilots' exposure to physical vibrations and sound, categorising human fatigue based on cumulative exposure to these factors using accelerometer data from a smartphone. The aim is to classify static postures (pilot monitoring) and dynamic movements (pilot flying) using 3-axis accelerometer data within two key activities: pilot monitoring and flying during various flight phases. These activities represent the fundamental static and dynamic tasks that pilots carry out in their daily routines, which are crucial for identifying fatigue levels through accumulated exposure to vibration and noise. This subchapter provides further explanations to clarify the rationale behind exploring alternative methods.

5.3.1 Placement for Data Acquisition

During the analysis of the best locations to place the cell phone, **Illustration 1** shows the identified best locations to quantify the possible pilot sensation of vibration and sound while performing daily activities without jeopardising flight, crews, and passengers, and without posing a safety risk to the operation. Blue dots show the chest, upper arm, thigh and calf areas.

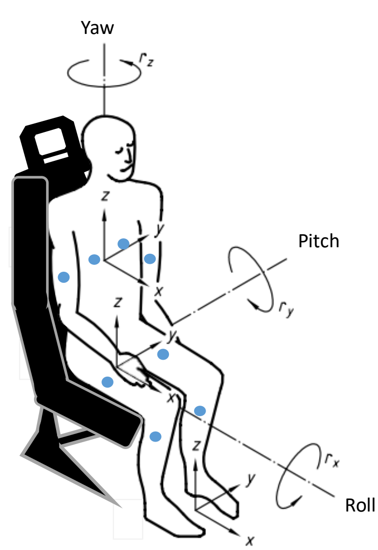
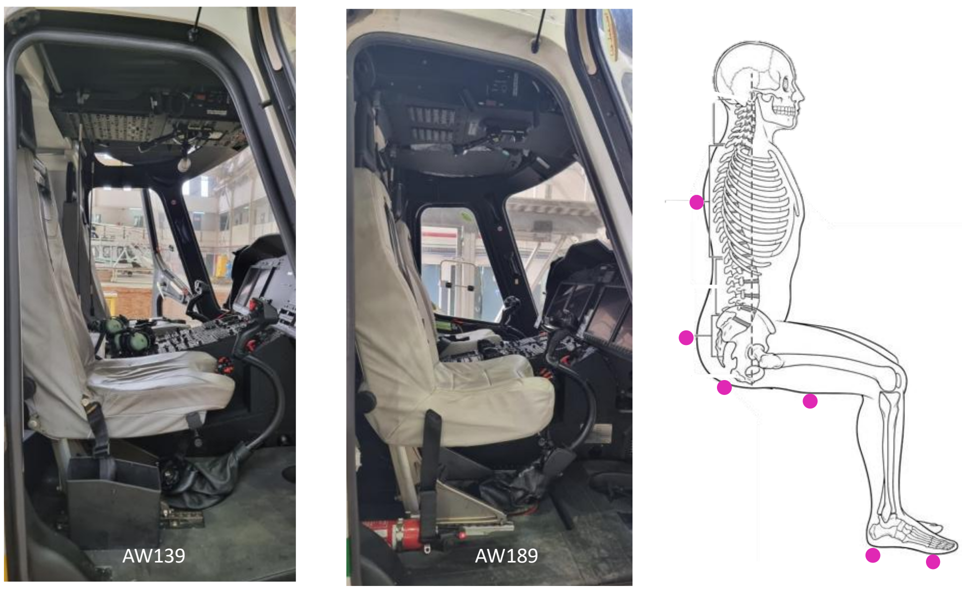


Illustration 1 – Locations identified for the possible placement of the acquisition of Data

Illustration 2 shows the normal seating position for pilot monitoring and a correct lateral viewpoint on the right side of both cockpits for the AW139 and AW189. **Illustrations 2a) and b) show the difference in ergonomics between the seats of the AW139, an older aircraft, and the AW189, a newer design helicopter**, resulting in additional comfort and more rib cage support. Additionally, the seat features a slight upward angle where pilots typically place their legs. **Illustration 2 c)** displays in pink dots the locations normally where the accelerometer circular pads would be placed, referred to in ISO2631, three areas for seated persons: the supporting seat surface, the seat-back and the feet (ISO-2631-1, 1997).



a) b) c)

Illustration 2 – Right lateral viewpoint on both the AW139 and AW189, and Surface Locations identified Pilot Body Contact relative to normal seating position and Vibration felt points on the whole body

Illustration 3 shows both crew flying configurations: pilot monitoring and pilot flying. **Illustration 3 a)** the locations of higher acceleration sensation on the x, y, and z axes **Illustration 3 b)** the red squares indicate the focus on the locations of higher concentration and body sensation towards the transmissibility of vibration to the body resulting in pilot discomfort, pain, and illnesses with long-term exposure both in pilot monitoring position, and **Illustration 3 c)** the Cervical and Thoracic inclination and rotation of pelvis, sacrum, coccyx and the setting bones in slumped asymmetric or circular position resulting in pain and discomfort (Arora & Grenier, 2013; Bongers et al., 1990; Dupuis & Zerlett, 1987; Pope et al., 1985).

Appendix 5 shows a 360º Overview of the pilot's positioning while flying on Controls. Adopting a forward-leaning posture during the flying position, the pilot's stance is slightly twisted and bent to the left. The layout of the cockpit flight controls encourages pilots to adopt this position, influenced by their physical characteristics. Pilots usually rest their right forearms or elbows on their right leg thighs to manage the cyclic stick more effectively. This practice dampens slight hand-arm vibrations and prevents overcontrolling the cyclic when using the force trim release. As a result, the pilots' trunks flex forward, resulting in a semi-circular, slumped, asymmetrical, twisted, leftward-bent position.

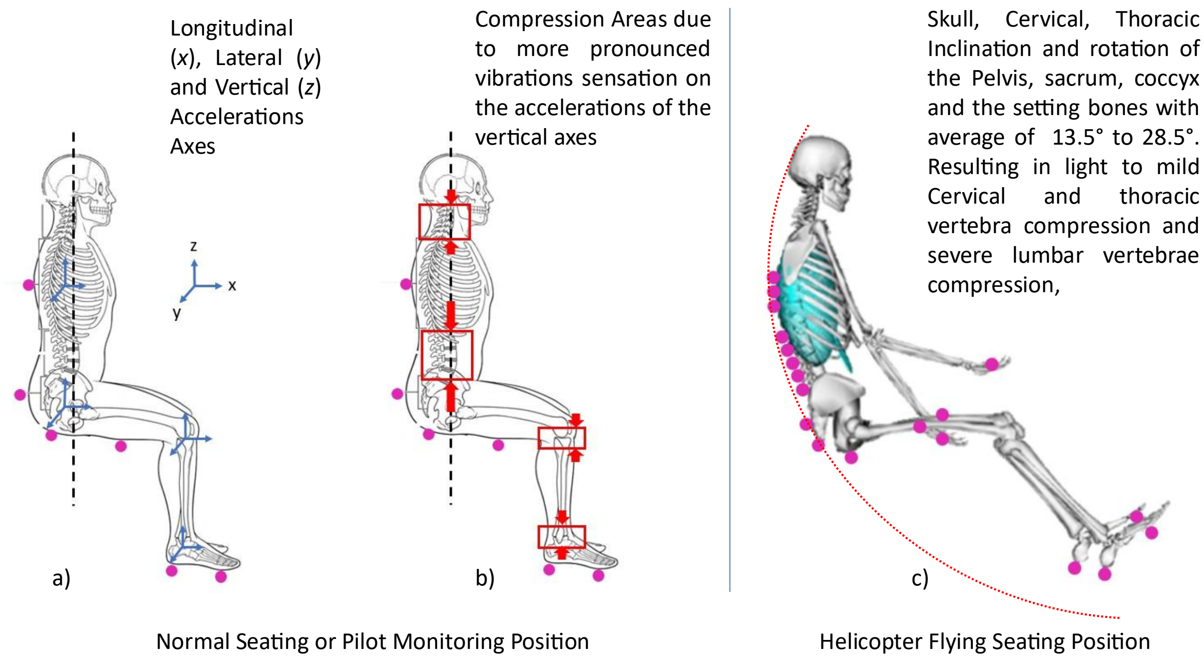


Illustration 3 – Surface Locations of Pilot Transition from Normal Seating Position or Pilot Monitoring to Pilot Flying Position and Body Contact Relative to Whole-Body and Hand-Arm Vibration Felt Points

Note: It is important to mention that the pilot flying may experience more vibration when in contact with cyclic, collective, and pedals.

The Zadon et al. 2021 research study stated the following findings and results: "*In the standing position, in all of the test participants the pelvis was in anteversion (the mean pelvic inclination angle being –16.09° ± 4.99°). In the group of females, the mean pelvic inclination angle amounted to -17.48 ° ± 4.45°, whereas in the group of males, the mean pelvic inclination angle amounted to -14.62 ° ± 5.11°. During the sitting position, the pelvis was in retroposture in 73% and in anteversion in 27% of the test participants (70% being females). The pelvic inclination angle in the sagittal plane was restricted within the range of –25.43° ÷7.90°….. The results-based analysis justified the formulation of the following conclusions:*

• *sitting posture forces a change in the position of the pelvis by on average 21.21° ± 7.44° in relation to the standing posture;*

•*sitting posture may on average increase loads in individual segments of the lumbar spine by 155–184%*

• *it was demonstrated that, during the sitting position, loads (resultant reaction forces in the intervertebral joints of the lumbar spine) affected the trunk inclination angle and pelvic inclination angle: pelvic retroposition* *was responsible for increased loads, the higher the trunk inclination, the greater the loads." (Zadoń et al., 2021).*

Prolonged vehicle sitting causes posterior pelvic tilt, leading to inadequate lumbar spine support for maintaining lordosis, which results in abnormal forces in the lumbopelvic region.

Illustrations 5 and 6 depict the pilot's flying position of the AW189 and AW139, with the left hand on the collective control, the right hand on the cyclic control, and both feet on the pedal controls. The body's inclination, including the pelvis, sacrum, and coccyx rotation, is also illustrated, as these bones are affected by the flying position shown in Illustration 4. According to Panjabi's study, the lumbar vertebrae region is impacted, demonstrating higher pressure between L1 and L3, which may increase the risk of injury to the lower lumbar area and the sacrum (Panjabi et al., 1986). Harrer et al., on the other hand, stated in their research that "Approximately four hours into a seven-hour *mission, both pilots experienced severe middle and lower back pain, which progressed to numbness and tingling sensations in their feet. After landing, both pilots experienced difficulty exiting the aircraft due to poor circulation in their lower extremities. Both aviators experienced severe back pain several hours later while trying to sleep. Evidence shows that insufficient seat pan cushioning causes a pinching of the sciatic nerve. This results in the legs becoming numb followed by paraesthesia (tingling sensation). In addition, a lack of lumbar support in the seat cushion leads to spinal support muscle fatigue*" (Harrer, 2005).

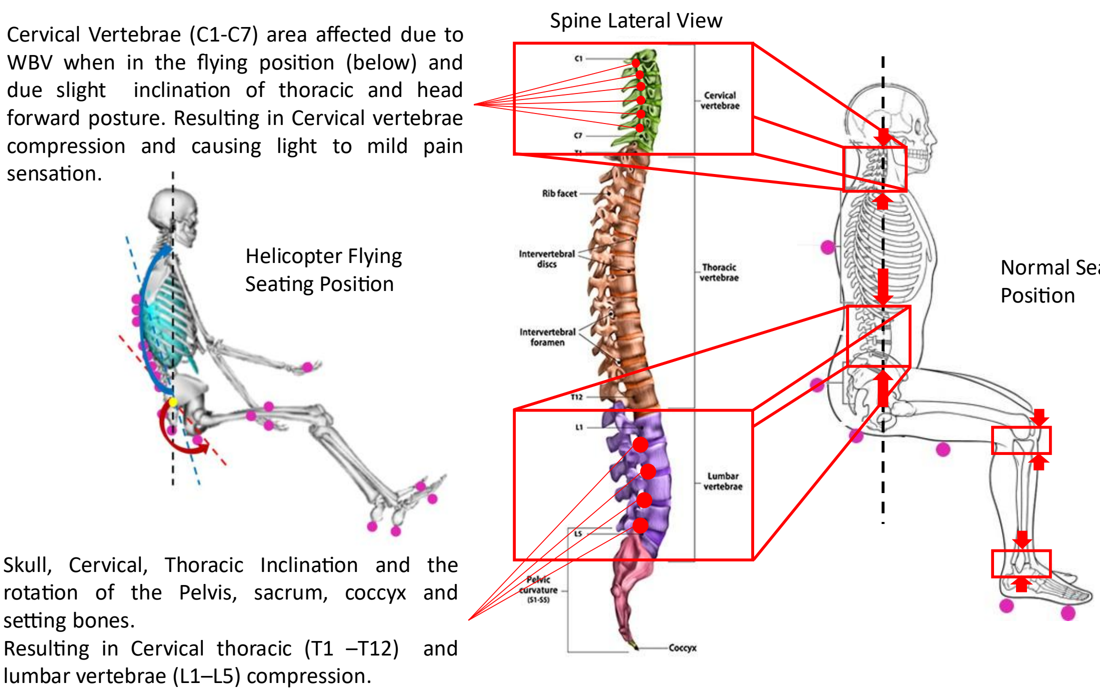


Illustration 4 – Surface Locations identified of Pilot Transition from Normal Seating Position or Pilot Monitoring to Pilot Flying Position and Body Contact Relative to Whole-Body and Hand-Arm Vibration Felt Points. Refer to Chapter II, sections 2.2 and 2.3

The author observed and acknowledged that this rotation may be more pronounced for shorter pilots and less pronounced for taller pilots (assuming that taller pilots have bigger body limbs), resulting in somewhat less or more comfort in an adjustable but limited position of the seat and pedals. **Illustrations 5 and 6** show a slight difference in the seating position while the pilot's hands and feet are on the controls for AW139 and AW189.

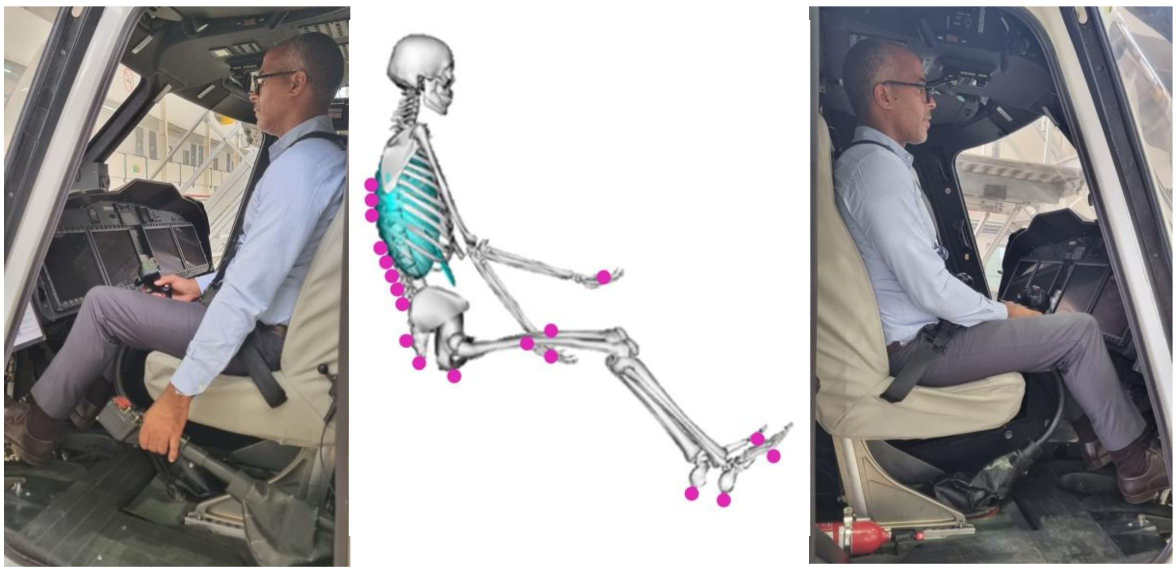


Illustration 5 – Surface Locations of AW189 Pilot Flying Body Contact Relative to Position With Contact of Controls and Vibration Felt Points on the Body

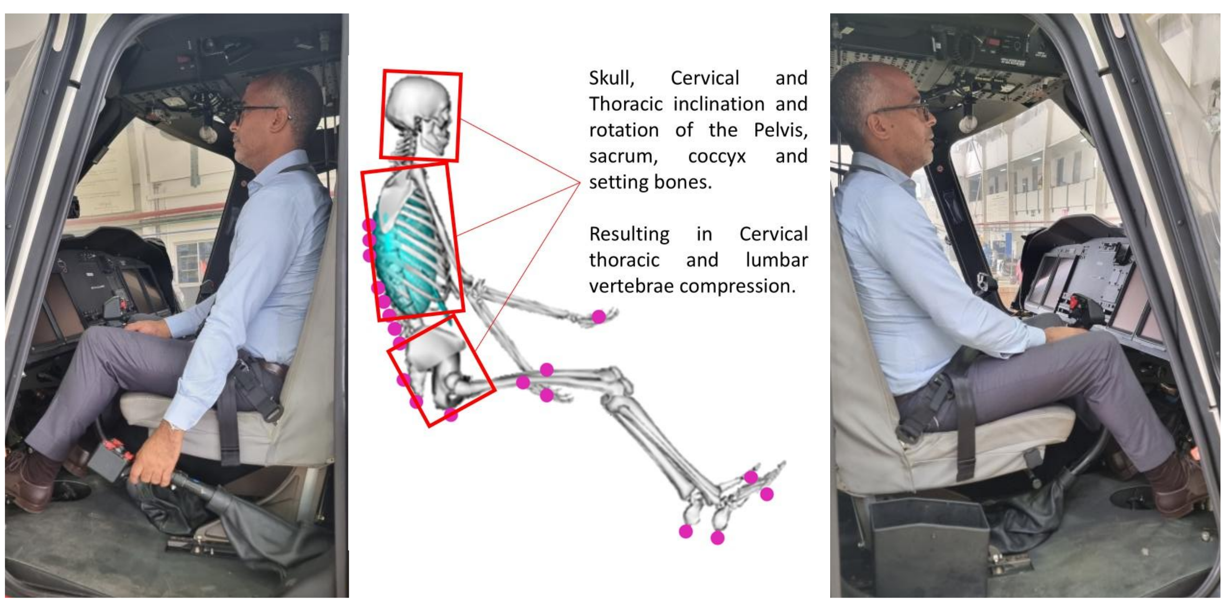


Illustration 6 – Surface Locations of AW139 Pilot Flying Body Contact Relative to Position With Contact of Controls and Vibration Felt Points on the Body

The same can be said in the pilot monitoring position. **Illustrations 7 and 8** below show a slight difference in the seating position compared to the pilot flying position above, with the hand and feet on the controls between AW139 and AW189 feet.

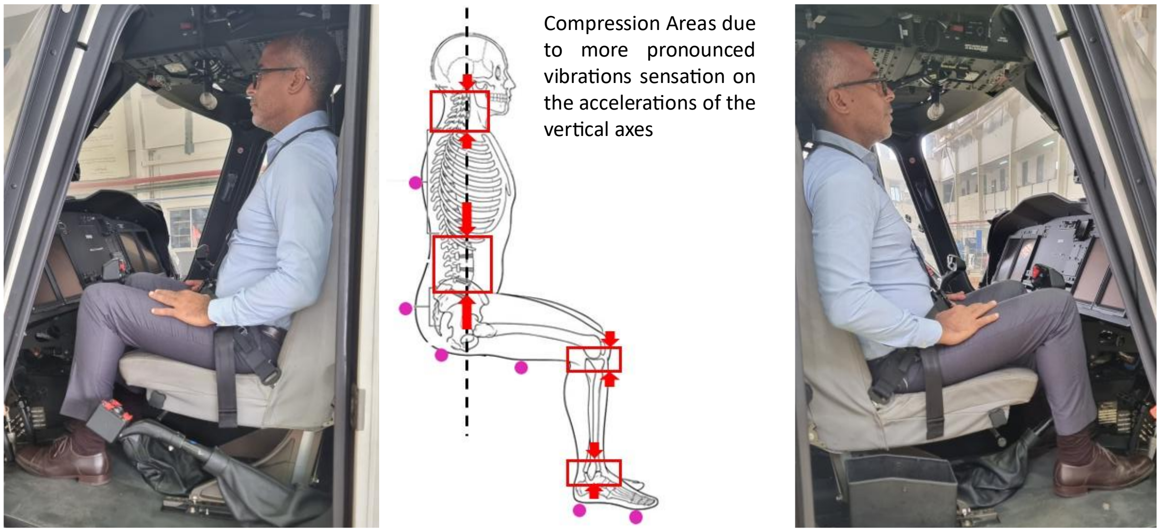


Illustration 7 – Surface Locations of AW139 Pilot Monitoring Body Contact Relative to Position Without Contact of Controls and Vibration Felt Points on the Body

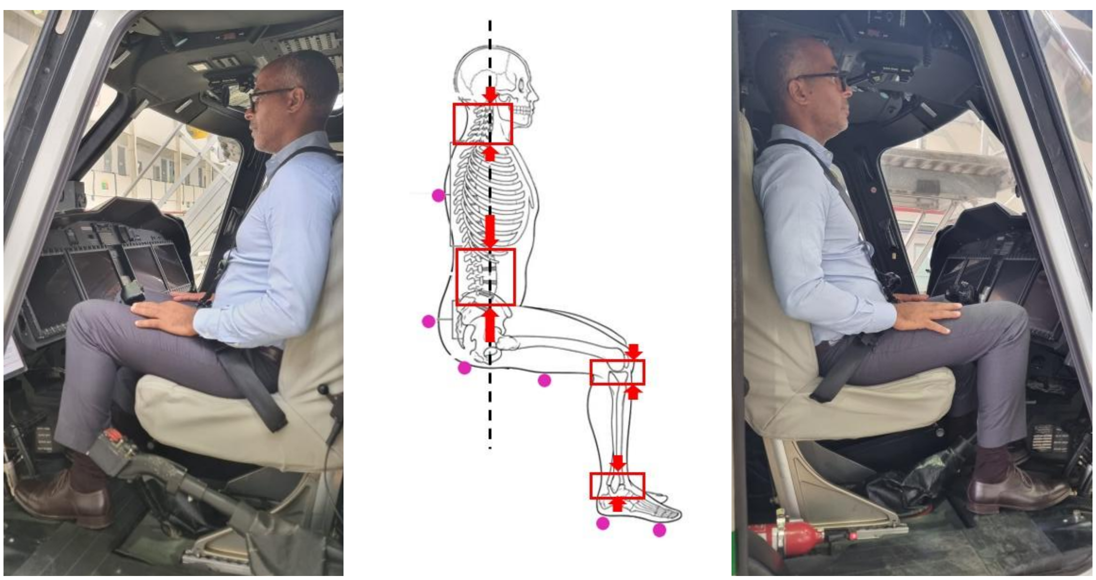


Illustration 8 – Surface Locations of AW189 Pilot Monitoring Body Contact Relative to Position Without Contact of Controls and Vibration Felt Points on the Body

Illustration 9 demonstrates the locations using a fixing support. On the chest, the area would be in the pilot's shirt pocket or in a support vest (**Illustration 9a**), which the pilot could wear in blue dots (**Illustration 9g**). After attempting to use it, it was observed that the MK50 lifejacket (**Illustration 9c**), mandatory for use on offshore flights, would be positioned in front of and on top of the so-called support vest, potentially causing additional interference with the collected signal. Furthermore, the vest was constructed from foam and rubber materials that would attenuate the signal, resulting in some discomfort for the pilots. Because smartphones use lithium batteries, there could be an additional risk to pilots if the phones catch fire during testing. Therefore, the position was deemed unfit due to safety concerns, vibration signal damping, noise muffling, and additional discomfort for pilots. On the arms using the jogging support arm brace (**Illustration 9b**), in the locations in yellow dots, it would be most likely to be better used for hand-arm vibration when the pilot would hold collective and cyclic when Pilot Flying (PF) (hands-on controls) but would have no information when mainly using autopilots and or when Pilot Monitoring (PM).

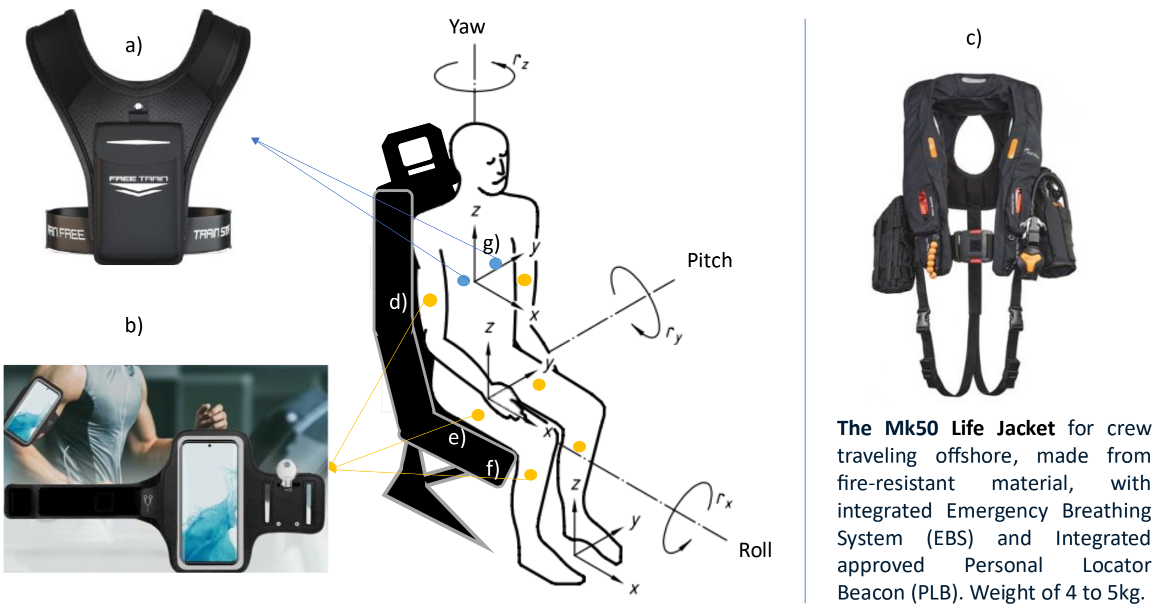


Illustration 9 – Equipment that may Support the Acquisition of Data to Hold Smartphones and the MK50 Life Jacket for Offshore

The risk could be placed on pilots if smartphones caught fire and they were unable to quickly remove the arm brace or the cell phone during testing. For this reason, the position (**Illustration 9d**) was considered unsuitable for commercial or training flights due to safety concerns, vibration signal damping, and sound noise muffling. The lower part of the legs, specifically the calf area (**Illustration 9f**), was also deemed unfit due to limitations in seat belt forward movement, which prevented pilots from controlling the start and end of the measurements being collected. The risk was considered similar to the arm location but slightly lower. Once again, pilots could face risk if smartphones caught fire due to overheating, and they could not quickly remove the arm brace or the cell phone during testing.

The author assumes that measurements taken on the seat with a pad, as specified in ISO 2631, would not accurately reflect the exact values to which pilots are exposed. The main frequency components related to body activities are located between 1 and 20 Hz, while those concerning helicopter vibration are found within the aforementioned range of frequencies and higher. The exact value is assumed to vary because pilots' feet are sometimes on the pedals instead of flat on the floor, and transmissibility varies with individual characteristics. Measurements collected around the calf area are assumed to have higher values due to the feet being in contact with the cockpit floor during pilot monitoring and lower when the pilot is flying with feet on the pedals, which may vary depending on the phase of flight. Measurements collected around the arm are assumed to be lower than those at the calf area during pilot monitoring and higher when the pilot is flying with hands on the cyclic and collective controls. The position was considered unsuitable for commercial or training flights due to safety concerns, vibration signal damping, and sound noise muffling.

The superior region of the legs, the thigh, depicted in **Illustration 9e (above) and Illustration 10 (below)** green and yellow dots, particularly the thigh area situated between the hip (pelvis) and the knee, has been identified as the most appropriate position, owing to the pilot's ability to regulate the commencement and conclusion of the measurements to be gathered.

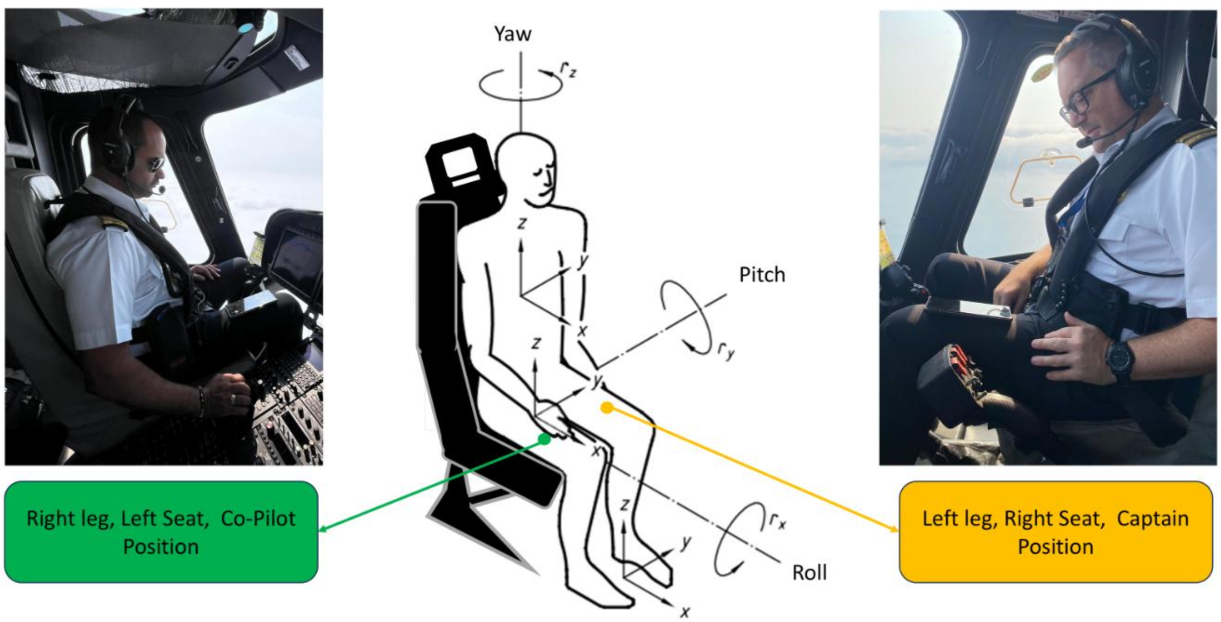


Illustration 10 – In-field Measurement and acquisition of Data (Source: Author´s Creation, Photograph taken by author and flight crew member in offshore flight on the AW189 on the 11th and 25th of September of 2024)

Additionally, due to the smartphone positioning, the three-axial acceleration sensors needed to be placed face upwards to align with the helicopter vibration axis, as previously explained in Chapter III, Section 3.1.3 Smartphone Three-Axial Sensors that Acquire the Acceleration.

Potential issues may arise from the constraints of the seat belt's forward movement, the capacity to swiftly stow the mobile phone, and the options available for deactivating the phone or placing it in a fireproof bag on board the aircraft. Consequently, risks can be effectively mitigated, and it appeared to the authors' knowledge that the data obtained from vertical acceleration via both free contact and seat contact would yield optimal data acquisition, considering the multiple points of contact the pilot would encounter while functioning as either Pilot Flying (PF) or Pilot Monitoring (PM). To ensure that the vibration signal would not be lost due to damping from the foam material of arm/leg brace, the decision was to measure without the arm/leg brace and use the phone placed on the thigh while in cruise and stable flight; also, to avoid the cell phone's microphone from having sound noise muffling, the same criteria were used. Because it was necessary to assure signal quality from the external environment and also a comparable value between crew and data collected from previous or future in-flight field testing, the co-pilot (left positioned inside the cockpit of the helicopter) would collect data on the right thigh and captain (right positioned inside the cockpit of the helicopter) would collect on the left thigh with cell phone facing the pilots. The central column between both pilots was not to be in contact with the pilot’s legs when measuring to avoid higher values with another contact point. Pilots were informed of this, and video recordings and pictures confirmed the pilots' compliance.

The 3-axis accelerometer data was collected from the user’s smartphone, placed on the subject's thigh, and transmitted via Bluetooth, WhatsApp, or email. The raw data was then transmitted to a remote computer, where processing, classification, and analysis occur. This results in two main subsystems: 1) the smartphone data collection device and 2) the remote processing and analysis unit. The acquisition of raw data occurs on apps and data collection devices installed on smartphone platforms, specifically on Android and IOS devices.

The proposed method is tailored for individual monitoring or observation, meaning that the vibration and noise measurements are designed for a single user. However, it can also be implemented for various users, such as a flight crew. This allows the research to focus on comparing two main activities and how accurately they classify each activity. This could lead to a classification technique based on a combination of results, providing an average outcome.

5.3.2 Participants and Sampling

The population study included 53 operational offshore helicopter pilots in Angola, working for both the state-owned company SonAir and the privately owned company BestFly. Due to the activities, a rigorous selection had to be made. Only 18 subjects were initially invited, and 7 more were added to support field testing used within the companies mentioned above. In total, 25 Pilots participated in the field testing. All subjects in the companies were male pilots. The selected demographic features included individuals between 30 and 65 years old, with a minimum of 500 hours of offshore experience and a qualification in type and flying on the AW139 and AW189. It is non-probabilistic, with convenience sampling comprising two companies that provide services to the offshore oil and gas industries. The pilots in this study are all class 1 aircrew medically certified, CPL or ATPL H crew licensed. The helicopters selected for this study were from Leonardo's Italian Manufacturer fleets, specifically the AW139 and AW189. To determine the sample size for a given level of accuracy in field measurements during a minimum of 3 months in flights that voluntary pilots had scheduled. In the worst-case scenario, a minimum acceptable sample size was identified: 15 leg flights, ideally 25 per fleet, with the AW139 and AW189 requiring 30 to 50 leg flights each. The reason was that fatigue can be subjective, and several factors contribute to fatigue levels with only a general level of accuracy; therefore, having vibration and sound noise values would directly contribute to understanding pilots' exposure to both. The confidence level used for this research was 95%, with a corresponding confidence interval (margin of error) of ±4. The author chose this audience because of being part of the workforce and intends to identify the levels of vibration and noise exposure associated with the two main causal factors of pilot fatigue. Thus, it is relevant to consider fatigue and rest management for all operators and to make management decisions to achieve the best rotation scheme.

5.4 Data Collection: Measurements and In-Flight Procedures.

For this experiment, the test procedure was kept simple. It only included one activity performed in the pilot monitoring position during the cruise phase of flight, after operational cruise checks had been completed. Measurements were conducted in cruise flight in autopilot configuration (hands-off controllers).

This is because having a fixed sequence of activities for each subject could pose safety issues, given the varied tasks (such as monitoring flight parameters and measuring vibration and noise) and loose objects, similar to daily activities.

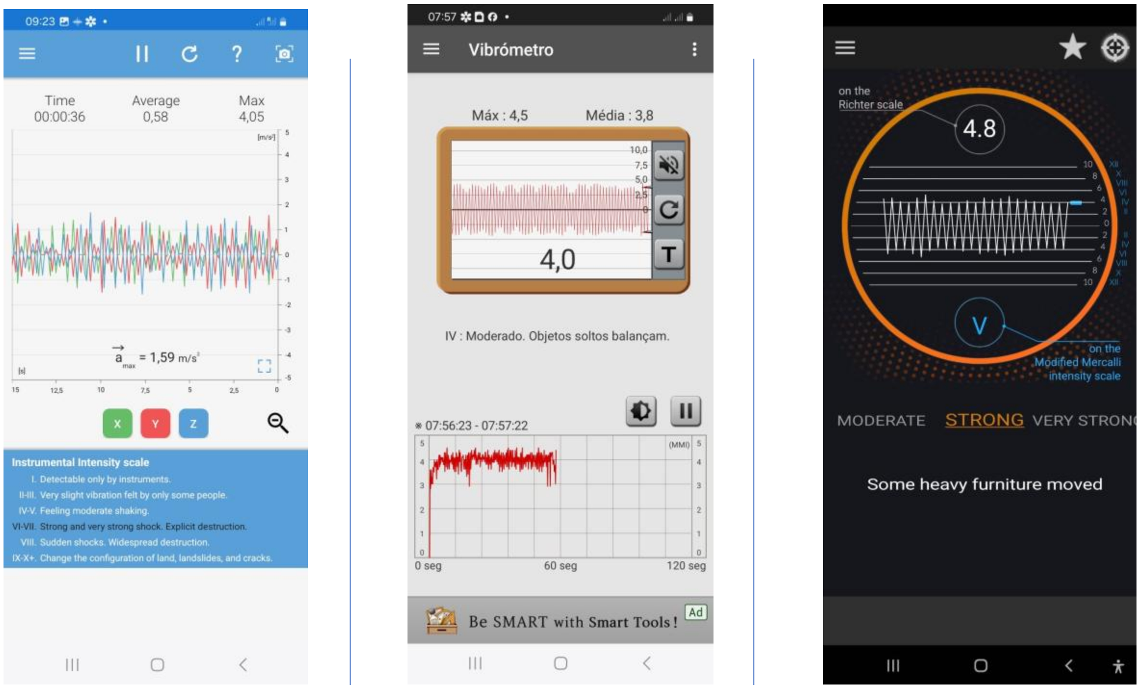
The activity lasted for a designated time frame of 30 seconds (s). Consequently, the test subjects performed measurements for 30 s in each app. The Co-pilot and Captain positions were recorded during the outbound leg to the offshore installation and the inbound leg back to the base airport for the initial 15 flights. Following this, a single measurement per flight was taken to assess variations in the collected data or notable differences between pilots' positions. Nevertheless, participation was exceptional, with 95% of the flight readings successfully obtained from both sides of the cockpit (captain and co-pilot positions) and during both legs of the flights. This significantly facilitated data collection, especially given the limited number of flights and the selection of pilots for this purpose.

The in-field measurements were compared with previous and future flights to identify possible errors. The technique used was smartphones and installed apps. It was conducted for at least 30 s to deem the sample valid. For accuracy, the recording could be reduced to 25 s during the analysis phase to ensure no activity change occurred while handling the smartphone and stopping the measurement. Initially, the pilot recorded or photographed the primary flight display to retain pertinent information for analysis, as shown in **Figure 37**.

Figure 37 – Measurement conducted on Samsung S21 Ultra reference measurement of AW189

Figure 37 is a reference measurement of AW189 on 03.09.2024 on the co-pilot side. The image on the left shows an altitude of 3500 feet and an indicated airspeed (IAS) of 130 knots, as recorded on the Primary Flight Display (PFD). The figure on the right shows the Main Flight Display (MFD), also on the co-pilot side. Both measurements were conducted in cruise flight with the autopilot engaged at different points in flight.

Vibration data was collected using apps such as the Vibrometer and Vibration Meter, powered by *ExaMobile* and Smart Tools (**Figure 38**). The author utilised the Resonance Vibration Analysis Tool in **Figures 38b and 38c** during some AW189 flights to grasp the eventual significance of the data difference. However, data collected from any flight was not used for this research, as shown in the two pictures below, which are of an app powered by Flutter. **Figure 38** shows vibration measurements in flight of AW189 on 28.11.2024 on the RIGHT LEG, co-pilot side. **Figure 38a)** was captured at 3500 feet altitude and 130 Knots of indicated airspeed (KIAS) using the Vibration Meter App **Figure 38b)** was also on RIGHT LEG, co-pilot side with image on the right at 1000 feet altitude and 130 KIAS with vibrometer app at 1000 feet, all conducted in cruise flight with autopilot engaged and in different periods in flight time. **Figure 38c)** Vibration Meter app measuring earthquake on the Richter and Mercalli Scales on an in-flight reading on an **AW139** at 7000 feet with 135 KIAS with autopilot engaged in cruise flight on the 23/09/2024.



a) b) c)

Figure 38 – Vibration Measurement

Another app, the Vibration Meter powered by Cards, measured earthquake vibration on the Richter and Mercalli scales. It was then converted using **Equation 1** (Conversion of Acceleration to Decibels below) and the **Conversion Table in Appendix 3** from Acceleration to Decibels. This app was primarily used with subjects who used iPhone cellphones or a combination of the three apps, as shown in **Figure 38c**.

$$a = 10^{\left(\frac{dB - dBref}{20}\right)} \times 9{,}81 \qquad (1)$$

The acronyms represent the following:

a	Acceleration in m/s²
dB	dB value from data collected from the Helicopter
dBref	120 dB the human being's auditive limit region

Note: Ref 1: 100 dB equals 0,98 m/s²; **Ref 2**: 0 dB equals 0,00001 m/s².

The three apps were used to identify reading differences and mitigate reading errors. Several live videos, **Figures 37 and 38**, were recorded in flight using the Sound Meter Pro App, the video recording function on the primary and main flight displays (PFD and MFD), and the Flight Management System (FMS) of AW189 and AW139. Relevant information was collected during the recordings, such as altitude, indicated air speed, ground speed, wind speed, heading, route and engine parameters, date, and time. Also, print screens of displays were collected in **Figures 37, 38 and 39**.

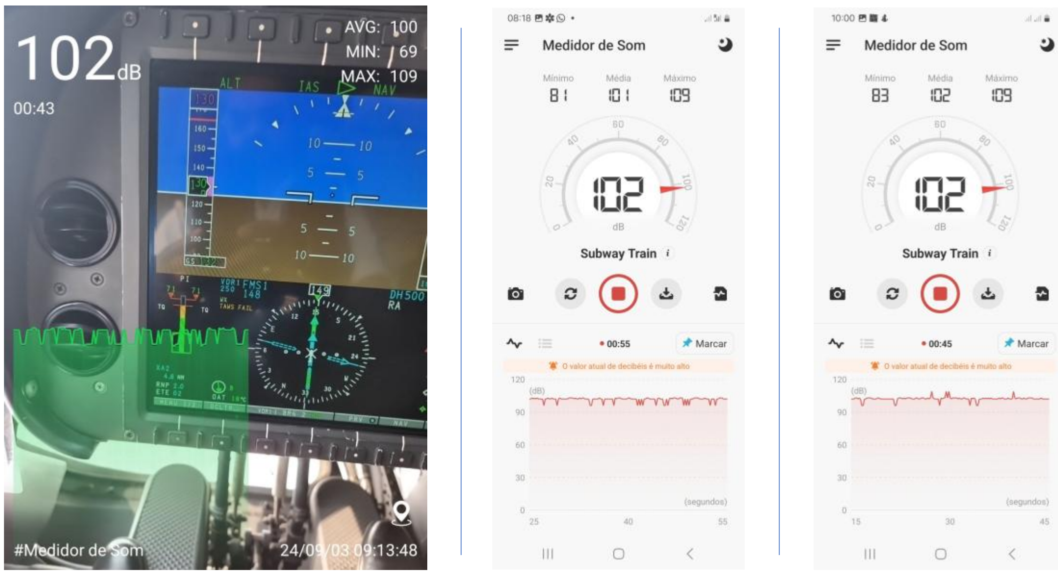
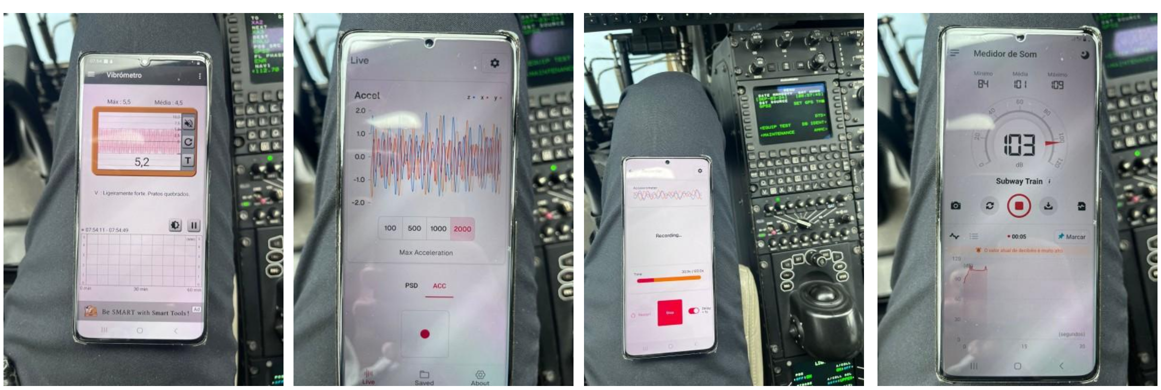


Figure 39 – Measurement conducted on Samsung S21 Ultra of AW189 co-pilot side with Sound Meter Pro

Figure 40a was recorded with the app Vibration Meter, Resonance Vibration Analysis Tool, Figures 40b and 40c, and Sound Meter Pro apps, Figure 40d, in cruise flight with autopilot engaged, with different periods in flight.



a) b) c) d)

Figure 40 – Measurement conducted on Samsung S21 Ultra of AW189 co-pilot side

5.4.1 Data Acquisition

The author used two methods for data collection: a survey and in-flight field measurements. In the first method, the Author used a survey resource (Google Forms) through a questionnaire, a total of 21 questions, some drawn from previous studies from the Sleep Condition Indicator – By Colin Espie, University of Oxford, Offshore Pilot Aviation Survey and NEMSPA Sleep and Fatigue Survey (Arianna Haffington, 2016; Gregory et al., 2010; Teixeira, 2020) .

The advantage is that it can quickly determine the likelihood of Age, Height, and the calculation of Body Mass Index as contributors to apparent and estimated fatigue levels, shift schemes, and the relationship between day and night, as well as rostering preferences for consecutive days of work, understanding, and predictive whole-body vibration dose exposure. It can rapidly determine the comfort levels of pilots after exposure to vibration and noise in flight, even after several hours of work per day.

The disadvantage of this approach is that reports may exhibit bias due to their reliance on subjective interpretation. Nevertheless, the author contends that this variability is acceptable, as it varies across pilots.

In the second method, the Author performed additional in-flight measurements conducted on offshore flights using smartphones and commercial applications.

The advantage is the ability to self-test with one's phone. Additionally, built-in motion sensors, as referred to in 3.1.3, offer an accuracy above 93% in smartphones when using only the smartphone accelerometer's y and z axes, during physical activities (Javed et al., 2020).

The disadvantage is that different readings may occur when smartphone brands and qualities vary. Additionally, the equipment's sensitivity may vary slightly between smartphones. Still, it is assumed to have a dispersible value across both brands of equipment competing for market share.

5.4.2 Demographics, Questionnaire and Field Research

The respondents were rotor-wing pilots operating in a two-pilot (multi-crew) environment, primarily in offshore activities. To measure the body mass index and explore the possible correlation between being overweight and the potential for further fatigue resulting from fixed seating positions in flight, slower metabolism, and lower daily body energy levels. The author asked about the participants' age, gender, weight, and height.

Based on the research study, the most appropriate methods included a set of questions formulated for all individual voluntary pilots and a field research study that measured real-life flights.

Advantages included selecting active crew members, allowing for both main functions, such as Co-Pilots/First Officers or SIC (Second in Command), and Captains or PIC (Pilot in Command), within companies. Such ability will promote enhanced comprehension of the crew's awareness of fatigue, age demographics, differing heights, varying weights, and diverse flying experience measured in hours.

Disadvantages: There are not many female pilots, and understanding in these fields of expertise may become more complicated for a complete human (male and female), clear understanding, limited to the author's known contacts that are willing to participate, reliability in external out-of-control subjects may be subject to process interference, and error may be above required margins.

The following questionnaire summary (**Table 13**) explains the demographic, professional, and criteria variables. It is composed of three parts, each with associated questions.

Table 13 – Questionnaire Summary.

Variables	Location	Item Sample
Demographics	**PART I**	
1. Age	**Demographic**	**1 – 4**
2. Gender	**Information**	
3. Weight		
4. Height		
Professional	**PART II**	
1. Pilot License	**Professional**	**5– 13**
2. Medical license	**Information**	
3. Helicopter Type Rating		
4. Number of Hours		
5. Main Role in the Organisation		
6. Pilot Headset with ANC		
Criteria Variables:	**PART II**	
1. Fatigue (Sleep)	**Sleep Quality and**	**14 – 21**
2. Rotation Scheme	**Fatigue**	

To measure exposure to WBV and noise, which directly impact pilots' fatigue and hearing loss (HL), the author asked pilots to report their pilot license, medical license, helicopter type rating, number of hours, and primary role within the organisation. To evaluate exposure to WBV and noise levels affecting pilots' HL that may lead to fatigue, and to understand their awareness of fatigue, the author inquired about pilots' headsets, fatigue, and self-reports on current sleep habits and quality.

The author acknowledges that different helicopter models and manufacturers may have varying values for WBV and SN, as multiple factors can yield variable results —for example, blades, engines, structural materials (metals and composites), cabin insulation, etc. However, this study was not particularly focused on other helicopter models and utilised only the AW139 and AW189. The author also recognises that several factors contribute to HL, including not wearing protective equipment on the ground, on the airport ramp, or outside the helicopter with the rotor running for short periods while on the helideck or helipad in offshore installations and vessels. Pilots using different headset models from different manufacturers may experience varying noise reduction. Additionally, poor ear care or high noise exposure during social activities—such as positioning near speakers at concerts, nightclubs, bars, or parties, using high-volume earphones, or even cleaning ears with cotton swabs—may also influence fatigue levels and HL.

5.4.3 Procedures

1—Volunteer pilots were invited to participate in the real-flight measurement in commercial offshore flights. Participating subjects were invited to respond to a 21-question online survey. The online survey used Google Forms between January 6th and March 3rd, 2025.

2—Engineering collected data from each flight related to the helicopter models AW139 and AW189 for FDM and VHM (Vibration Health Monitoring) analyses. If any relevant data is acquired that may affect the vibration reading, it will be reported, and the files will be deleted from this research study.

3—All data related to helicopter vibration information was referenced to specific flights where subjects were on work duty flying the helicopters.

4—Pilots who used the app referred to in 5.2.3 were to send the information from the app to the author's email, WhatsApp, or exchange via Bluetooth after each flight.

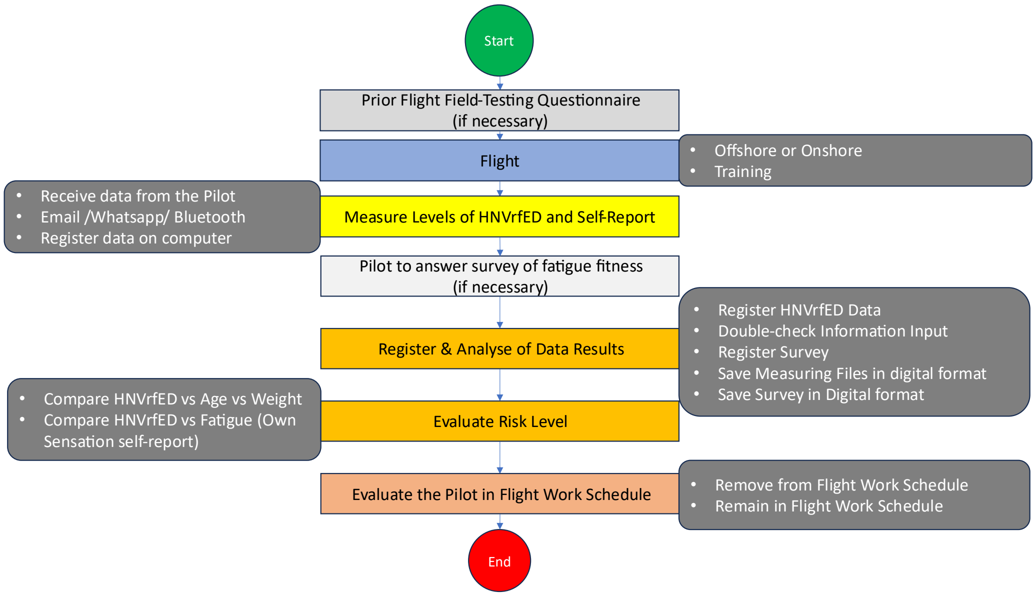
5—The author carefully analysed measurements. Valid data were recorded for this study, and any slight differences identified as false readings or incorrect procedures, based on images and videos recorded from each volunteer, were eliminated.

NOTE: Data was discarded whenever there was insufficient flight information and or recording was below 30 s.

5.4.4 Data extraction method from measuring Equipment

The method of extraction is as follows in the chart Description:

Flow Chart 4 – Data extraction method from measuring equipment



The type of flight is separated into two phases: training and commercial.

Phase 1 - Onshore or Offshore Training Flights

- Base Check,
- IFR or
- Night Rig

Phase 2 - Onshore or Offshore Commercial Flight

- Controlled Airport – Controlled Airport
- Controlled Airport – Offshore Installation – Controlled Airport

5.4.5 Period of Data Collection

The data collection period was set to last between 1 and 6 months, depending on the number of flights scheduled for the subjects. Once sufficient awareness of relevant information was achieved for the study's objectives and data collection, the process would only be paused after reaching the minimum period. The data collection goal was defined as 25 to 50 flights.

5.4.6 Data extraction method from pilot exposure

After each flight was registered, analysed, and saved, the file was named and coded with the aircraft's tail number, date, altitude, and indicated airspeed in knots (KIAS) to prevent duplicate information when downloading to the computer.

5.4.7 Instrument

The iPhone and Samsung smartphone brands, along with the installed apps mentioned in Section 5.2.3, were used as field-measuring equipment to collect data on vibration and noise exposure during flights.

The data was sent to the author via WhatsApp or email. The data was either manually transferred from the smartphone to the laptop via Bluetooth, sent via WhatsApp or email.

Note: Grouios et al used similar brands and make models (Grouios et al., 2023)

5.4.8 Initial Numerical Analyses Matrix of HNVED and Tolerable Level of Pilot

Based on the equation presented below in Teixeira, C., 2020, regarding Helicopter Noise and Whole-Body Vibration Estimated Exposure Dose (HNVED) in conjunction with a variant of (a) for multiple acoustic sources in decibels (dB), the Safety Risk Analysis Matrix for WBV and HL in Helicopter Pilots, and the Performance Risk Chart for HL & WBV Daily Exposure will determine the tolerability level. Teixeira's study introduced **Equation 2**, Helicopter Noise and Whole-Body Vibration Estimated Exposure Dose (HNVED), which relied on estimated, known, and calculated values derived from manufacturing and ISO 2631-2018. Consequently, a correction was necessary to distinguish the estimated value from the actual flight values.

$$HNVED = (dB_{total}) \times TFT \tag{2}$$

$$HNVED = \left[10 \times log\left(10^{\left(\frac{manfAvg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{manfAvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{3}$$

Therefore, from the proposed ***Equations 2 and 3,*** the Decomposed Equation of HNVED (Teixeira, C., 2020). *An* adaptation or recreation of it was proposed below in ***Equations 4*** Helicopter Noise and Whole-Body Vibration Manufacture Estimated Exposure Dose (HNVmfED)***, Equations 5*** Helicopter Noise and Whole-Body Vibration Real Flight Estimated Exposure Dose (HNVrfED) and ***Equations 6*** Decomposed Equation of HNVrfED*,* and used for this research study. To interpret the difference, the decomposition needed to be explained:

$$HNVmfED = \left[10 \times log\left(10^{\left(\frac{manfAvg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{manfAvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{4}$$

$$HNVrfED = (dB_{total}) * TFT \tag{5}$$

$$HNVrfED = \left[10 \times log\left(10^{\left(\frac{Real\,Flight\,Avg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{Real\,Flight\,AvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{6}$$

The new acronyms represent the following:

HNVED	Helicopter Noise and Whole-Body Vibration Exposure Dose
HNVmfED	**Helicopter Noise and Whole-Body Vibration Manufacture Estimated Exposure Dose**
*manfAvg*ND (dB1)	The average manufacture value of Noise Dose. Value is calculated from the sum of all the minimum and maximum values from the TCDSN reference TAKEOFF, OVERFLIGHT, and APPROACH and divided into three (3). **Note:** Helicopter noise levels, depending on age, model, and size category, typically range from 85 to 115 dBA.
*manfAvg*VD (dB2)	Is the average manufacturing value of Whole-Body Vibration Dose or the value obtained from HUMS on a helicopter **Note:** When no value is obtained, 95,73 dBA shall be used as the estimated average reference value per ISO 2631-2018.
HNVrfED	**Helicopter Noise and Whole-Body Vibration Real Flight Estimated Exposure Dose**
*REALFLIGHT Avg*ND (dB1)	This is the average **Noise Dose exposure in Real Flight, recorded using a sound-measuring** app for at least 30 seconds. **Note:** The value used from the app is the average over the 30 seconds in Cruise flight only, not the maximum value obtained at a single point in helicopter real-flight measurements.
*REALFLIGHT Avg*VD (dB2)	It is the average **whole-body vibration dose, measured in the Real Flight recording, for magnitude or acceleration over 30 seconds during** a cruise flight ONLY. **Note:** The Value is then calculated into dB using the conversion table in Appendix 3,
TFT	Total Flight Time in hours (Note: Expressed in decimal)

HNVrfED calculations are based solely on cruise flights and do not account for the periods of increased vibration and noise exposure that occur during landing and take-off. The exposure dose for this time frame is measured as part of the total flight time (TFT), and the author acknowledges that these values can be significantly higher. Since this flight phase is considered critical and demands the full attention of all crews for safety reasons, these phases were excluded from this study, despite manufacturers recognising them as moments of heightened vibration and noise.

Converted Richter scale magnitude to decibels based on the conversion **Equation 7**

$$\text{dB} = 20 \times \log_{10}(A) \tag{7}$$

Based on the Converted Richter scale magnitude to decibels, Equation 7, an adaptation or recreation is presented in **Equation 8** for Real Flight Average Vibration Dose

$$REALFLIGHTAvgVD = 20 \times \log_{10}(A) \qquad (8)$$

(A) is the average value obtained from the vibrometer app of the amplitude of the seismic waves during a captured recording of a minimum of 30 seconds?

Offshore Training Flights Analysis

None were executed; therefore, all analyses were conducted in accordance with the company's standard operating procedures for commercial flights.

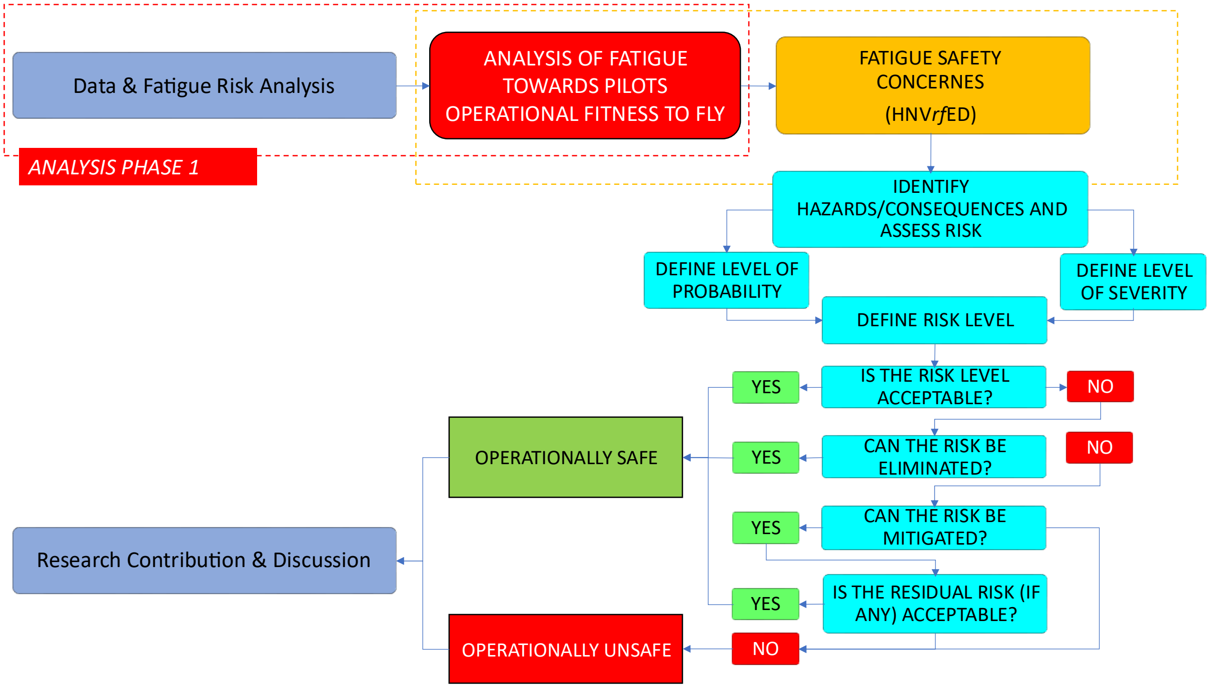
5.5 Data Analysis of In-Flight Data Collected and Pilot Fatigue Levels

This sub-chapter divides the data analysis into three phases: initial, intermediate and final. No dates were set for each phase, and the analysis was conducted based on the time the author could draw relevant conclusions within the available time between flights, training, etc., and the rostering schedule's ON/OFF periods.

As previously described, Data analysis followed the methodology outlined in two schemes:

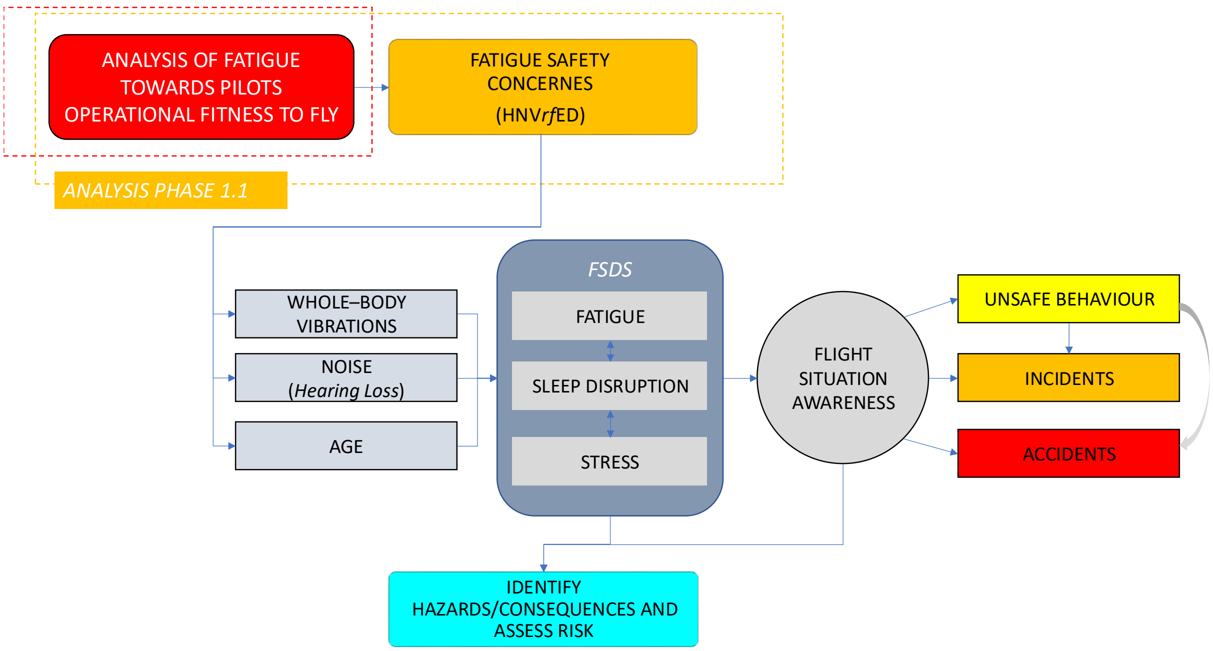
- Analysis of Fatigues towards Pilots' Operational Fitness to Fly (**Flow Chart 5**)
- Fatigue Safety Concerns (**Flow Chart 6**)

Flow Chart 5 – Research Methodology – Analysis of Fatigue towards Pilots' Operational Fitness to Fly (Source: Adaptation from Research Methodology Revised with Safety Risk Management Analysis (Teixeira, C., 2020)



Flow Chart 5 presents the overall general view. Upon data collection, fatigue is analysed to determine the pilot's operational fitness to fly based on Helicopter Noise and Vibration Real Flight Exposure Dose. With levels identified as high or low from the reference obtained from Teixeira, C.'s 2020 study, analysis of concerns of Fatigue, Sleep Disruption, Stress, and Situation Awareness is conducted (**Flow Chart 6**).

Flow Chart 6 – Research Methodology – Fatigue Safety Concerns (Source: Adaptation of "The Proposed relationship between WBV, Noise (HL) and Age with in-flight SA and unsafe behaviour, incident/accident" (Teixeira, C., 2020)



Flow Chart 6 provides an overview of the HNVrfED fatigue analysis and its associated safety concerns. Although previous studies have emphasised that pilots start to have "*back and leg pain after two to four hours into flight, and this pain increases with time….. Crews reported that after flying a full day….. the pain took several hours to subside or in some cases lasted one to two days after landing"* (Harrer, 2005). Yet despite facts and evidence presented, aviation safety and health specialists have not proposed recommendations for change in the exposure limits. It analyses and considers the initial safety level, being safe whenever below the reference of 6 hours and 15 minutes of flying time (Teixeira, C., 2020). The hazard and risk are then identified and measured for severity and probability in a quick Yes or No assessment, as shown in **Flow Chart 5**. The outcome provides relevant information to determine the operational safety level.

The information is collected to identify relevant facts for the Research Contribution and Discussion. The author assumes that the daily limit value is influenced by helicopter vibration and noise exposure, which could lead to lower daily exposure limits and potentially avoid costly medical treatments, surgeries, and lost working days for pilots and operators.

5.6 New Proposed Equipment Philosophy and Design

The equipment design was developed based on a philosophy inspired by the 6th-generation iPod, featuring a clean and user-friendly presentation layout. The author presents PILVISOUVEX (Pilot Vibration Sound and UV Exposure), a proposed measuring device designed for creation and sale to operators or crews. The goal is for all pilots to carry and monitor Vibration, Sound and possibly Ultraviolet ray levels to provide information on exposure. The author has developed this concept concerning the design and characteristics of equipment relevant to a prospective Phase 2 advancement of the existing research project. This advancement aims to enhance data acquisition, informed by research, highlighting the need for comprehensive information over time to improve aviation safety standards, particularly concerning Flight Risk Management Systems (FRMS) and rostering schemes.

PILVISOUVEX is split into physical measuring equipment and accessories:

1. PILVISOUVEX Hardware (**Illustration 11**)
2. PILVISOUVEX Software (**Illustration 12**)
3. PILVISOUVEX Nomex Gloves (**Illustration 13**)
4. PILVISOUVEX Pilot Seating Pillow (**Illustration 14**)
5. PILVISOUVEX 3 in 1 Fast Charger Pad (**Illustration 16**).

5.6.1 PILVISOUVEX Hardware – Characteristics & Equipment Design

Equipment Characteristics

- Reduced size (shirt pocket)
- Lightweight (recycled rubber casing)
- 16h to 24h of autonomy, GPS antenna
- Bluetooth
- 4x Class 1 microphones
- Vibration Sensor (3-axis accelerometers)
- USB-C and Wireless charging capability
- 64G microSD memory card
- WI-FI 4G or 5G antenna
- Automatic email sending after disconnection.
- ISO 2631 -1,2 and 5/ 5349/ 5805/ 8041/ 1999
- Lithium battery
- Data acquisition measures 2000 x 3 samples per second, enabling vibration measurement within a frequency range of 0.5 to 2000 Hz.
- Reading via Android or IOS app available for free on Google Play™ or Apple App Store

Metric Modes

- Vibration: RMS, Peak, Min, Max (x, y, z, & Σ)
- Hand-arm: RMS, Peak, Min, MTVV, A(1), A(2), A(4), A(8) (x, y, z & Σ)
- Whole-body: RMS, Peak, Min, MTVV, A(8), A(8)Exp, EP, VDV (x, y, z & Σ)

Frequency Weight

- Vibration: Fa (0.4 Hz to 100 Hz), Fb (0.4 Hz to 1250 Hz), Fc (6.3 Hz to 1250 Hz)
- Hand-arm: Wh
- Whole-body: Wb, Wc, Wd, We, Wf, Wj, Wk, Wm
- Measurement Units: m/s^2, cm/s^2, ft/s^2, in/s^2, g, dB

Historical Record by Time

- Storage Interval: 1, 2, 5, 10, 20, 30 s; 1, 2, 5, 10, 20, 30 min; 1 hr
- Saved Values: RMS and peak for x, y, z & Σ

Equipment Design

Illustration 11 demonstrates the equipment in front, back, bottom, top, lateral and interior views.

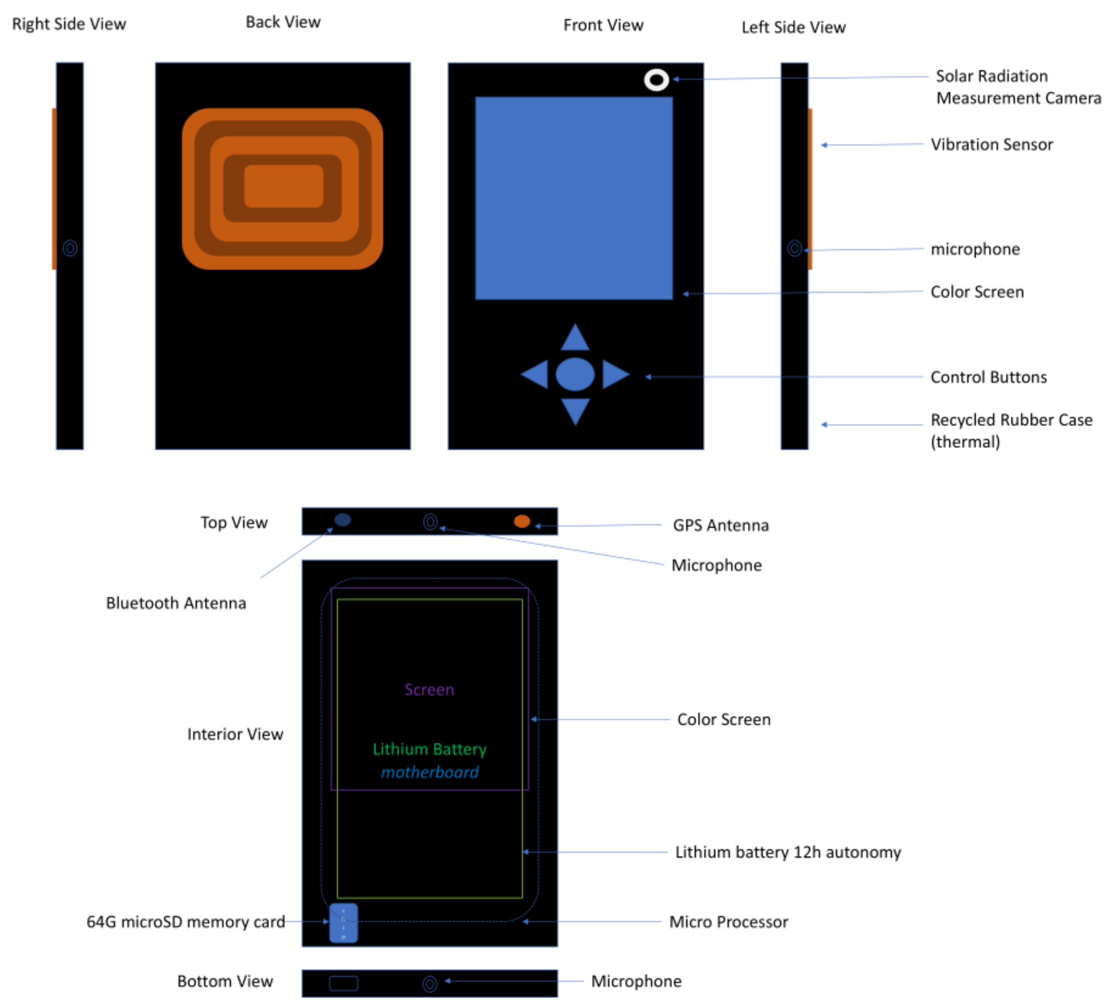


Illustration 11 – PILVISOUVEX Front, Back, Top, Bottom, Lateral and Interior View

5.6.2 PILVISOUVEX Software - Menus & Functions

The software has a self-test before use and five additional display screens per **Illustration 12.**

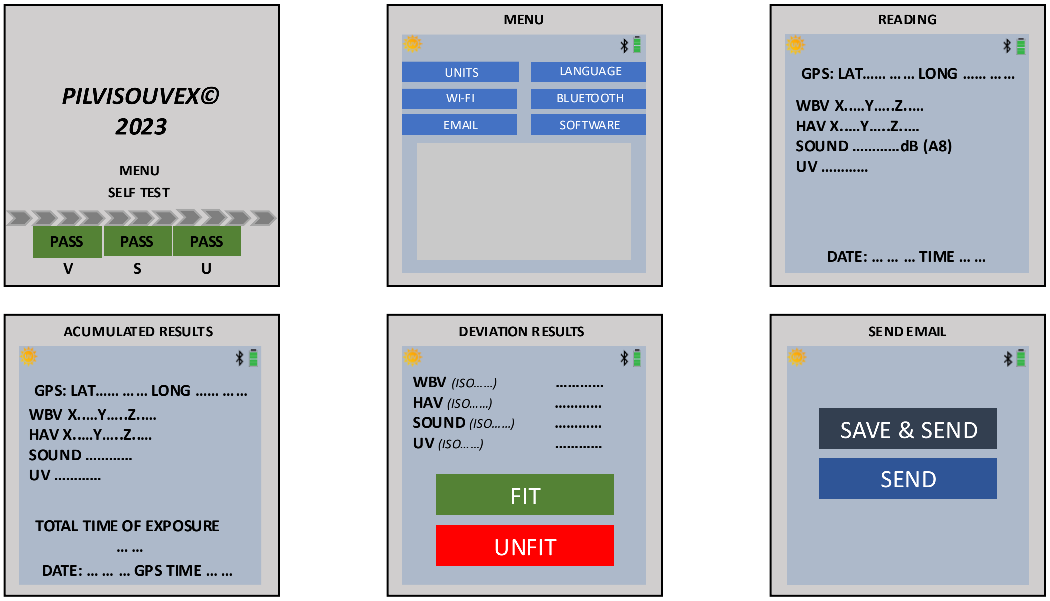


Illustration 12 – PILVISOUVEX Menus 1 to 6

5.6.3 Equipment Accessories

To support the PILVISOUVEX, the equipment utilises auxiliary accessories for more accurate measurements, which can be applied in other industries, such as mining, drilling, and transportation (jobs like forklift drivers, truck drivers, and train drivers), where the nature of their work activities causes similar fatigue effects on the body. They are:

1. PILVISOUVEX Nomex Gloves (**Illustration 13**)
2. PILVISOUVEX Pilot Seating Pillow (**Illustrations 14 & 15**)
3. PILVISOUVEX 3 in 1 Fast Charger Pad (**Illustration 16**).

5.6.3.1 PILVISOUVEX Nomex Gloves

Characteristics PILVISOUVEX Nomex Gloves

- Light
- Comfortable
- Lithium Micro Battery with 8 hours of Battery Life
- Bluetooth Antenna
- Vibration Sensor
- Wireless Charging
- ISO 2631 -1.,2 and 5/5349/5805/8041 Certificate
- Measurement between 0.5 Hz and 2000 Hz

Illustration 13 shows the layout of the Bluetooth antenna and the sensor used to measure hand-arm vibration while the pilot operates the collective and cyclic controls during hands-on flying.

Illustration 13 – PILVISOUVEX Nomex Gloves

NOTE: EarPod Philosophy

5.6.3.2 PILVISOUVEX Pilot Seating Pillow

Characteristics of the **PILVISOUVEX Pilot Seating Pillow**

- Light
- Comfortable
- Lithium Micro Battery with 8 hours of Battery Life
- Bluetooth antenna
- Wireless Charging
- Vibration Sensor
- ISO 2631 -1.,2 and 5/5349/5805/8041 Certificate
- Measurement between 0.5 Hz and 2000 Hz

Illustration 14 illustrates the arrangement of the Bluetooth antenna, microprocessor, battery compartments, and vibration sensors employed to measure whole-body vibration while the pilot is seated.

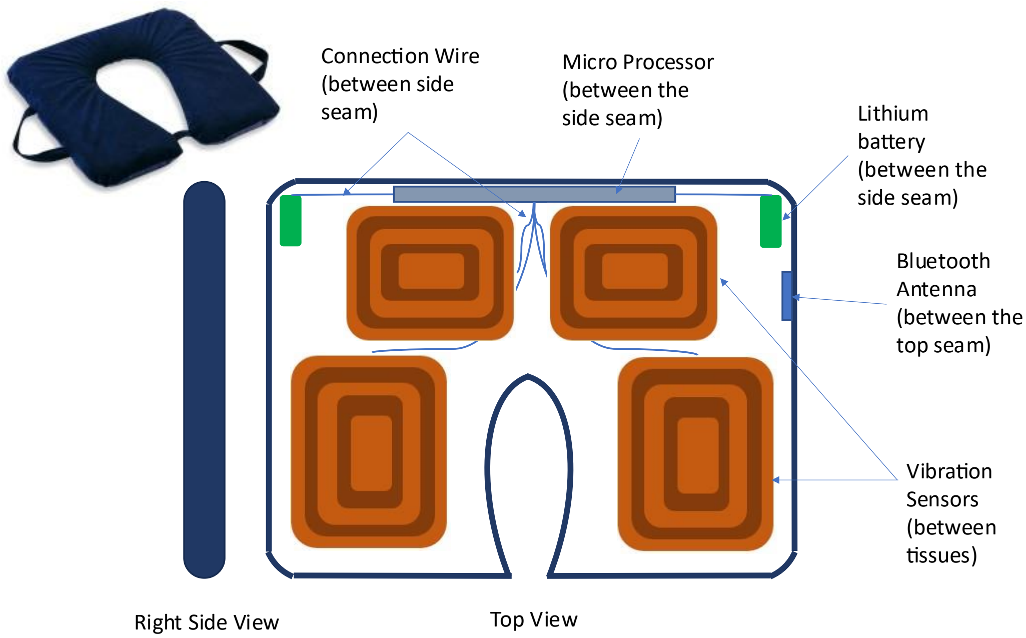


Illustration 14 – PILVISOUVEX Pilot Seating Pillow

Illustration 15 shows the arrangement and positioning of the seating pillow on the pilot's seat. This pillow measures whole-body vibration while the pilot is seated.

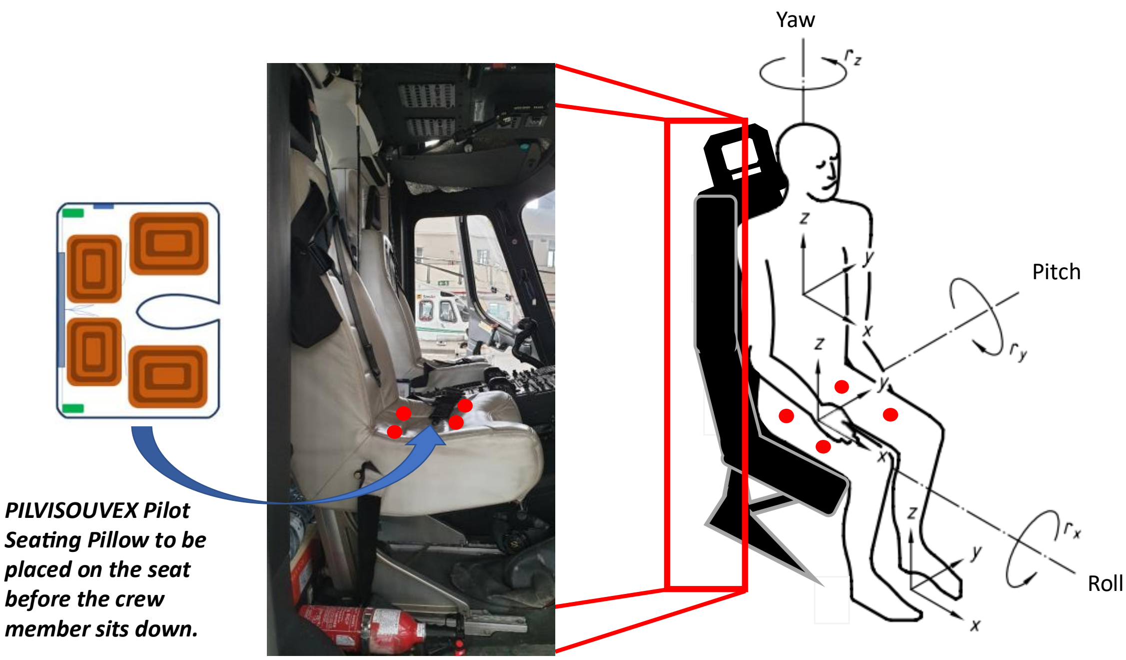


Illustration 15 – PILVISOUVEX Pilot Seating Pillow Positioning Configuration on AW189 (Source: Adaptation (Teixeira, C., 2020)

5.6.3.3 PILVISOUVEX Fast-Charging Pad

Illustration 16 shows the arrangement of the Fast-Charging Pad, along with all its equipment and accessories.

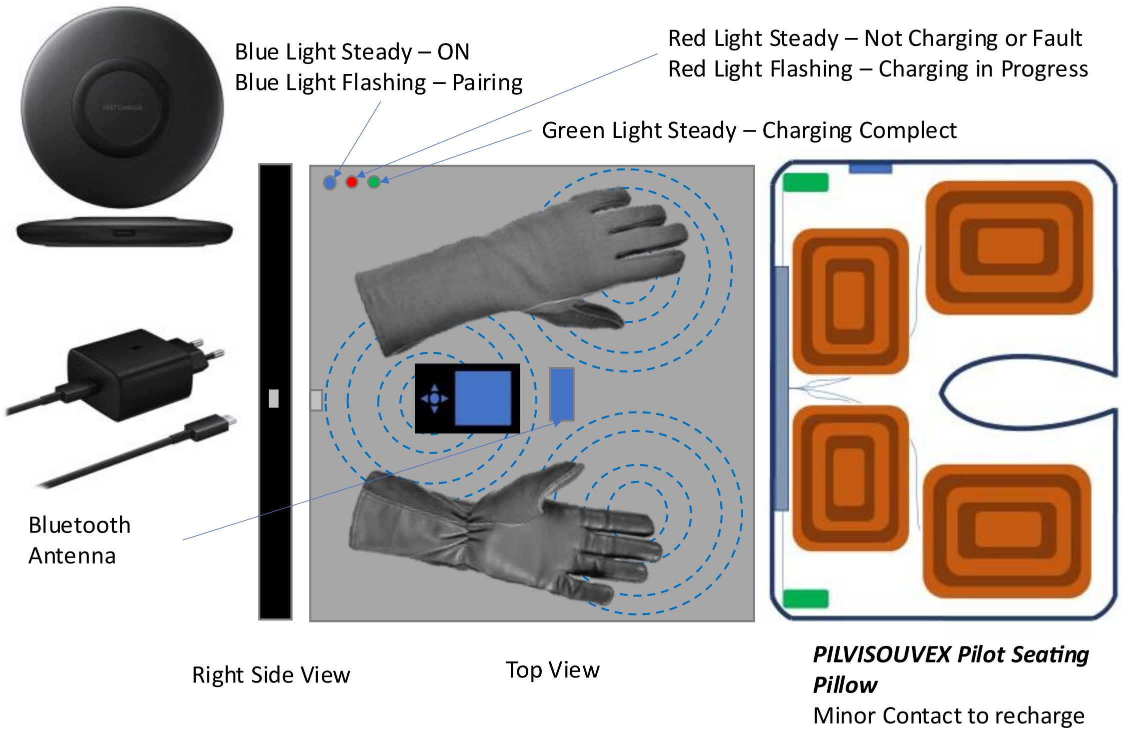


Illustration 16 – PILVISOUVEX Fast Charging Pad

Characteristics of PILVISOUVEX Fast Charging Pad

- Bluetooth Antenna
- 3 Indication Lights (Blue, Red, Green)
- Wired charging Cable

NOTE: Wireless charging technology.

Chapter VI Result Analysis

The following chapter outlines the data collection, survey, in-flight experimental field-testing measurements, and data analysis. It is divided into two parts: Part I addresses the survey data, and Part II discusses the data obtained from in-flight measurements and their analysis.

PART I

This section details the data gathered through survey applications and the analysis of the selected sample. A total of **18 valid responses** were obtained, covering 100% of the carefully chosen population sample, which included **two operational companies**. Additionally, seven subjects were invited to assist with the final phase involving in-flight data collection; these subjects did not complete the survey. Part 1 provides the statistical analysis, sample characterisation, professional details, shifts, fatigue, sleep indicators, and a summary of the findings.

6.1 Statistical Analysis

The statistical analysis involved descriptive statistics (absolute and relative frequencies, means, and respective standard deviations) and inferential statistics. Inferential statistics were extrapolated using Spearman's rank-order correlation coefficient (ρ), for ordinal and nonparametric data, and Cramer's V (Φ) coefficient for categorical association. The significance level for rejecting the null hypothesis was set at $\alpha \leq 0.05$ (two-tailed) All Statistical analysis was performed using IBM SPSS (Statistical Package for the Social Sciences) version 30.0 software.Qualitative variables were presented as *N* and percentages (%), and quantitative variables were reported as means (*M*) and standard deviations (*SD*). According to the convention used to determine statistical significance, the p-value was set to ≤ 0.05 (5%) in statistical hypothesis testing. This means that if the p-value were less than or equal to 0.05, the results would be considered statistically significant, suggesting that the null hypothesis should be rejected.

6.2 Sample Characterisation

Table 14 presents the sociodemographic characteristics of 18 male helicopter pilots. The average age was 46.3 years (SD = 9.8), ranging from the youngest at 33 to the oldest at 62. The average weight was 89.5 kg (SD = 13.6), ranging from a minimum of 72 kg to a maximum of 122 kg. The average height was 1.76 m (SD = 0.06), ranging from the shortest at 1.68 m to the tallest at 1.90 m. The Body Mass Index (BMI) stood at 28.6% (SD = 2.8), ranging from 25.21% to a maximum of 33.80%. Approximately 66.7% were classified as overweight and 33.3% presented with Class I obesity. The BMI distribution is similar to the Truszczynska et al. study, which also involved helicopters (Truszczynska et al., 2012)

Table 14 – Sociodemographic Characterisation (N = 18)

	M	SD	N	%
Gender				
Female			0	0
Male			18	100
Age (M;SD)	46.3	9.8	18	100
Weight (M; SD) (kg)	89.5	13.6	18	100
Overweight			*12*	*66.7*
Type I obesity			*6*	*33.3*
Height (M; SD) (m)	1.76	0.06	18	100
BMI (M; SD) (%)	28.6	2.8	18	100

M - Mean, SD – Standard deviation

The sample shows a homogeneous, middle-aged profile with elevated BMI levels, typical of professional pilots due to a prolonged period of seated time. Nearly all participants fall within the overweight or mildly obese range.

6.3 Professional Information

In professional terms, **Table 15** shows that most pilots held an Airline Transport Pilot licence (61.1%). Generally, all pilots were medically classified as Class 1 fit. **Tables 16 and 17** show that pilots frequently flew an AW139 Helicopter (55.65%).

Table 15 – Pilot License & Medical License Class 1.

	N	%
Airline Transport Pilot license (ATPL (H))	11	61.1
Commercial Pilot License (CPL (H))	7	38.9
Total	18	100
Annually Fit	17	94.4
Annually Fit (with Restrictions)	1	5.6
Total	18	100

All participants were fully certified and active. The predominance of ATPL holders reflects extensive professional experience and high levels of training.

Table 16 – Helicopter Type Rated (mostly fly).

	N	%
AW139	10	55.6
AW189	7	38.9
OTHER	1	5.6
Total	18	100

More than half the pilots primarily flew the AW139, followed by the AW189. These two aircraft types accounted for 94.5% of respondents' fleet exposure.

Table 17 pertains to dually rated pilots (those holding multiple type ratings) who are permitted to fly both types on different days. The average flight hours in the most utilised helicopter was 1,336, while the average flight time was 7,383 (**Table 18**).

Table 17 – Dually type rated.

	N	%
AW139	8	44.4
AW189	1	5.6
S76	2	11.1
OTHER	7	38.9
Total	18	100

Almost half of the respondents (44.4%) were dual-rated on AW139 plus another type. Dual qualification enhances operational flexibility but may increase workload variability.

All pilots held a valid type rating at the time of the survey and during in-flight data collection. **Table 18** shows the experience levels of the pilots who flew the aircraft, detailing their type ratings and total flying experience. The less experienced pilot, who flew and conducted testing, had only 100 hours of flight time on the type, as he was newly rated on the aircraft. In comparison, the most experienced pilot had a total of 18,000 hours of flying experience.

Table 18 – Hours on type mostly flown and Total Hours of Flying Experience.

	Minimum	Maximum	M	SD
Nr. of hours on type mostly flown (M; SD)	100	4500	1366.4	1492.4
Nr. of total hours (M; SD)	1174	18200	7383.5	5728.5

M - Mean, SD – Standard deviation

Flight experience varied substantially, from newly rated pilots to veterans. The large standard deviations confirm high heterogeneity in experience level.

Table 19 shows the relationship between the main role of pilots in the organisation; the majority served as captains (55.6%), while only 38.9% acted as co-pilots or second in command.

Table 19 – Main Role in the Organisation.

	N	%
Main Role		
Co-Pilot (SIC)	7	38.9
Captain (PIC)	10	55.6
Instructor (LTC/TRI/TRE)	1	5.6

The majority of pilots held the rank of Captain, consistent with the high prevalence of ATPL licenses. A small fraction acted as instructors, highlighting senior expertise.

As shown in **Table 20**, approximately 61% of the pilots used Headphones or Headsets equipped with Active Noise Cancellation during flights.

Table 20 – Headphones with Active Noise Cancellation

	N	%
No	7	38.9
Yes	11	61.1
Don’t Know	0	0
Total	18	100

Over 60% used active noise-cancelling headsets, which can mitigate auditory fatigue and improve in-flight comfort and communication.

6.4 Shifts

In **Tables 21, 22, and 23**, concerning shifts, respondents typically worked consecutive shifts of 3 or 4 days in most instances (38.9%). The minimum rest period between alternating day and night shifts was 24 hours in most cases (66.7%), as was the transition from night to day shifts (66.7%).

Table 21 – How many consecutive DAY shifts do you typically work?

	N	%
1 or 2	3	16.7
3 or 4	7	38.9
5 or 6	6	33.3
≥ 7	2	11.2
Total	18	100

Table 22 – How long are you typically OFF when transitioning from DAY to NIGHT shifts?

	N	%
24 hours	12	66.7
2 to 3 days	3	16.7
4 to 5 days	1	5.6
6 to 7 days	1	5.6
greater than 7 days	1	5.6
Total	18	100

Table 23 – How long are you typically OFF when transitioning from NIGHT to DAY shifts?

	N	%
24 hours	12	66.7
2 to 3 days	3	16.7
4 to 5 days	1	5.6
6 to 7 days	1	5.6
greater than 7 days	1	5.6
Total	18	100

The predominant rest period of 24 hours may limit physiological recovery between shifts. Only a minority benefits from rest intervals exceeding two days.

6.5 Sleep Quality

As shown in **Table 24**, the same 24 hours are necessary to feel rested and remain alert during the day (66.7%).

Table 24 – How much sleep do you typically require to feel completely rested and alert during the day?

	N	%
5 to 6 hours	3	16.7
7 to 8 hours	14	77.8
> 8	1	5.6
Total	18	100

Nearly 78% of pilots reported needing 7–8 hours of sleep to feel completely rested and alert. This aligns with aviation fatigue management guidelines.

6.6 Fatigue

Fatigue impacted pilots' flight performance in two primary ways, as shown in **Table 25**: performance degraded (38.9%) and alertness degraded (27.8%).

Table 25 – In what ways has fatigue affected your flight performance?

	N	%
Alertness degraded	5	27.8
Alertness degraded;	1	5.6
Can´t concentrate	1	5.6
Can´t concentrate; Alertness and Performance degrade	2	11.1
Performance degraded	7	38.9
Alertness and Performance degraded	2	11.1
Total	18	100

Performance degradation was the most reported effect (38.9%), followed by alertness issues. These results indicate subjective awareness of fatigue symptoms among pilots, though without operational refusals.

Pilots reported that they rarely (44.4%) or Occasionally (27.8%) catch themselves "nodding off[4]" during a flight, as shown in **Table 26**. Surprisingly, no one (100%) has ever turned down a flight due to fatigue, as shown in **Table 27**.

Table 26 – "Nodding Off" during Flight.

	N	%
Never	4	22.2
Occasionally	5	27.8
Rarely	8	44.4
Somewhat frequently	1	5.6
Total	18	100

Almost three-quarters acknowledged occasional or rare episodes of microsleep ("nodding off"), an important fatigue risk indicator in aviation operations.

Table 27 – Have you ever turned down a flight due to fatigue?

	N	%
No	18	100
Yes	0	0
Total	18	100

Despite reported fatigue symptoms, none of the pilots had ever refused a flight, possibly due to cultural, organizational, or operational constraints.

6.7 Flight Hours and Body Under the Influence of Fatigue

By analysing pilots' opinions on self-reporting their sense of safety before they feel fatigued after flying for a certain number of hours, over 16% believe this occurs between 3 and 4 hours. However, the majority, 50%, reported that it happens after 5 to 6 hours of flying, while 33.3% reported between 7 and 8 hours, as shown in **Table 28**.

[4] *The term "nodding off" is an informal expression commonly employed to denote an individual who inadvertently drifts into sleep or momentarily closes their eyes. This phenomenon typically occurs during activities such as sitting or observing visual content.*

Table 28 – When flying, how many hours would you consider safe before you feel your body is under the influence of fatigue?

	N	%
3 - 4 hours	3	16.7
5 - 6 hours	9	50.0
7 - 8 hours	6	33.3
Total	18	100

Half the pilots perceived 5–6 flight hours as safe before fatigue onset, while one-third cited 7–8 hours. The perceived endurance aligns with standard operational duty limits in rotary-wing aviation.

6.8 Correlations

A nonparametric Spearman's (ρ), and Phi (Φ) coefficients were calculated to examine correlation between BMI and fatigue variables, questions 18 and 21 presented in **Table 29**, as well as the correlation between age and fatigue variables, questions 13, 17, 18, and 21 shown in **Table 30**, and the correlation between Helicopter Type Rated and fatigue variables, question 21 in **Table 31**. No correlations reached statistical significance ($p > .05$). Results are summarised below.

Table 29 – Correlation of BMI Vs Q18 and Q21. (N = 18)

	Spearman's (ρ)	p-value	Interpretation
In what ways has fatigue affected your flight performance?	-.011	.967	NA
When flying, how many hours would you consider to be safe before you feel your body is under the influence of fatigue?	.091	.718	NA

NA- No Association

NOTA: With N = 18 observed, the power ≈ 30 % for a medium effect ($\rho \approx .35$); $n \geq 70$ is required for 80 % power.

Both correlations were very weak and not statistically significant, indicating no clear link between BMI and pilots' subjective fatigue reports or their estimates of safe flight duration before fatigue sets in. This lack of meaningful correlation may imply that, among this uniform professional group, body mass differences do not impact how fatigue is perceived or endurance levels.

Table 30 – Correlation of Age Vs Q13, Q17, Q18 and Q21. (N = 18)

	Spearman's (ρ)	p-value	Interpretation
Headphones or Headsets used in flight are equipped with Active Noise Cancellation?	-.022	.931	NA
How much sleep do you typically require to feel completely rested and alert during the day?	-.355	.148	Weak negative, not significant
In what ways has fatigue affected your flight performance?	-.258	.301	Weak negative, not significant
When flying, how many hours would you consider to be safe before you feel your body is under the influence of fatigue?	-.190	.450	Weak negative, not significant

NA- No Association

NOTA: With N = 18 observed, the power ≈ 30 % for a medium effect ($\rho \approx .35$); $n \geq 70$ is required for 80 % power.

The negative correlations suggest a slight trend where older pilots report needing less sleep and experiencing fewer fatigue effects. However, this pattern is not strong enough to make definitive conclusions. It is possible that increased age-related experience and adaptation to operational demands reduce perceived fatigue, but this remains speculative due to the limited sample size.

Table 31 – Correlation of Helicopter Type Rated vs Q21. (N = 17)

	Cramér´s V (Φ)	p-value	Interpretation
When flying, how many hours would you consider to be safe before you feel your body is under the influence of fatigue?	.323	.413	Weak, not significant

NOTA: With N = 18 observed, the power ≈ 30 % for a medium effect ($\rho \approx .35$); $n \geq 70$ is required for 80 % power.

Pilots of the AW189 tended to report slightly longer perceived safe flight durations compared to those flying the AW139, though the variability was limited. Operational and ergonomic differences between aircraft types might partially explain this variation, but the effect is minimal in this sample.

None of the relationships were statistically significant. All effect sizes were weak ($\rho \leq 0.35$). The strongest, yet still non-significant, association was between Age and Sleep Requirement ($\rho = -0.355$, $p = .148$), suggesting a slight trend toward older pilots reporting lower sleep requirements. The BMI-fatigue correlation was near zero, indicating no link between body composition and fatigue perception. The Helicopter Type–Safe Hours association ($\Phi = 0.323$, $p = .413$) was weak and non-significant. Across all analyses, no significant correlations were found between demographic or physiological variables (such as age and BMI) and operational factors (like aircraft type) with subjective fatigue indicators. However, consistent patterns indicate that older pilots and those with higher BMI may experience slightly less perceived fatigue, possibly due to factors like adaptation, experience, or self-selection bias. With just 18 participants, the study had limited statistical power, reducing the likelihood of detecting small to moderate correlations. The absence of significant results may stem from the small, homogeneous sample ($N = 18$), which reduces the study's power. Both BMI and age exhibited limited variation, further limiting the strength of the correlation. The fatigue-related items (Q18, Q21) are self-reported and may be influenced by personal interpretation or situational factors rather than by physiological or demographic factors.

Due to the small and specialized nature of the sample, these findings should be viewed with caution. Further research with larger samples and multivariate designs could clarify whether subtle physiological or operational factors affecting fatigue are more noticeable in varied environmental or workload scenarios. Future studies should incorporate more diverse samples, objective fatigue measures, and data from multiple operators to verify these patterns.

6.9 Summary of Survey Results of Volunteer Research Pilots

Pilot subjects were 25 volunteers selected; only 18 answered the survey. All subjects were male, with 61% having an age below 47 years. 61.2% acting as Captain, with 38.9% pilots having commercial pilot licenses, 55.6% flying AW139, and 38.9% flying AW18.

Schedule Schemes and Rostering for offshore oil and gas activities: 38,9% reported working 3 to 4 days, while 33.3% reported working 5 to 6 consecutive days. Meanwhile, 66.7% reported resting for at least 24 hours OFF, and 16.7% reported resting between 2 and 3 days OFF before transitioning from DAY to NIGHT and vice versa. Additionally, 11.1% reported having 4 to 5 days OFF from transitioning from NIGHT to DAY shifts.

Sleep habits revealed that 77.8% of the subjects require 7 to 8 hours of sleep to feel completely rested and alert during the day, while 16.7% require only 5 to 6 hours of sleep.

Fatigue: Subjects reported that their performance was affected and degraded by 38.9%, and alertness was affected by 27.8%. Combined with the above, 16.7% reported a lack of capacity to concentrate, and 44.4% of pilots reported rarely “nodding off” during a flight. However, more than 27% reported occasionally “nodding off,” and no pilots turned down a flight due to fatigue.

Pilots’ general opinion was that the number of hours they felt safe before under the influence of fatigue was 66.7% between 3 and 6 hours.

Analysing the survey results reveals the reasons behind some answers from research subjects, when combined with the findings from field research, that contribute to answering the research questions. The author feels that safety concerns are demonstrated. However, safety calls for further development, including additional costly versus safety studies, which may answer more questions. To ensure a mitigating tool can be used for the time being, the Author reveals good insight into research contribution by presenting an adaptation of (Teixeira, C., 2020). Mitigating tools for the aviation industry.

PART II

The following section describes the in-flight field data collected in cruise flights only for AW189 and AW139. To analyse the data retrieved and understand the evolution of the research study, it was decided to divide it into three phases (Initial, Intermediate, and Final). No specific timing was defined to determine the transition from each phase of data collection and analysis; the focus was on the amount of data available to draw timely conclusions. This allowed for continuous comparison during 6 months with 25 volunteers. The volunteers involved were of several nationalities, as described below in alphabetical order: Angolan, Australian, British, Canadian, Irish, Nigerian, Portuguese, South African, and Venezuelan. Part 2 exposes only the resulting average and maximum peak WBV and SN measured exposures to helicopter pilots during offshore cruise flights. Additionally, the results are compared with the noise-reported values of helicopter manufacturers and the standard recommended limits for human body exposure to vibration and noise.

Figure 41 illustrates the ISO limits for WBV and helicopter manufacturing noise values during three phases of flight. Since a working value was required, an average value for all three phases was adopted. Values were added from the inferior and superior values of each phase and then divided by six.

Figure 41 – Helicopter Manufacture & ISO Values vs Authors Calculated Average Exposure Limits. Source: Author´s Creation and Adaptation from Manufacture Noise Exposure and ISO 2631-2018 WBV Daily Limits (ISO 2631-5, 2018).

MANUFACTURE & ISO VALUES vs Auhtors Calculated Average Exposure Limites									
HELICOPTER model	SOUND NOISE (SN) (dB)*			AVERAGE NOISE EXPOSURE in FLIGHT/H (HL) (dB1)	WBV (dB)			AVERAGE WBV EXPOSURE in FLIGHT/H (dB2)	CALCULATED AVERAGE(SN+WBV) *HVNmfED dB total* EXPOSURE in FLIGHT/H
	TAKEOFF	OVERFLIGHT	APPROACH		TAKEOFF	OVERFLIGHT	APPROACH		
AW139	90,3 – 98,5	90,7 – 97,5	94,1 – 99,5	95.10	92,67 - 98,79 (ISO 2631-2018 Inferior & Superior Limit for WBV)			95.73	98.44
AW189	91,3 – 96,3	94,3 - 95,2	99,1 – 99,3	95.91				95.73	98.83
S-76C++	96,0 – 97,3	93,2 – 96,3	97,7 – 98,3	96.46				95.73	99.12
AS332L2	94,6 – 99,7	93,4 – 98,7	96,1 – 100,7	97.20				95.73	99.54
EC225	95,6 – 100,4	93,5 – 99,4	98,9 – 101,4	98.20				95.73	100.15
*(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)					No manufacture value was able to be obtained at disposal and for this reason a calculated average out of the ISO 2631-2018 was used for reference. Were values are present, data was collected from HUMS and maintenace from previous past flights				

Since inferior and superior limits were referenced for WBV, they were calculated as the average medium working values using the same method above for noise and then divided by two. The last column is the calculated result with the use of **Equation 4** presented above in Chapter V, section 5.4.8, which calculates the Helicopter Noise and Vibration Manufacture Exposure Dose (HNV*mf*ED) pilots experience based on the results obtained in dB1 (blue column) and dB2 (orange column) per one (1) hour of flight.

Both values were defined as the limit working region for WBV and SN. In the AW139, the average SN exposure for a flight was 95.10 dB, and for the AW189, it was 95.91 dB. Since there is nothing explicitly specified in ISO 2631 for flight in both cases, the average WBV exposure for a flight was calculated to be 95.73 dB. When calculating the combined sources with the manufacturer-reported values and WBV from ISO 2631, the HNV*mf*ED average per hour value was established as a reference. The calculated established reference values for the AW139 are 98.44 dB and 98.83 dB for the AW189.

Figure 42 below clarifies the exposure for operators and pilots. If pilots were to adhere to the limits permitted in the regulations, they would represent the reference limits based on ISO and OSHA standards. However, when calculated using the formula HNV*mf*ED per hour, values derived from the manufacturer and ISO standards yield a higher result when employing the combination of both sources, SN+WBV, along with inferior and superior limits. With this knowledge, it becomes possible to calculate and establish reference limits for the combined sources' inferior and superior boundaries. Using **Equation 9**, the calculation of combined noise from multiple acoustic sources can be achieved. **The reference exposure limits for these combined sources are identified as averaging 94.55 dB for the Noise and WBV Inferior Limit combination source value and 99.33 dB for the Noise and WBV Superior Limit combination source value.** Therefore, operational safety latent risk is present at medium to high levels, as values exceed the maximum limit permitted in both ISOs.

$$dB_{total} = 10 \times LOG\left(\sum_{i=1}^{n}\left(10^{\left(\frac{dBi}{10}\right)}\right)\right) \tag{9}$$

Note 1: The equation provides a logarithmic average in dB, as an arithmetic average would yield incorrect exposure values for lower exposure levels.

Note 2: For this research project, only two sources were used: the noise combination measured inside the cockpit with microphones and the vibration combination measured from an accelerometer.

Note 3: For calculation and analysis purposes, the second (vibration) is converted into decibels using Equation 8 presented above in Chapter V, section 5.4.8.

Figure 42 – Exposure Limits, TWO Acoustic Sources Towards Sound Noise and Whole-Body Vibration.

ISO 1999 -2013, OSHA1910.95 & ISO 2631-2018 LIMITES, INCREASE REFERENCE AND CALCULATED ACCUMULATED AVERAGE EXPOSURE LIMITE TIME PER DAY											
NOISE (SN) (dB1)	NOISE EXPOSURE LIMIT TIME/DAY (hh:mm)	WBV INFERIOR LIMIT (dB2)	WBV SUPERIOR LIMIT (dB2)	WBV EXPOSURE LIMITE TIME/DAY (hh:mm)	CALCULATED AVERAGE COMBINED SOURCES (SN+WBV INFERIOR LIMIT) (dB)	INCREASE DIFFERENCE OF COMBINED SOURCES FROM WBV INFERIOR LIMIT *REFERENCE* (dB)	INCREASE DIFFERENCE OF COMBINED SOURCES WITH INFERIOR LIMIT FROM NOISE REFERENCE (dB)	CALCULATED AVERAGE COMBINED SOURCES (SN+WBV SUPERIOR LIMIT) (dB)	INCREASE DIFFERENCE OF COMBINED SOURCES FROM WBV SUPERIOR LIMIT *REFERENCE* (dB)	INCREASE DIFFERENCE OF COMBINED SOURCES WITH SUPERIOR LIMIT FROM NOISE REFERENCE (dB)	CALCULATED AVERAGE SN+WBV EXPOSURE LIMIT TIME/DAY (hh:mm)
90	08:00	92.67	98.79	08:00	**94.55**	1.88	4.55	**99.33**	0.54	9.33	**06:15**
91	07:00	93.67	99.79	07:00	95.55	1.88	4.55	100.33	0.54	9.33	05:30
92	06:00	94.67	100.79	06:00	**96.55**	1.88	4.55	**101.33**	0.54	9.33	**04:45**
93	05:20	95.67	101.79	05:20	97.55	1.88	4.55	102.33	0.54	9.33	04:20
94	04:40	96.67	102.79	04:40	98.55	1.88	4.55	103.33	0.54	9.33	03:55
95	04:00	97.67	103.79	04:00	**99.55**	1.88	4.55	**104.33**	0.54	9.33	**03:30**
96	03:30	98.67	104.79	03:30	100.55	1.88	4.55	105.33	0.54	9.33	03:00
97	03:00	99.67	105.79	03:00	**101.55**	1.88	4.55	**106.33**	0.54	9.33	**02:30**
98	02:40	100.67	106.79	02:40	102.55	1.88	4.55	107.33	0.54	9.33	02:05
99	02:20	101.67	107.79	02:20	103.55	1.88	4.55	108.33	0.54	9.33	01:40
100	02:00	102.67	108.79	02:00	**104.55**	1.88	4.55	**109.33**	0.54	9.33	**01:15**
A correlation study was conducted for calculation of the increase of minimum and maximum values do WVB dB balues based on the same criteria used in the ISO 2631-2018 for the calculation of NOISE and Hearing Loss (HL) regarding the increase of dB to the original value of 8 hours 90+dB of 2,5,7 and 10, resulting the reference of 6,4,3,and 2 hours .											

Figure 42 is the allowable noise exposure based on 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 and Exposure Limits, TWO Acoustic Sources Towards NIHL of HELICOPTER PILOT ROSTERING ON/OFF SCHEDULE SCHEME IN ANGOLA OIL AND GAS OFFSHORE INDUSTRY Fatigue in Offshore Helicopter Pilots (ISO 1999, 2013; ISO 2631-5, 2018; OSHA, 2020; Teixeira, 2020)

Note: Values in the box filled in blue are calculations based on standards and the sum of two acoustic sources.

Based on **Figure 42**, the recommended daily limit reference for helicopter pilots should be changed in the International Civil Aviation Organisation (ICAO) regulations. The reason towards this observation is the two sources of exposure that raise decibel values of noise and WBV. When calculating the two sources starting from the reference value of 90 dB of noise and 92.67 dB of WBV Inferior Limit, an increase in the logarithmic average increase of vibration by 1.88 dB and 4.55 dB in the noise, corresponding to an arithmetic average of 3.21 dB when summed and divided by two for every increase of 1 dB above the reference initial values. On the other hand, when calculating the two sources starting from the reference value of 90 dB of noise and 98.79 dB of WBV Superior Limit an increase in the logarithmic average increase of vibration by 0.54 dB and 9.33 in the noise, corresponding to a arithmetic average of 4.93 dB when summed and divided by two per every increase of 1 dB above the reference initial values. Therefore, theoretically, the recommended reference value should have been placed below the current ICAO regulations, which are currently set at 8 hours of the daily Flight Time (FT) limit. Based on research, an initial reference value for Maximum Daily Flight Time (MDFT) is 6 hours and 15 minutes. This value was used in this research as a reference point for the conclusions.

6.10 Initial Results in Real Flight Measurements

Between 3rd September 2024 and 3rd October 2024, a total of 23 measurements were conducted during actual flights on an AW189 not equipped with Active Vibration Control Systems (AVCS), exclusively in cruise flight within the offshore environment at 130 KIAS (knots indicated airspeed). Additionally, seven measurements were conducted during actual flights on an AW139 equipped with AVCS, also exclusively in cruise flight within the offshore environment at or above 120 KIAS.

All aircraft that use the Active Vibration Control System (AVCS) help mitigate transient manoeuvres by reducing peak vibration levels at key locations.

Initial results concerning sound noise exposure have already begun to show an exceedingly high average level of exposure, significantly exceeding the recommendations in ISO 1999, OSHA, DIRECTIVE 2003/10/EC and CCOHS, which set a limit between 85 and 90 dB per day for an 8-hour duration (DIRECTIVE 2003/10/EC, 2003; ISO 1999, 2013; Noise-Occupational Exposure Limits in Canada, 2023; OSHA, 2020). As defined in the initial findings and obtained in data reading from data collection in Figures 52 and 55 in Appendix 4 – In Flight Data. The average value was 12.04 dB above the recommended dose, achieving an overall average of 102.04 dB for the AW189. Similarly, the average value was 12.12 dB above the recommended dose, resulting in an overall average of 102.12 dB for the AW139. A clear demonstration of possible direct results in hearing loss in the long term and added fatigue to pilots due to their exposure, based on the time-of-flight hours each pilot conducts each day.

On the other hand, the initial results related to WBV were based solely on measurements of the pilot's legs, with the right leg flying as the copilot and the left leg flying as the captain. Values demonstrate a significant average exposure, despite being within the recommended limit in ISO 2631-2018, which is 92.67 dB as the inferior limit and 98.79 dB as the superior limit, based on an 8 hour daily limit. It was noted that the superior limit exceeded ISO recommendations in multiple measurements (ISO 2631-5, 2018). To establish inferior and superior limits similar to ISO 2631, the Author defines the inferior limit as the average value obtained in data readings and the superior limit as the maximum peak value obtained in data readings from the data collection in Figures 52 and 55 of Appendix 4 – In-Flight Data. On the AW189, the average value is 92.8 dB in the inferior limit, 106.1 dB in the superior limit, and the average value is 93.4 dB in the inferior limit and 99.64 dB in the superior limit for the AW139.

A reasonable demonstration of possible direct results in accumulated fatigue and adhered sickness to body organs in the short and long term, due to its exposure based on the time-of-flight hours each pilot conducts each day.

When using the Helicopter Noise and Whole-Body Vibration real flight estimated Exposure Dose (HNVrfED) **Equation 5 and 6** without the multiplication of Total Flight Time (TFT), the author assumes that the value is the total exposure time per hour, despite knowing that the sum of decibels is not calculated directly since it is a logarithmic calculation being the noise exposure plus vibration exposure average dose value of 103.67 dB and 103.25 dB in the inferior limit and the calculated noise exposure plus vibration exposure average dose value of 111.28 dB and 108.78 dB in the superior limit respectively for AW189 and AW139.

Based on the initial collected data in flight and using the reference value of ISO 2631-2018 WBV superior limit, the presented research study and in Teixeira´s the calculated value is above the calculated average SN+WBV total exposure inferior limit in dB per hour of 94.55 dB and calculated average SN+WBV total exposure superior limit in dB per hour of 99.33 dB for both the AW139 and AW189. (ISO 2631, 2018; Teixeira, C., 2020)

The author establishes recommended and ideal limits for the number of hours per day, defining the recommended limit as 30 to 45 minutes less than the daily limit value and the ideal limit as 45 minutes to 1 hour less than the daily limit value.

The initial conclusion shown in **Table 32** below relates to the AW139 and AW189. This research indicates that the limit is 6 hours and 15 minutes per day. The findings recommend reducing the flight exposure time to a shorter period, as illustrated in **Figures 41 and 42**. Findings suggest an ideal flight exposure time of 2 hours and 30 minutes to protect the pilot's health, with a recommended average flight limit of 3 hours to maintain operational fitness to fly. The daily flight duration limit should not exceed 3 hours and 30 minutes, as exceeding this may adversely affect pilots' health, potentially leading to high fatigue and reduced operational fitness to fly, which can influence pilot responses in both normal and abnormal contexts and impair situational awareness.

Despite the differences, when adding both fatigue sources, SN+WBV, the values are only 0.42 dB from the inferior limit and 2.5 dB above the superior limit for both helicopters, the AW139 and AW189. The author assumes that an increase of 20 to 40 minutes above the limited maximum flight time per day may be foreseeable in safe conditions for some pilots. However, the author recommends that pilots have a good awareness of their fatigue levels and conditions and that operators have a good fatigue measuring system implemented with monitoring safeguards that can assess the Analysis of Fatigues towards Pilots Operational Fitness to Fly ***(Flow Chart 5 and 6)*** monthly, preferably biweekly, to assess correct rostering schemes.

Table 32 – Initial Real Flight Measuring Summary Analysis Chart for AW189 & AW139

			MEASUREMENT RESULTS CHART						
			INITIAL	Remarks	INTERMEDIATE	Remarks	FINAL	Remarks	
			SET 3 - OCT 3						
AW189	SOUND (REF: 90dB ISO 2631-2018)	AVERAGE	102.04 dB	ABOVE REF. +12.04 dB					PER HOUR
AW189	SOUND (REF: 90dB ISO 2631-2018)	MAX PEAK	104.86 dB	ABOVE REF. +14.86 dB					PER HOUR
AW189	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	INFERIOR LIMIT	92.8 dB	ABOVE REF. +0.13 dB					PER HOUR
AW189	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	*Calculated Average WBV*	*99.45 dB*	N/A					PER HOUR
AW189	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	SUPERIOR LIMIT	106.1 dB	ABOVE REF. +7.31 dB					PER HOUR
AW189	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	INFERIOR LIMIT	103.67 dB	ABOVE REF. +9.12 dB					PER HOUR
AW189	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	*Calculated SN+WBV Average Expossure in dB / H*	*107.47 dB*	N/A					PER HOUR
AW189	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	SUPERIOR LIMIT	111.28 dB	ABOVE REF. +11.95 dB					PER HOUR
AW189	RECOMMENDED FLIGHT TIME / DAY	IDEALLY	2H30MIN						
AW189	RECOMMENDED FLIGHT TIME / DAY	RECOMENDED	3H00MIN						
AW189	RECOMMENDED FLIGHT TIME / DAY	DAILY LIMIT	3H30MIN ** (+ 20 to 40 min)						
AW139	SOUND	AVERAGE	102.12 dB	ABOVE REF. +12.12 dB					PER HOUR
AW139	SOUND	MAX PEAK	106.85 dB	ABOVE REF. +16.85 dB					PER HOUR
AW139	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	INFERIOR LIMIT	93.4 dB	ABOVE REF. +0.73 dB					PER HOUR
AW139	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	*Calculated Average WBV*	*96.52 dB*	N/A					PER HOUR
AW139	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	SUPERIOR LIMIT	99.64 dB	ABOVE REF. +0.85 dB					PER HOUR
AW139	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	INFERIOR LIMIT	103.25 dB	ABOVE REF. +8.7 dB					PER HOUR
AW139	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	*Calculated SN+WBV Average Expossure in dB / H*	*105.75 dB*	N/A					PER HOUR
AW139	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	SUPERIOR LIMIT	108.78 dB	ABOVE REF. +9.45 dB					PER HOUR
AW139	RECOMMENDED FLIGHT TIME / DAY	IDEALLY	2H30MIN						
AW139	RECOMMENDED FLIGHT TIME / DAY	RECOMENDED	3H00MIN						
AW139	RECOMMENDED FLIGHT TIME / DAY	DAILY LIMIT	3H30MIN ** (+ 20 to 40 min)						

TOTAL REAL MEASUREMENTS	AW189	23						
TOTAL REAL MEASUREMENTS	AW139	7						

SCALE OF MEASUREMENTS	
(red)	0 - 12
(orange)	13 - 24
(yellow)	25 - 37
(green)	38 - 50

****Author believes that an increase of flight time of plus 20 to 40 min per day may be foreseeable in safe conditions in some pilots, although author recommends that pilots have good awareness of their fatigue levels and conditions and that operators have a good fatigue measuring system implemented with monitoring safeguards that are able to assess the Analysis of Fatigues towards Pilots Operational Fitness to Fly (Description chart 2) preferably weekly and ideally daily to access correct rostering schemes.**

Note: The recommended flight time is calculated based on the authors presented equations, research contributions, and discussion arguments in Chapter VII.

6.11 Intermediate Results After Real Flight Measurements

Between 3rd September 2024 and 9th December 2024, a total of 44 measurements were conducted during actual flights on an AW189 not equipped with Active Vibration Control Systems (AVCS), exclusively in cruise flight within the offshore environment at 130 KIAS (knots indicated airspeed). Additionally, 13 measurements were conducted during actual flights on an AW139. Two flights on the AW139 were not equipped with AVCS, and they were exclusively in cruise flight within the offshore environment at or above 120 KIAS.

As defined in the intermediate findings and obtained from data reading in Figures 53 and 56 of Appendix 4 – In-Flight Data. The average value is 11.4 dB above the recommended dose, reaching an average of 101.54 dB across all current measurements and a maximum peak average of 104.5 dB for the AW189. On the other hand, the AW139 had an average value of 9.53 dB above the recommended dose, reaching an average value of 99.53 dB across all current measurements and a maximum peak value of 104.15 dB. A clear demonstration of possible direct results in hearing loss in the long term and added fatigue to pilots due to their exposure, based on the time-of-flight hours each pilot conducts each day.

Regarding the WBV intermediate results, values demonstrate a significant average exposure despite being within the limit recommendation in ISO 2631-2018 (ISO 2631-5, 2018). It was noted that the superior limit was well surpassed in several instances. The average value is 93.1 dB in the inferior limit and 108.2 dB in the superior limit for the AW189, and the average value is 91.63 dB in the inferior limit and 101.72 dB in the superior limit for the AW139. A credible demonstration of a highly probable direct result is the accumulation of fatigue and adherent sickness in the body organs in both the short and long term. This adds fatigue to the pilot due to its exposure based on the time-of-flight hours each pilot conducts daily.

When using the Helicopter Noise and Whole-Body Vibration real flight estimated Exposure Dose (HNV*rf*ED), **Equations 5 and 6**, without the multiplication of total flight time (TFT), it is assumed that the value is the total exposure per hour, despite knowing that the sum of decibels is not calculated directly since it is a logarithmic calculation. Being the calculated noise exposure plus vibration exposure average dose value of 103.23 dB and 102.34 dB in the inferior limit, and the calculated noise exposure plus vibration exposure average dose value of 111.98 dB and 110.35 dB in the superior limit, respectively, for the AW189 and AW139.

In comparison to the initial result and the intermediate results, collected data in flight and using the reference value of ISO 2631-2018 WBV superior limit, the presented research study and in Teixeira´s the calculated value is above the calculated average SN+WBV total exposure inferior limit in dB per hour of 94.55 dB and calculated average SN+WBV total exposure superior limit in dB per hour of 99.33 dB for both the AW139 and AW189 (ISO 2631, 2018; Teixeira, 2020). Referenced in **Figure 42.**

As shown in **Table 33** below, the intermediate conclusion relates to the AW139 and AW189. The exposure daily flight limit time per day should be reduced by 30 minutes as per Teixeira's research study to a value below 5 hours and 45 minutes until the end of the research, based on the collected data in flight and using the reference value of ISO 2631-2018 WBV superior limit, which has concurrence with **Figures**

41 and 42. Based on the research presented and the analysis from **Figures 41 and 42 above and Table 33** below**,** the author agrees and finds, as a pilot, that the daily flight limit time should be revised to include an additional 60 minutes to all flight times indicated, as a conservative and cautious approach was adopted in the initial findings.

In this case, as established in the initial conclusions, the ideal average flight time limit should be 3 hours and 30 minutes to preserve the most extended range of pilots' health throughout their careers. It is particularly suitable for 35 days of ON/OFF rostering. The recommended average flight limit is 4 hours for 28 days ON/OFF rostering to guarantee operational fitness to fly. In comparison, the maximum flight time should be limited to 4 hours and 30 minutes for 21 days ON/OFF rostering to avoid negatively affecting pilots' health, which may result in high fatigue levels as referenced in Chapter II. This fatigue directly impacts bodily organs and causes several side effects and disorders in pilots, ultimately reducing their operational fitness to fly, particularly in terms of pilot response in both normal and abnormal situations, as well as diminished situational awareness.

The difference is higher than the initial measurements in the intermediate analysis, with an average value of 0.89 dB for the inferior limit and a lower value of 1.63 dB for the superior limit between the AW139 and AW189 helicopters. The author assumes that an increase in daily flight time of more than 20 to 40 minutes may be foreseeable under safe conditions for specific pilots. Consequently, the maximum flying limit per day may be revised to 5 hours and 10 minutes, compared to the previous limit of 4 hours and 45 minutes. Although the author still recommends that pilots have a good awareness of their fatigue levels and conditions and that operators have a good fatigue measuring system implemented with monitoring safeguards that can assess the Analysis of Fatigues towards Pilots' Operational Fitness to Fly ***(Flow Charts 5 and 6)***, preferably biweekly, ideally weekly, to assess correct rostering schemes.

Table 33 – Intermediate Real Flight Measuring Summary Analysis Chart for AW189 & AW139

			MEASUREMENT RESULTS CHART						
			INITIAL SET 3 - OCT 3	Remarks	INTERMEDIATE SET 3 - DEC 9	Remarks	FINAL	Remarks	
AW189	SOUND (REF: 90dB ISO 2631-2018)	AVERAGE	102.04 dB	ABOVE REF. +12.04 dB	↓ 101.54 dB	ABOVE REF. +11.54 dB			PER HOUR
		MAX PEAK	104.86 dB	ABOVE REF. +14.86 dB	↓ 104.5 dB	ABOVE REF. +14.5 dB			
	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	INFERIOR LIMIT	92.8 dB	ABOVE REF. +0.13 dB	↑ 93.1 dB	ABOVE REF. +0.43 dB			
		Calculated Average WBV	*99.45 dB*	N/A	*100.65 dB* ↑	N/A			
		SUPERIOR LIMIT	106.1 dB	ABOVE REF. +7.31 dB	↑ 108.2 dB	ABOVE REF. +9.41 dB			
	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	INFERIOR LIMIT	103.67 dB	ABOVE REF. +9.12 dB	↓ 103.23 dB	ABOVE REF. +8.68 dB			
		Calculated SN+WBV Average Expossure in dB / H	*107.47 dB*	N/A	*107.60 dB* ↑	N/A			
		SUPERIOR LIMIT	111.28 dB	ABOVE REF. +11.95 dB	↑ 111.98 dB	ABOVE REF. +12.65 dB			
	RECOMMENDED FLIGHT TIME / DAY	IDEALLY	2H30MIN		3H36MIN	(+ 66 MIN) ↑			
		RECOMENDED	3H00MIN		4H00MIN	(+ 60 MIN) ↑			
		DAILY LIMIT	3H30MIN ** (+ 20 to 40 min)		4H30MIN ** (+ 20 to 40 min)	(+ 60 MIN) ↑			
AW139	SOUND	AVERAGE	102.12 dB	ABOVE REF. +12.12 dB	↓ 99.53 dB	ABOVE REF. +9.53 Db			PER HOUR
		MAX PEAK	106.85 dB	ABOVE REF. +16.85 dB	104.15 dB	ABOVE REF. +14.15 dB			
	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	INFERIOR LIMIT	93.4 dB	ABOVE REF. +0.73 dB	↓ 91.63 dB	ABOVE REF. -1.04 dB			
		Calculated Average WBV	*96.52 dB*	N/A	*96.67 dB* ↑	N/A			
		SUPERIOR LIMIT	99.64 dB	ABOVE REF. +0.85 dB	↑ 101.72 dB	ABOVE REF. +2.93 dB			
	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	INFERIOR LIMIT	103.25 dB	ABOVE REF. +8.7 dB	↓ 102.34 dB	ABOVE REF. +7.79 dB			
		Calculated SN+WBV Average Expossure in dB / H	*105.75 dB*	N/A	*106.34 dB* ↑	N/A			
		SUPERIOR LIMIT	108.78 dB	ABOVE REF. +9.45 dB	↑ 110.35 dB	ABOVE REF. +11.02 dB			
	RECOMMENDED FLIGHT TIME / DAY	IDEALLY	2H30MIN		3H36MIN	(+ 66 MIN) ↑			
		RECOMENDED	3H00MIN		4H00MIN	(+ 60 MIN) ↑			
		DAILY LIMIT	3H30MIN ** (+ 20 to 40 min)		4H30MIN ** (+ 20 to 40 min)	(+ 60 MIN) ↑			

TOTAL REAL MEASUREMENTS	AW189	23		44	(+ 21)		
	AW139	7		13	(+ 6)		

SCALE OF MEASUREMENTS	
Red	O - 12
Orange	13 - 24
Yellow	25 - 37
Green	38 - 50

****Author believes that an increase of flight time of plus 20 to 40 min per day may be foreseeable in safe conditions in some pilots, although author recommends that pilots have good awareness of their fatigue levels and conditions and that operators have a good fatigue measuring system implemented with monitoring safeguards that are able to assess the Analysis of Fatigues towards Pilots Operational Fitness to Fly (Description chart 2) preferably weekly and ideally daily to access correct rostering schemes.**

Note: The recommended flight time is calculated based on the authors' presented equations, research contributions, and discussion arguments in Chapter V**II**.

6.12 Final Results After Real Flight Measurements

Between the 3rd September 2024 and 3rd March 2024, a total of four additional measurements were taken during actual flights on an AW189 not equipped with Active Vibration Control Systems (AVCS), exclusively in cruise flight within the offshore environment at 130 KIAS (knots indicated airspeed). Additionally, 33 extra measurements were conducted during actual flights on an AW139. One flight on the AW139 was not fitted with AVCS, and it was exclusively in cruise flight within the offshore environment at or above 120 KIAS. A total of 339 pictures and/or phone screen prints were captured, and 104 videos recorded, with footage exceeding 30 seconds in length.

Final results related to sound noise exposure demonstrate a significant average exposure well above the recommendations in ISO 1999, OSHA, Directive 2003/10/EC, and CCOHS (DIRECTIVE 2003/10/EC, 2003; ISO 1999, 2013; Noise-Occupational Exposure Limits in Canada, 2023; OSHA, 2020). As established in the inferior and superior limits similar to ISO 2631, the Author defines the inferior limit as the average value obtained in data readings and the superior limit as the maximum peak value obtained in data readings from data collection in **Figures 54 and 57 in Appendix 4 – In Flight Data**. **For 48 AW189 flights with an average of 3 hours and 37 minutes per flight per crew rostered, the average results were 11.65 dB and a maximum peak of 14.48 dB, above the recommended dose. Reaching an average value within all current measurements of 101.65 dB and a maximum peak of 104.48 dB for the AW189. For the AW139, presented after a total of 46 flights, totalling an average of 4 hours and 17 minutes per flight per crew rostered, the average results were 9.28 dB and a maximum peak of 13.53 dB, both values above the recommended dose. Reaching an average value within all current measurements of 99.28 dB and a maximum peak value of 103.55 dB for the AW139.** A clear demonstration of possible direct results in hearing loss in the long term, and added fatigue to pilots due to their exposure based on the time-of-flight hours each pilot conducts daily.

Regarding the **final results related to WBV**, **based on the measurement of the pilot's legs only, the values demonstrate a significantly higher average exposure than the limit recommendation in ISO 2631-2018** (ISO 2631-5, 2018). It was noted that the superior limit was exceeded in several instances. **The average value was 93.25 dB in the inferior limit and 108.46 dB in the superior limit for the AW189, and the average value was 92.07 dB in the inferior limit and 102.19 dB in the superior limit for the AW139.** A clear demonstration of guaranteed probable direct result in accumulated fatigue and adhered sickness to body organs in the short and long term, adding fatigue to the pilot due to their exposure based on the time-of-flight hours each pilot conducts each day.

When using the Helicopter Noise and Whole-Body Vibration real flight estimated Exposure Dose (HNVrfED) **Equation 5 and 6** without the multiplication of total flight time (TFT), **the overall calculated sound noise exposure plus whole-body vibration exposure average dose value of 102.23 dB and 101.64 dB in the inferior limit and the calculated sound noise exposure plus whole-body vibration exposure average dose value of 109.92 dB and 108.28 dB in the superior limit respectively for the AW189 and AW139.**

In comparison to the initial and intermediate results, collected data in flight and using the reference value of ISO 2631-2018 WBV superior limit, the presented research study and in Teixeira´s study, the calculated value is above the calculated average SN+WBV total exposure inferior limit in dB per hour of 94.55 dB and calculated average SN+WBV total exposure superior limit in dB per hour of 99.33 dB for both the AW139 and AW189. (ISO 1999, 2013; ISO 2631, 2018; Teixeira, C., 2020)

The conclusion, as shown in **Table 34** below, for the AW139 and AW189, is that the exposure flight limit time, recommended based on the calculated daily exposure limit, should be 5 hours and 30 minutes, as determined by the collected data in this research study and in-flight measurements. According to concurrence data analysis presented in **Figures 41 and 42** above, alongside **Table 34** below and the research detailed in the Discussion & Research Contribution section of Chapter VII, the author, drawing on pilot experience, advocates for a further revision of the daily flight limit time, proposing an increase of at least 30 additional minutes for all specified flight durations. This recommendation is supported by the availability of an expanded dataset, which allows for a more realistic operational framework compared to the preliminary results.

The emphasis on a more realistic operational framework and clarification of the new ideal recommends setting daily limits, with an average flight time of 4 hours and 6 minutes, to preserve the most extended range of the pilot's health throughout their career lifespan. Bongers et al., state a more conservative limit due to the onset of symptoms of low back pain, being between 1.5 and 4 hours in several flights per day (Bongers et al., 1990)**. It is limited to 3 hours and 10 minutes for rostering 35 days ON/OFF, during which pilots will work 30 days, allowing them to fly within the recommended average daily flight time. They will rest for 5 days, taking one day of rest after every 6 days of flying, accumulating a maximum of 95 hours within 28 days cycle and therefore a total of 102 hours and 20 minutes per rotation.** (See Chapter VII)

The recommended average flight limit time is 4 hours and 48 minutes, which the author considers the best ratio of the pilot's longevity range of health in their career lifespan versus the operator's flight operations necessity. The rostering is limited to 3 hours and 57 minutes for 28 days ON/OFF, during which pilots will work 24 days, allowing them to fly, within the recommended average flight time per day. They will rest for 4 days and have one day of rest after every 6 days of flying, accumulating a maximum of 95 hours per rotation.

The DAILY LIMIT average flight limit time is 5 hours and 30 minutes, although limited to 5 hours and 16 minutes for rostering of 21 days ON/OFF to guarantee operational fitness to fly, to avoid affecting pilots health that may result in high levels of fatigue referred above affecting the body organs directly and causing several side effects and disorders on pilots reducing the operational fitness to fly which is related to pilot response in normal and abnormal situations and reduced situational awareness. Pilots will work 18 days, are permitted to fly with the recommended average flight time per day, rest for 3 days, and have one day of rest after every 6 days of flying, accumulating a maximum of 95 hours per rotation.

In the final analysis, the difference between the intermediate measurements is higher for the inferior limit average value, 1.61 dB, and higher for the superior limit average value, 4.62 dB, for both helicopters, the AW139 and the AW189.

Table 34 – Final Real Flight Measuring Summary Analysis Chart for AW189 & AW139

			MEASUREMENT RESULTS CHART						
			INITIAL SET 3 - OCT 3	Remarks	INTERMEDIATE SET 3 - DEC 9	Remarks	FINAL SET 3 - MAR 3	Remarks	
AW189	SOUND (REF: 90dB ISO 2631-2018)	AVERAGE	102.04 dB	ABOVE REF. +12.04 dB	↓ 101.54 dB	ABOVE REF. +11.54 dB	↑ 101.65 dB	ABOVE REF. +11.65 dB	PER HOUR
AW189	SOUND (REF: 90dB ISO 2631-2018)	MAX PEAK	104.86 dB	ABOVE REF. +14.86 dB	↓ 104.5 dB	ABOVE REF. +14.5 dB	↓ 104.48 dB	ABOVE REF. +14.48 dB	PER HOUR
AW189	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	INFERIOR LIMIT	92.8 dB	ABOVE REF. +0.13 dB	↑ 93.1 dB	ABOVE REF. +0.43 dB	↑ 93.3 dB	ABOVE REF. +0.63 dB	PER HOUR
AW189	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	*Calculated Average WBV*	*99.45 dB*	N/A	*100.65 dB* ↑	N/A	*100.90 dB* ↑	N/A	PER HOUR
AW189	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	SUPERIOR LIMIT	106.1 dB	ABOVE REF. +7.31 dB	↑ 108.2 dB	ABOVE REF. +9.41 dB	↑ 108.5 dB	ABOVE REF. +9.71 dB	PER HOUR
AW189	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	INFERIOR LIMIT	103.67 dB	ABOVE REF. +9.12 dB	↓ 103.23 dB	ABOVE REF. +8.68 dB	↓ 102.23 dB	ABOVE REF. +7.68 dB	PER HOUR
AW189	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	*Calculated SN+WBV Average Exposure in dB / H*	*107.47 dB*	N/A	*107.60 dB* ↑	N/A	↓ *105.71 dB*	N/A	PER HOUR
AW189	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	SUPERIOR LIMIT	111.28 dB	ABOVE REF. +11.95 dB	↑ 111.98 dB	ABOVE REF. +12.65 dB	↓ 109.2 dB	ABOVE REF. +9.87 dB	PER HOUR
AW189	RECOMMENDED FLIGHT TIME / DAY	IDEALLY	2H30MIN		3H36MIN	(+ 66 MIN) ↑	4H06MIN	(+ 30 MIN) ↑	
AW189	RECOMMENDED FLIGHT TIME / DAY	RECOMENDED	3H00MIN		4H00MIN	(+ 60 MIN) ↑	4H48MIN	(+ 48 MIN) ↑	
AW189	RECOMMENDED FLIGHT TIME / DAY	DAILY LIMIT	3H30MIN ** (+ 20 to 40 min)		4H30MIN ** (+ 20 to 40 min)	(+ 60 MIN) ↑	5H30MIN	(+ 60 MIN) ↑	
AW139	SOUND	AVERAGE	102.12 dB	ABOVE REF. +12.12 dB	↓ 99.53 dB	ABOVE REF. +9.53 Db	↓ 99.28 dB	ABOVE REF. +9.28 dB	PER HOUR
AW139	SOUND	MAX PEAK	106.85 dB	ABOVE REF. +16.85 dB	104.15 dB	ABOVE REF. +14.15 dB	↓ 103.55 dB	ABOVE REF. +13.53 dB	PER HOUR
AW139	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	INFERIOR LIMIT	93.4 dB	ABOVE REF. +0.73 dB	↓ 91.63 dB	ABOVE REF. -1.04 dB	↓ 92.7 dB	ABOVE REF. +0.03 dB	PER HOUR
AW139	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	*Calculated Average WBV*	*96.52 dB*	N/A	*96.67 dB* ↑	N/A	*97.45 dB* ↑	N/A	PER HOUR
AW139	WBV (REF: INFERIOR LIMIT 92,67 dB - SUPERIOR LIMIT 98,79 dB ISO 2631-2018)	SUPERIOR LIMIT	99.64 dB	ABOVE REF. +0.85 dB	↑ 101.72 dB	ABOVE REF. +2.93 dB	↑ 102.19 dB	ABOVE REF. +3.4 dB	PER HOUR
AW139	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	INFERIOR LIMIT	103.25 dB	ABOVE REF. +8.7 dB	↓ 102.34 dB	ABOVE REF. +7.79 dB	↓ 101.64 dB	ABOVE REF. +7.09 dB	PER HOUR
AW139	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	*Calculated SN+WBV Average Exposure in dB / H*	*105.75 dB*	N/A	*106.34 dB* ↑	N/A	↓ *104.96 dB*	N/A	PER HOUR
AW139	SN+WBV (REF: INFERIOR LIMIT 94,55 dB - SUPERIOR LIMIT 99,33 dB)	SUPERIOR LIMIT	108.78 dB	ABOVE REF. +9.45 dB	↑ 110.35 dB	ABOVE REF. +11.02 dB	↓ 108.28 dB	ABOVE REF. +8.95 dB	PER HOUR
AW139	RECOMMENDED FLIGHT TIME / DAY	IDEALLY	2H30MIN		3H36MIN	(+ 66 MIN) ↑	4H06MIN	(+ 30 MIN) ↑	
AW139	RECOMMENDED FLIGHT TIME / DAY	RECOMENDED	3H00MIN		4H00MIN	(+ 60 MIN) ↑	4H48MIN	(+ 48 MIN) ↑	
AW139	RECOMMENDED FLIGHT TIME / DAY	DAILY LIMIT	3H30MIN ** (+ 20 to 40 min)		4H30MIN ** (+ 20 to 40 min)	(+ 60 MIN) ↑	5H30MIN	(+ 60 MIN) ↑	

TOTAL REAL MEASUREMENTS	AW189	23		44	(+ 21)	48	(+ 4)
TOTAL REAL MEASUREMENTS	AW139	7		13	(+ 6)	46	(+ 33)

SCALE OF MEASUREMENTS	
red	0 - 12
orange	13 - 24
yellow	25 - 37
green	38 - 50

****Author believes that an increase of flight time of plus 20 to 40 min per day may be foreseeable in safe conditions in some pilots, although author recommends that pilots have good awareness of their fatigue levels and that operators have a good fatigue measuring system implemented with monitoring safeguards that are able to assess the Analysis of Fatigues towards Pilots Operational Fitness to Fly (Description chart 2) preferably weekly and ideally daily to access correct rostering schemes.**

Note: The recommended flight time is calculated based on the authors' presented equations, research contributions, and discussion arguments in Chapter VII.

The author assumes that an increase in flight time of 20 to 40 minutes per day may be foreseeable under safe conditions for some pilots, depending on the average number of hours in the current rostering scheme rotation, age, scheduled duty time on the present day, sleep cycle in the current rotation, and fitness to fly. Flying below the 5 hours and 30 minutes maximum daily limit is also highly recommended.

The author HIGHLY recommends that pilots be well aware of their fatigue levels and conditions and that operators implement a good fatigue measuring system with monitoring safeguards that can assess the Analysis of Fatigues towards Pilots' Operational Fitness to Fly *(Flow Chart 5 and 6)*, preferably weekly, ideally daily, for operators with a limited number of pilots to access correct rostering schemes.

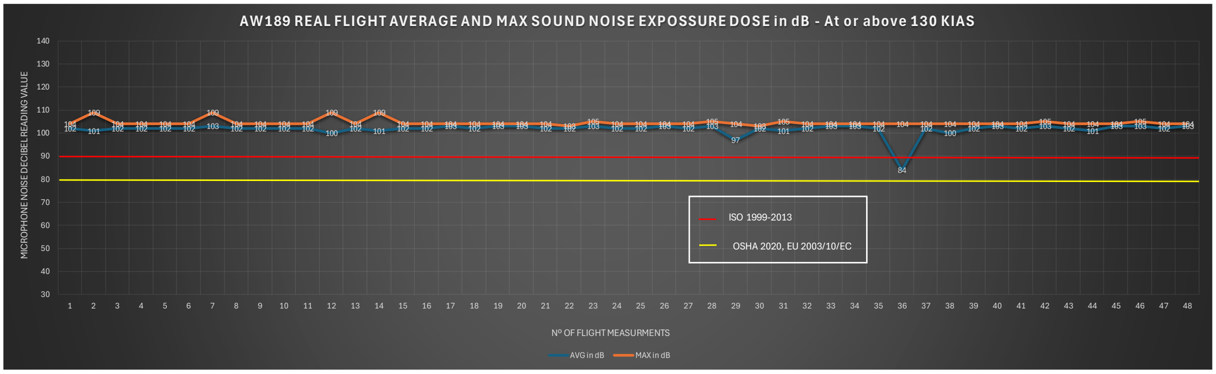
After comparing the values in **Table 34** regarding the noise reported by manufacturers shown in **Figure 41** with those obtained from real flight measurements, it is evident from **Graphics 1 and 2** that the values for the AW189 and AW139 are consistently higher than those during the overflight phase. Regarding the WBV values, reference EU 2002/44/EC, which sets an 8 hour daily limit of 101.35 dB, and ISO 2631, which defines boundaries for wellbeing risk levels between 92.67 and 98.79 dB. It can be stated that the values were apparently within the limits, with some cases of exceeding the average dose for the AW189, and stable with some exceeded cases for the AW139; when considering the maximum average values on the AW189 the majority are out of range, with some very high, while the AW139 showed slightly more stable values with some exceedances, in line with both the European Parliament regulation and the international standard references. On the other hand, it should be noted and clarified that these values are based on 30 s data collection from measurements; therefore, exposure exceeds the limit.

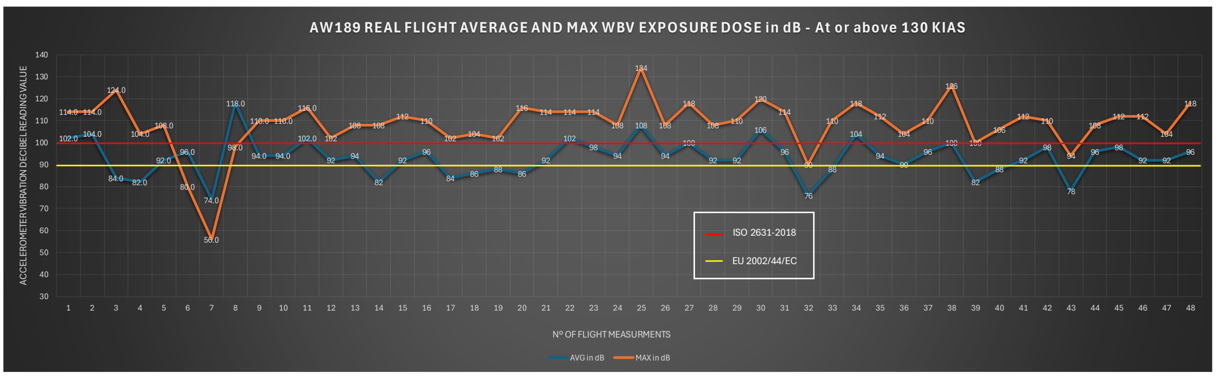
The authors' advice and awareness to Operators and Pilots, along with their alarming concern about the effects and consequences of accumulated fatigue when exposed to both leading indicators, are all the more reasons to bring forward the ability to measure pilots' fitness to fly based on rotation ON/OFF and its exposure limitations within the operation ON rotation period.

The author considers the error margin negligible across acknowledged high-quality smartphone brands and accelerometers, as supported by the collected data. Result values confirm this statement, as measurements were conducted using several smartphones from Apple and Samsung of different models, and the results were similar. When compared under similar conditions, such as fleet type, flight altitude, registration, year of production, indicated cruising speed in knots, indicated ground speed, day of flight, region, route, seating positions, yearly season, and weather conditions. All values were practically the same, with negligible decimal values.

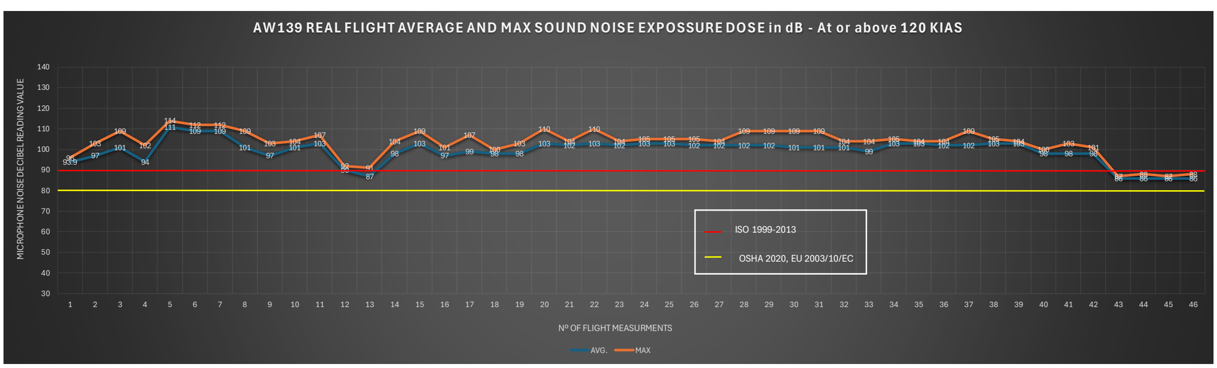
Graphics 1 and 2 show the consistency in measured noise and vibration exposure dose per hour within the research time frame and the number of measurements on the AW189 and AW139 fleets.

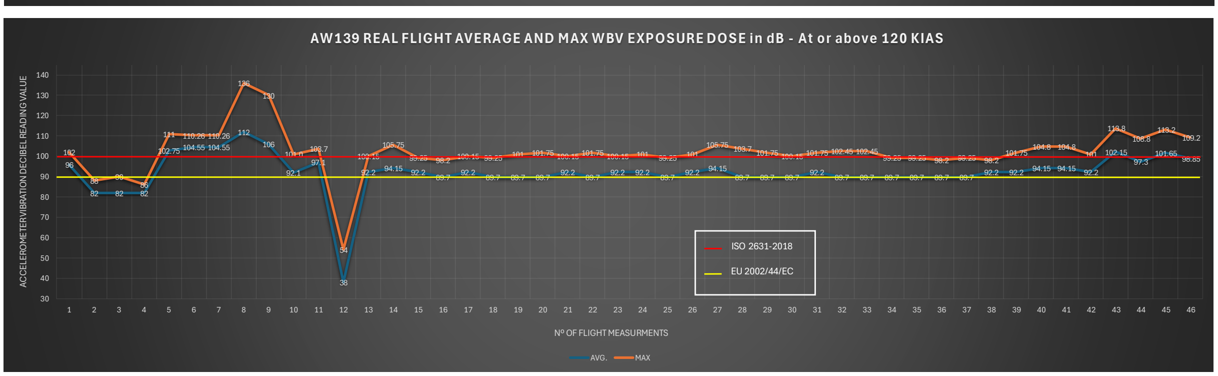
Graphic 1 – AW189 Real Flight Average and Max Sound Noise and WBV Exposure Dose in dB at or above 130 KIAS





Graphic 2 – AW139 Real Flight Average and Max Sound Noise and WBV Exposure Dose in dB at or above 120 KIAS





6.13 Comparing Measurements Concerning Pilot Position

To highlight the differences between each helicopter and the side that has a more significant impact, as determined by the collected data, **Tables 35 and 36** compare both the AW189 and AW139 on the Captain's (CPT) side, specifically the left leg, and on the First Officer's (FO) side, specifically the **right leg.**

On the AW189, with an average baseline of 3 hours and 28 minutes, 19 measurements were compared in equal calendar time frames. The comparison revealed higher noise and vibration exposure at the FO position. In sound, there is an increase of average by +0.95 dB and in average vibration by +2.2 dB. However, all Max peak values were equal in both sound noise and WBV exposures in both positions.

The Average calculated exposure for both SN and WBV per hour increased by +2.28 dB at the FO position; however, surprisingly, the maximum exposure was higher at the CPT position, with +2.39 dB. When calculated based on the total flight time exposure per day, the average value was +0.9 dB, with a maximum of +11.7 dB, both at the CPT position.

Table 35 – Average Comparing Data Analysis from Leg on the Left (CPT) and Right (FO) of the AW189

		AVERAGE COMPARING DATA ANALYSIS FROM LEG ON THE LEFT (CAPTAIN) vs RIGHT (FIRST OFFICER) OF THE AW189											
		SOUND NOISE (SN) EXPOSURE in dB		WBV - EXPOSURE in Richter Magnitude Scale		WBV - EXPOSURE in dB		Calculated SN+WBV Average Exposure in dB / H	Calculated SN+WBV MAX Exposure in dB / H	Average TFT by each pilot within the 19 measurements analysed		Calculated HNV*rf*ED in dB /Day TFT	Calculated HNV*rf*ED in dB /Day TFT
		(Sound Meter Pro)		*(Vibration Meter)*		Converted AVG	Converted MAX						
Nº of Measurements	PILOT	AVG in dB	MAX in dB	AVG.	MAX	AVG in dB	MAX in dB	AVG in dB	MAX in dB	hh, decimal	hh:mm	AVG in dB	MAX in dB
19	CPT	101.1	104.47	4.6	5.4	92.9	108.4	102.58	**113.47**	3.5	03:30	**360.1**	**395.4**
19	FO	**102.05**	104.47	**4.7**	5.4	**94.7**	108.4	**104.3**	111.08	3.5	03:27	359.2	383.7
TOTAL DIFFERENCE		(+0.95)	0.00	(+0.1)	0.00	(+2.2)	0.00	(+2.28)	(+2.39)	0.00	00:03	(+0.9)	(+11.7)

On the other hand, in the AW139, with a baseline of an average of 4 hours and 43 minutes, 18 measurements were compared in equal calendar time frames. The comparison revealed a higher incidence of noise and vibration exposure at the CPT position, as observed in all collected data, including exposure per hour and total flight time per day. In sound, the average increase was +1.28 dB, with a maximum peak value of +1.39 dB. In vibration, the average increase was +3.84 dB, with a maximum peak value of +2.69 dB.

The Average calculated exposure for SN and WBV per hour increased by +1.62 dB, and the maximum peak value was +2.55 dB. When calculated based on the total flight time exposure per day, the average value was +15.25 dB, with a maximum of +15.96 dB.

Table 36 – Average Comparing Data Analysis from Leg on the Left (CPT) and Right (FO) of the AW139

		AVERAGE COMPARING DATA ANALYSIS FROM LEG ON THE LEFT (CAPTAIN) vs RIGHT (FIRST OFFICER) OF THE AW139													
		SOUND NOISE (SN) EXPOSURE in dB		WBV - EXPOSURE in Acceleration (m/s^2)		WBV - EXPOSURE in Richter Magnitude Scale		WBV - EXPOSURE in dB		Calculated SN+WBV Average Exposure in dB / H	Calculated SN +WBV MAX Exposure in dB / H	Average TFT by each pilot within the 18 measurements analysed		Calculated HNV*rf*ED in dB / Day TFT	Calculated HNV*rf*ED in dB / Day TFT
		(Sound Meter Pro)		(*Vibration Meter*)		(*Vibration Meter*)		Converted AVG	Converted MAX						
Nº of Measurements	PILOT	AVG.	MAX	AVG.	MAX	AVG.	MAX	AVG.	MAX	AVG in dB	MAX in dB	hh, decimal	hh:mm	AVG in dB	MAX in dB
18	CPT	**101.5**	**105.5**	**0.64**	**1.75**			**94.74**	**103.79**	**103.02**	**108.91**	4.7	04:44	**488.18**	**525.26**
18	FO	100.22	104.11	0.35	1.13			90.9	101.1	101.04	106.36	4.7	04:43	472.93	509.3
TOTAL DIFFERENCE		(+1.28)	(+1.39)	(+0.29)	(+0.62)			(+3.84)	(+2.69)	(+1.62)	(+2.55)	4.7	00:01	(+15.25)	(+15.96)

Based on the data collected, the author assumes that the AW189, being of a newer design, has more stable noise and WBV exposure to both crew members than the AW139. The AW189's value difference is below +1 dB per position, whereas on the AW139, the value difference exceeds +15 dB when exposed to the same number of hours per day. However, noticeable values were recorded for the CPT position at the maximum peak value per day.

Kasin et al., stated in their study, "The results were sampled from the right pilot position, but it is reasonable to believe that the vibration levels can vary slightly from our results from the left pilot position" (Kåsin et al., 2011). To some extent, this study supports his statement that values differ slightly between left and right seat measurements. A possible explanation is the direction of the main rotor's rotation, which can be clockwise or counterclockwise. The Doppler Effect may also be relevant, as the direction of rotor rotation can affect how sound waves are perceived by an observer on the ground or in the cockpit. It is primarily related to the advancing blade, which produces a higher-pitched sound as the helicopter moves forward, while the retreating blade produces a lower-pitched sound.

In this study, both helicopters exhibit counterclockwise rotation of their main rotors when viewed from above, with a main rotor hub featuring five blades and a fully articulated main rotor system. It is noted that both helicopters rotate the tail rotor counterclockwise when viewed from the rear, with a fully articulated tail rotor hub featuring four blades. This design allows both rotor hubs to independently perform flapping, feathering, and lead/lag movements. For a counterclockwise-rotating main rotor, vibration characteristics are primarily influenced by the aerodynamic forces acting on the advancing and retreating blades. The advancing blade will be on the right side for a counterclockwise rotation, resulting in higher airspeed and lift, which in turn lead to increased vibration and sound levels. This can mainly be attributed to the values shown in **Tables 35 and 36**, which are more pronounced in the AW139, with a maximum increase of +15.96 dB when comparing the co-pilot's left side to the Captain's right side. On the AW189, the maximum difference is +11.7 dB, again comparing the Co-pilot's side on the left to the Captain's side on the right.

Chapter VII Research Contribution & Discussion

The author's research contribution in the following chapter is hereby presented, along with revised and recreated equations and operator tools. These tools will help clarify the discussion subchapter by comparing the collected data. Additionally, direct operational feedback from rotor and fixed-wing pilots supports the research results and highlights pertinent facts. The scope of the discussion was limited to the most relevant factors and their interaction based on direct or indirect effects on flight safety.

7.1 Research Contribution

In the following section, the author presents several adaptation tools based on new and relevant information from surveys and in-flight field measurements, which contribute to the safety standards in helicopter operations. Three advanced, revised, and created tools for operational use to assess and calculate fatigue levels based on vibration and noise exposure: An Equation to quantify Helicopter SN and WBV real flight exposure dose (HNV*rf*ED), Safety Risk Analysis Matrix towards WBV and SN in Helicopter Pilots and an Operational Risk Condition Due to Vibration and Noise Exposure Chart. The author would like to point out that an employer shall look for measures that help diminish the exposure as much as possible to crews and or change the work methods to achieve satisfactory results (ISO 1999-2013, 2013; ISO 9612, 2009) .

7.1.1 HNV*mf*ED & HNV*rf*ED Equations

As explained in Section 5.8.1.1, the initial **Equations 2, 3, 4, 5 and 6** were based on the manufacturer's estimated known and calculated values, as well as ISO 2631-2018. The equation was corrected, adapted, or recreated to differentiate the estimated value from absolute flight values.

$$HNVED = (dB_{total}) \times TFT \qquad (2)$$

$$HNVED = \left[10 \times \ log\left(\ 10^{(\frac{manf\,Avg\mathrm{ND}(dB1)}{10})} + 10^{(\frac{manf\,AvgVD(dB2)}{10})}\right)\right] \times TFT$$

(3)

Therefore, from the above (**Equations 2 and 3**), a recreation or adaptation of it was proposed below (**Equations 4, 5 and 6**) and used. To interpret the difference, the decomposition needed to be explained:

$$HNVmfED = \left[10 \times log\left(\ 10^{\left(\frac{manfAvg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{manfAvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{4}$$

$$HNVrfED = (dB_{total}) \times TFT \tag{5}$$

$$HNVrfED = \left[10 \times log\left(\ 10^{\left(\frac{Real\ Flight\ Avg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{Real\ Flight\ AvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{6}$$

The new acronyms represent the following:

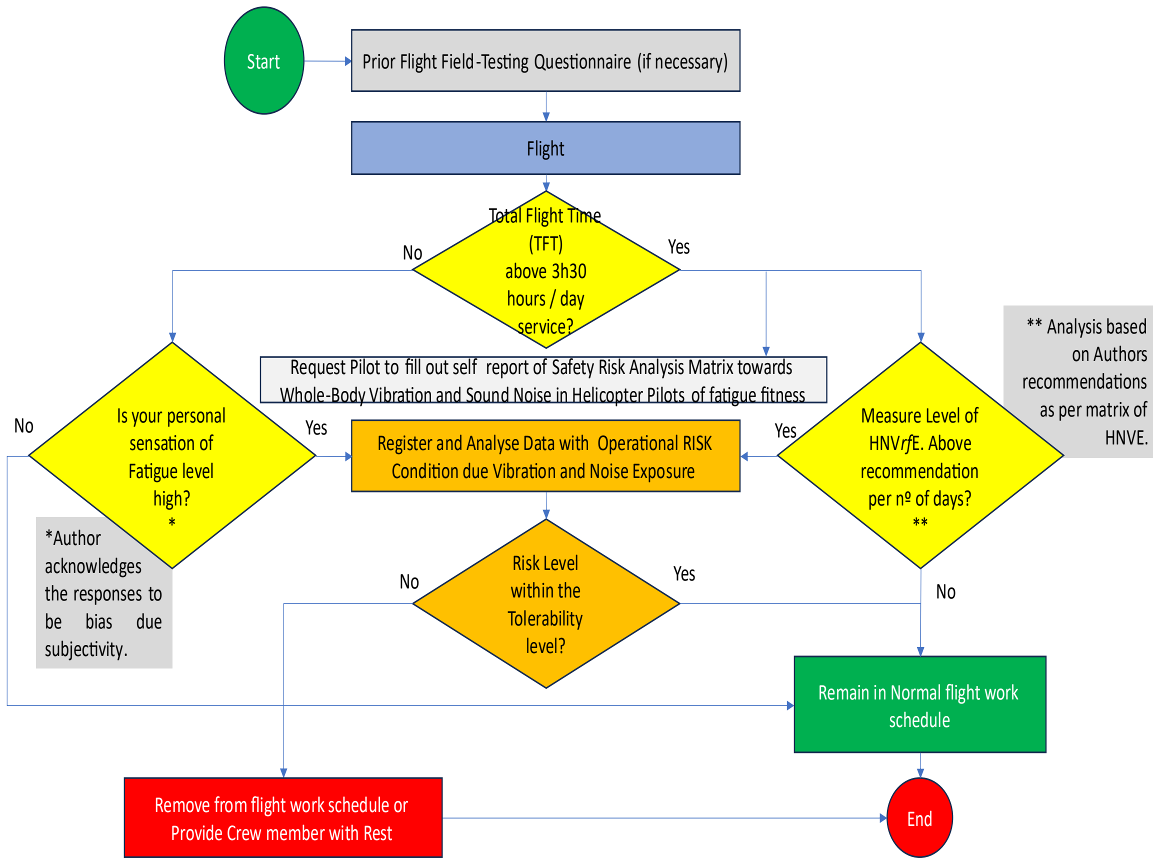
HNVED	Helicopter Noise and Whole-Body Vibration Estimated Exposure Dose
HNVrfED	Helicopter Noise and Whole-Body Vibration Real Flight Estimated Exposure Dose
HNVmfED	Helicopter Noise and Whole-Body Vibration Manufacture Estimated Exposure Dose
*Real Flight Avg*ND (dB1)	This is the average Noise Dose exposure in Real Flight. The value is calculated using a measuring app for at least 30 seconds. **<u>Note:</u>** The value used from the app is the average within 30 seconds in Cruise flight only, not the maximum value obtained at a specific point of measurement in helicopter real-flight measurements.
*Real Flight Avg*VD (dB2)	It is the average whole-body vibration dose recorded during 30 seconds of a cruise flight, measured by magnitude or acceleration. NOTE: The Value is then calculated into dB,
TFT	Total Flight Time in hours (Note: Expressed in decimal)

HNV*rf*ED calculations are based solely on cruise flights and do not account for higher vibration and noise exposure during approach and takeoff periods. The time frame within this exposure dose is considered relative to the total flight time (TFT), and the author acknowledges that these values can be significantly higher. Although if measured, the author believes that overall average vibration and noise could become negligible since the time frame of one take off and one landing may be limited to less than 10 minutes for both cases on short final for landing before and after the landing decision point (LDP) and for takeoff before and after the takeoff decision point (TDP). On the other hand, if two or more landings and takeoffs are conducted, as is normally the case for offshore flights, then the value may be significant. Since these phases of flight are considered critical and require the full attention of crews for safety reasons, it was excluded from this study, despite manufacturers recognising them as phases with higher vibration and noise.

7.1.2 Safety Management Manual Tool to Mitigate HNV*rf*ED

A safety management tool was developed to support and facilitate operators' improved understanding of flight crew fatigue levels within helicopters, as outlined in **Flow Chart 7** and **Figures 43 and 44.**

Flow Chart 7 - Safety Risk Analysis Matrix towards Whole-Body Vibration and Sound Noise in Helicopter Pilots of Fatigue Fitness.



7.1.3 Safety Risk Analysis Matrix towards WBV and Sound Noise in Helicopter Pilots

Safety is a continuous process of eliminating risk; safety and operations managers must monitor pilots' fatigue. Therefore, the author presents a revised Safety Risk Analysis Matrix Towards Vibration and Sound Noise in Helicopter Pilots, as shown in **Figures 43 and 44**. A tolerance level is defined as being easily identifiable through the colour scheme, which will be explained in **Figures 45 and 46**, based on total exposure.

Figure 43 – Safety Risk Analysis Matrix Towards Vibration and Sound Noise in Helicopter Pilots. Source: Adaptation from Safety Risk Analysis Matrix towards WBV and HL in Helicopter Pilots.(Teixeira, C., 2020)

<table>
<tr><th colspan="42">Safety Risk Analysis Matrix towards WBV and HL in Helicopter Pilots</th></tr>
<tr><td colspan="2">Age (years)</td><td colspan="5">18-23</td><td colspan="5">24-29</td><td colspan="5">30-35</td><td colspan="5">36-41</td><td colspan="5">42-51</td><td colspan="5">52-60</td><td colspan="5">61 - 65</td><td colspan="5">≥65</td></tr>
<tr><td colspan="2">Height (cm)</td><td>BELOW</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>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>ABOVE</td></tr>
<tr><td colspan="2">Weight (kg)</td><td>BELOW</td><td>61</td><td>62</td><td>63</td><td>64</td><td>65</td><td>66</td><td>67</td><td>68</td><td>69</td><td>70</td><td>71</td><td>72</td><td>73</td><td>74</td><td>75</td><td>76</td><td>77</td><td>78</td><td>79</td><td>80</td><td>81</td><td>82</td><td>83</td><td>84</td><td>85</td><td>86</td><td>87</td><td>88</td><td>89</td><td>90</td><td>91</td><td>92</td><td>93</td><td>94</td><td>95</td><td>96</td><td>97</td><td>98</td><td>ABOVE</td></tr>
<tr><td colspan="2" rowspan="2">BMI (%)</td><td colspan="5">Under Weight</td><td colspan="5">Normal Low</td><td colspan="5">Normal Ideal</td><td colspan="5">over weight</td><td colspan="5">Very Over Weight</td><td colspan="5">obese</td><td colspan="10">Very Obese</td></tr>
<tr><td colspan="5">< 18.5</td><td colspan="5">18.5 - 22.8</td><td colspan="5">22.9 - 24.9</td><td colspan="5">25.0 - 27.8</td><td colspan="5">27.9 - 29.9</td><td colspan="5">30.0 - 32.8</td><td colspan="10">32.9 - 34.9</td></tr>
<tr><td colspan="2">Medical Class I</td><td colspan="20">FIT NO RESTRICTIONS</td><td colspan="20">FIT <u>WITH RESTRICTIONS</u></td></tr>
<tr><td colspan="2">Position</td><td colspan="6">SIC</td><td colspan="6">PIC</td><td colspan="6">LTC</td><td colspan="5">FI</td><td colspan="6">TRI or TRE</td><td colspan="11">Pilot + Administrative Responsabilities</td></tr>
<tr><td rowspan="3">Days on Rotation</td><td>21</td><td colspan="40"></td></tr>
<tr><td>28</td><td colspan="40"></td></tr>
<tr><td>35</td><td colspan="40"></td></tr>
<tr><td colspan="2">Hours Flown (H)</td><td colspan="5">1 - 9</td><td colspan="5">10 - 19</td><td colspan="5">20 - 29</td><td colspan="5">30 - 44</td><td colspan="5">45 - 59</td><td colspan="5">60 - 74</td><td colspan="5">75 - 90</td><td colspan="5">90 - 100</td></tr>
<tr><td colspan="2">Nº of Landings</td><td colspan="5">1 - 19</td><td colspan="5">20 -39</td><td colspan="5">40 - 59</td><td colspan="5">60 - 79</td><td colspan="5">80 - 99</td><td colspan="5">100 - 110</td><td colspan="5">110 - 120</td><td colspan="5">>120</td></tr>
<tr><td colspan="2" rowspan="3">Average Fleet Noise (SN) & Vibration (WBV) in Cruise Flight (dB)</td><td colspan="5">AW169</td><td colspan="5">H160</td><td colspan="5">AW139</td><td colspan="5">AW189</td><td colspan="5">H175</td><td colspan="5">S92</td><td colspan="5">B525</td><td colspan="5"></td></tr>
<tr><td colspan="5"></td><td colspan="5"></td><td colspan="5">(SN) 101.31</td><td colspan="5">(SN) 103.06</td><td colspan="5"></td><td colspan="5"></td><td colspan="5"></td><td colspan="5"></td></tr>
<tr><td colspan="5"></td><td colspan="5"></td><td colspan="5">(WBV)97.13</td><td colspan="5">(WBV) 100.85</td><td colspan="5"></td><td colspan="5"></td><td colspan="5"></td><td colspan="5"></td></tr>
<tr><td colspan="2" rowspan="2">Sound Noise (dB) Exposure LIMITE to (hh:mm)/day</td><td colspan="3">90</td><td colspan="3">91</td><td colspan="3">92</td><td colspan="3">93</td><td colspan="3">94</td><td colspan="3">95</td><td colspan="3">96</td><td colspan="3">97</td><td colspan="3">98</td><td colspan="3">99</td><td colspan="3">100</td><td colspan="3">101</td><td colspan="4">102</td></tr>
<tr><td colspan="3">08:00/day</td><td colspan="3">07:00/day</td><td colspan="3">06:00/day</td><td colspan="3">05:20/day</td><td colspan="3">04:40/day</td><td colspan="3">04:00/day</td><td colspan="3">03:30/day</td><td colspan="3">03:00/day</td><td colspan="3">02:40/day</td><td colspan="3">02:20/day</td><td colspan="3">02:00/day</td><td colspan="3">01:50/day</td><td colspan="4">01:20/day</td></tr>
<tr><td colspan="2" rowspan="3">WBV (dB)
or
WBV (m/s²)
Exposure LIMITE to (hh:mm) / day</td><td colspan="3">92,67 - 98,79</td><td colspan="3">93,67 - 99,79</td><td colspan="3">94,67 - 100,79</td><td colspan="3">95,67 - 101,79</td><td colspan="3">96,67 - 102,79</td><td colspan="3">97,67 - 103,79</td><td colspan="3">98,67 - 104,79</td><td colspan="3">99,67 - 105,79</td><td colspan="3">100,67 - 106,79</td><td colspan="3">101,67 - 107,79</td><td colspan="3">102,67 - 108,79</td><td colspan="3">103,67 - 109,79</td><td colspan="4">104,67 - 110,79</td></tr>
<tr><td colspan="3">0,42 - 0,85</td><td colspan="3">0,47 - 0,96</td><td colspan="3">0,53 - 1,07</td><td colspan="3">0,60 - 1,21</td><td colspan="3">0,67 - 1,35</td><td colspan="3">0,75 - 1,52</td><td colspan="3">0,84 - 1,70</td><td colspan="3">0,94 - 1,91</td><td colspan="3">1,06 - 2,14</td><td colspan="3">1,19 - 2,41</td><td colspan="3">1,33 - 2,70</td><td colspan="3">1,50 - 3,03</td><td colspan="4">1,68 - 3,40</td></tr>
<tr><td colspan="3">08:00/day</td><td colspan="3">07:00/day</td><td colspan="3">06:00/day</td><td colspan="3">05:20/day</td><td colspan="3">04:40/day</td><td colspan="3">04:00/day</td><td colspan="3">03:30/day</td><td colspan="3">03:00/day</td><td colspan="3">02:40/day</td><td colspan="3">2h20m/day</td><td colspan="3">02:00/day</td><td colspan="3">1h50m/day</td><td colspan="4">1h40m/day</td></tr>
</table>

NOTE: The colour scheme in this safety risk analysis matrix is as follows: blue to light green indicates negligent to acceptable risk, and red indicates unacceptable risk. Yellow is the tolerance region, and orange indicates tolerable with limitations. Similar to the colour scheme explained above, the colour scheme becomes clearer throughout the rest of the research, with more data presented in a similar way.

Figure 44 - Safety Risk Analysis Matrix towards Vibration and Sound Noise in Helicopter Pilots (cont.). Source: Adaptation from Safety Risk Analysis Matrix towards WBV and HL in Helicopter Pilots.(Teixeira, C., 2020)

	Helicopter Noise and Whole-Body Vibration Real Flight Exposure Dose (HNV*rf* ED) (seated or standing)							
HL + WBV TOTAL EXPOSURE dB / day (HNV*rf* ED / day ON)	≤ 393,75	≤ 442,97	≤ 492,18	≤ 541,40	≤ 566,44;	≤ 590,62	≤ 623,10	≤ 658,10
RISK Condition	ACCEPTABLE		TOLERABLE		TOLERABLE WITH LIMITATIONS		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	
Sports Activity (hh:mm) / day	Every Day	6 days a week	5 days a week	4 days a week	3 days a week	2 days a week	1 day a week	Never
	00:15 min / day	00:30 min / day	00:45 min / day	01:00 / day	01:30m / day	02:00 / day	02:30m / day	daily bi training
Smoke	Don´t Smoke	casual or social smoker	1pack/ WEEK	1/2 pack/day	1 pack/day	1 1/2 packs/day	2 packs/day	≥2 packs/day
Alcohol	Don´t Drink	casual or social drinker	1 glass cup/day	1 1/2 glass cup/day	2 glass cups/day	2 1/2 glass cups/day	3 glass cups/day	3 1/2 glass cups/day
Lower Back Pain (LBP)	No Disconfort or Pain	Very Slight Disconfort	Slight Disconfort	Disconfort	Achy	Very Achy	Painful	Very Painful
Normal Daily Sleep Cycle (H)	≥ 8	≥ 7	≥ 6	≤ 6	≤ 5	≤ 4	≤ 3	≤ 2
Sleep Information	Sleep in Very good shape, keep current attitude	Sleep in good shape, but many steps can make it better	Some Sleep problems, it's important to examine sleep	Sleep problems, it's important to examine sleep habits and make	Sleep problems seem to be severe	Sleep problems seem to be very severe, medical checkup recommended		

DATA: __/__/____ Remarks:

PILOT NAME AND SIGNATURE		DISPATCH OFFICER or SAFETY OFFICER NAME & SIGNATURE		FLIGHT OPERATIONS MANAGER or SAFETY MANAGER NAME & SIGNATURE	

Fitness condition	Fit to fly	Good to fly	Ok to fly,	CAUTION, REST SHOULD be recommended	REST SHALL be recommended	UNFIT TO FLY, rest MANDATORY		

FOM or SM, SHALL state reason for UNFITNESS TO FLY:

To calculate the BMI (Body Mass Index), the author applied **Equation 10** BMI Calculator *Created by Belgian Adolphe Quetelet in 1832* and **Figure 45** index reference.

$$BMI = \frac{weight}{(height * height)} \tag{15}$$

NOTE: Measurement units of Weight in kg and height in meters.

Figure 45 – Body Mass Index Calculator & Reference for the Proposed Safety Risk Analysis Matrix (Figures 43 and 44).

BODY MASS INDEX CALCULATOR & REFERENCE			
CALCULATOR		REFERENCE	
BMI (%)	25.8	Under Weight	< 18.5
		Normal Low	18.5 - 22.8
		Normal Ideal	22.9 - 24.9
WEIGHT (kg)	80	Over Weight	25.0 - 27.8
		Very Over Weight	27.9 - 29.9
HEIGHT (m)	1.76	Obese	30.0 - 32.8
		Very Obese	32.9 - 34.9

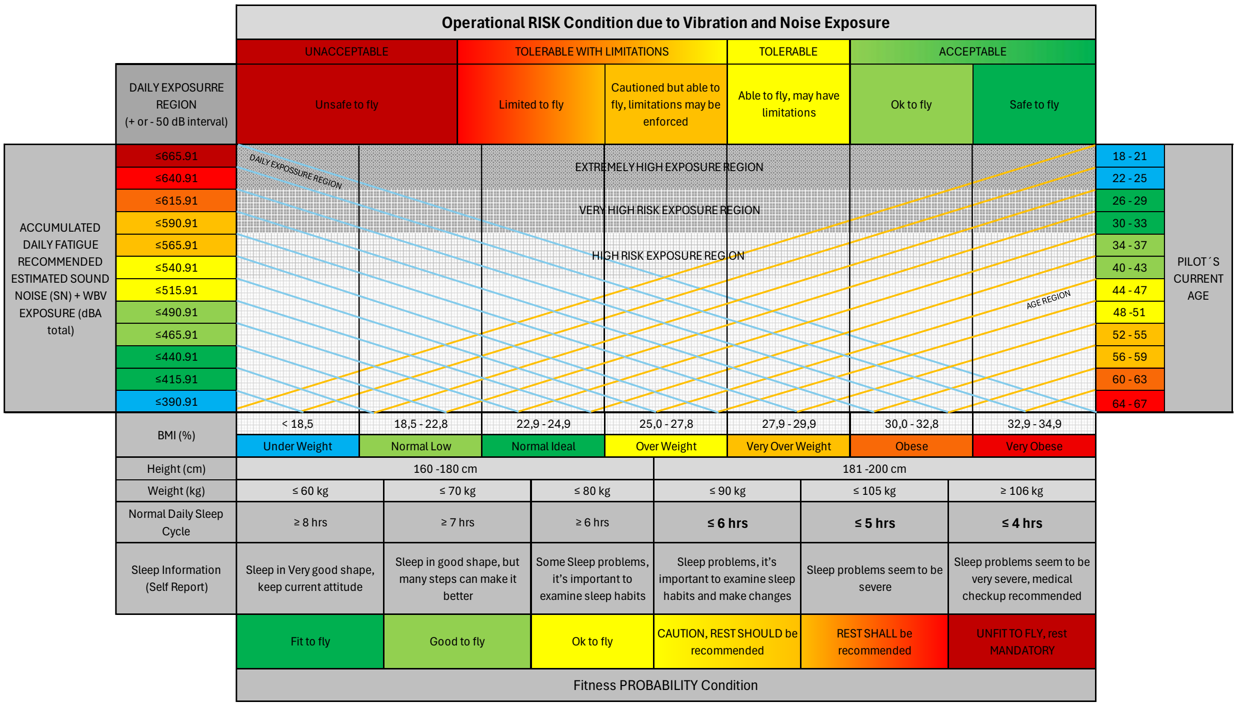
NOTE: Values presented of BMI, Weight and Height correspond to the author's body values.

7.1.4 Operational Risk Condition Due to Vibration and Noise Exposure

Improving crews' knowledge of their limits is fundamental to operational safety and health. The author provides an enhanced understanding of the Operational Risk Condition Due to Vibration and Noise Exposure, including maximum exposure limits and tolerable thresholds, to prevent the accumulation of complete fatigue resulting from exposure to noise and vibration. The crew's Age and BMI can significantly influence their understanding of fitness conditions, likely resulting in higher levels of fatigue and bodily sensations, as well as both psychological and physiological aspects of fatigue.

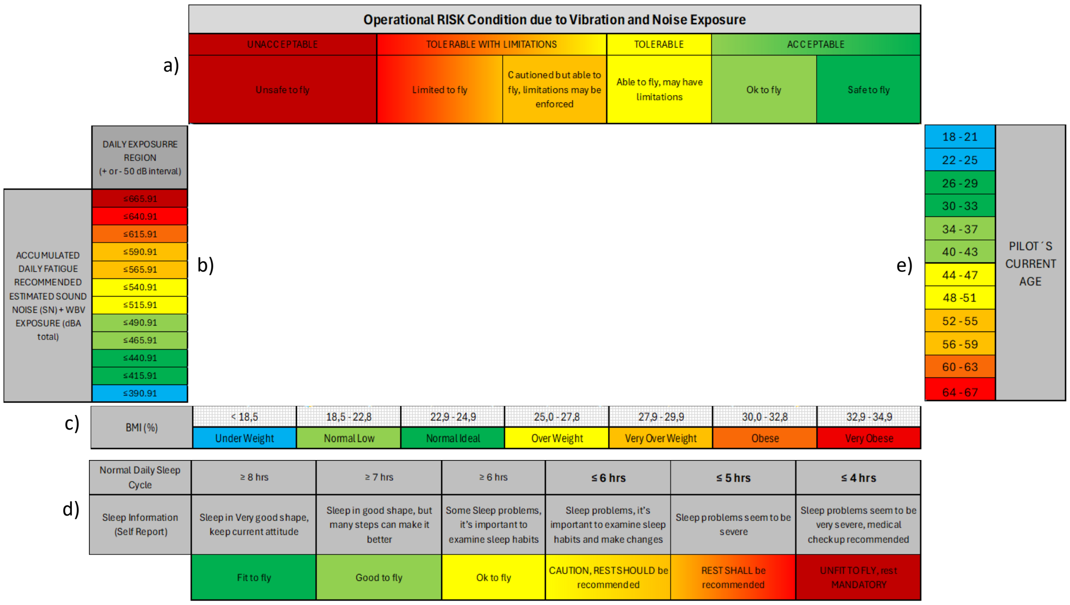
Figure 46 is a cross-reference diagram illustrating the correlation between the information obtained from the Safety Risk Analysis Matrix and the Vibration and Sound Noise data concerning helicopter pilots, as shown in **Figures 43 and 44**. Safety officers or operations managers can analyse this information to identify pilots' tolerance limits regarding accumulated daily fatigue, as indicated by the recommended exposure dose. Additionally, the association between fatigue levels, age and BMI, as well as sleep cycle and SN+WBV, is illustrated in **Figure 46**.

Figure 46 – Operational Risk Condition due to Vibration and Noise Exposure. Source: Author´s Creation and Adaptation from Performance Risk Chart for HL & WBV Daily Exposure (Teixeira, C., 2020).



After data collection, it became clear that the measurement values exceeded the manufacturers' values (**Table 34**). **It was necessary to establish a tolerance scale defined by the colour scheme**, which ranges from green to red: **green is acceptable, yellow is tolerable, orange is tolerable with limitations, and red is unacceptable**. Blue is considered to have no risk for pilots relative to SN and WBV. The colour scheme is illustrated with a tolerance scale in **Figures 46 and 47**, and the analysis and averages are calculated using the manufacturer values and ISO2631, along with actual flight data to support the creation of the tolerance region in **Figure 48**, which determines the values for the daily exposure region scale in **Figure 47 b). Figure 47** analyses age, BMI, and daily exposure limits against the daily flight limit, recommended daily limit for operations, and ideal limit for pilots' health, all related to age and BMI ratios. However, when analysing the whole spectrum, it is vital to consider the sleep cycle, as it can lead to an increased incidence of fatigue.

Figure 47 – Operational Risk Condition Due to Vibration and Noise Exposure defines the operating risk region with tolerance scales. Source: Author´s adaptation and Creation from Performance Risk Chart for HL & WBV Daily Exposure (Teixeira, 2020)



The **colour scheme will also correlate with the operational risk condition due to vibration and sound noise exposure, which defines the operating risk region by considering BMI (Figure 47c), age (Figure 47e), and sleep cycle (Figure 47d). The unacceptable (dark red), tolerable with limitations (orange), tolerable (yellow),** and **acceptable (green)** regions, as explained above, are the **tolerance scale defined by the colour scheme,** which is here associated and described in terms of dB exposure per day.

Since no daily exposure region-scale exists, it was necessary to create one. **Figure 48** references the Daily Exposure Regions of the Operation Risk chart in **Figure 47b).** The reference scale calculation involved summing the three values from HNVED (**Equation 3**), HNVmfED (**Equation 4**), and HNVrfED (**Equation 6**), the inferior and superior limits, and then dividing the total by an appropriate factor of three. The reference scale of exposure was established with an interval of ±50 dB. Although the difference between the limits of 6 hours 15 minutes and 6 hours, and 6 hours 30 minutes was based on an interval of ±25 dB.

The author has designated the orange tolerable-with-limitations region as a zone to avoid exceeding the daily limit. It agrees to some extent with occasional entries when a reasonable, unforeseen operational situation arises with services or crews. Since safety is of primary concern in every aviation sector and the oil and gas industries, the author recommends and sets the daily safe limit in yellow, within the tolerable region, for daily limit working purposes, calculations for best rostering, and comparison with other fleets, services, and based on time and exposure.

Figure 48 – AW139 and AW189 Average Exposure in Cruise Flight per Hour for Two Sources (SN & WBV) and Tolerance Regions Calculation

AW139 and AW189 AVERAGE EXPOSURE IN CRUISE FLIGHT PER HOUR FOR TWO SOURCES (SN & WBV) AND TOLERANCE REGIONS							
HOURS	HVNmfED (Manufacture and ISO2631) (dB)	HNVrfED (INFERIOR Limit) (dB)	HNVrfED (SUPERIOR Limit) (dB)	OBSERVATION	IDENTIFYING LIMIT BASED ON FLIGHT DATA WITH AVERAGE VALUE (dB)	AUTHORS CONVENTION WITH +/- 50 INTERVAL (dB)	AUTHORS CONVENTION OF TOLERANCE REGION (dB)
	98.63	101.13	107.87				
8	789.07	809.08	862.94	OPERATIONALLY UNACCEPTABLE REGION	820.36	790.91	≤790.91
7.5	739.75	758.51	809.01		769.09	740.91	≤740.91
7	690.44	707.94	755.07		717.82	690.91	≤690.91
6.5	641.12	657.37	701.14		666.54	665.91	≤665.91
6.25	**616.46**	**632.09**	**674.17**	**AUTHOR LIMIT FOR TWO SOURCES OF EXPOSURE (6 H 15 MIN)**	**640.91**	**640.91**	≤640.91
6	591.80	606.81	647.21		615.27	615.91	≤615.91
5.5	542.49	556.24	593.27	TOLERABLE WITH LIMITATIONS REGION	564.00	565.91	≤590.91
5	493.17	505.67	539.34		512.73	515.91	≤565.91
4.5	443.85	455.11	485.40	TOLERABLE REGION	461.45	465.91	≤540.91
4	394.54	404.54	431.47		410.18	415.91	≤515.91
3.5	345.22	353.97	377.54	ACCEPTABLE REGION	358.91	365.91	≤490.91
3	295.90	303.40	323.60		307.64	315.91	≤465.91
2.5	246.58	252.84	269.67		256.36	265.91	≤440.91
2	197.27	202.27	215.74		205.09	215.91	≤415.91
1.5	147.95	151.70	161.80	NEGLECTABLE RISK	153.82	165.91	≤390.91
1	98.63	101.13	107.87		102.55	115.91	≤365.91

The limitation of hours per rotation necessitates calculation, resulting in the creation of **Tables 37 and 38**. These tables are based on a maximum of 95 hours allowed within a 28 day work period (four consecutive weeks) (DR. N.141 NTA 15, 2022). The total hours are then divided by the number of working days in rotations of 21 and 28 ON/OFF cycles. In this cycle, pilots work for six days and rest on the seventh.

Therefore, the calculation was based on the following system: 6+1+6+1+6+1 for 21 days ON, resulting in 18 flying days and 3 days of rest, and 6+1+6+1+6+1+6+1 for 28 days ON, resulting in 24 flying days and 4 days of rest. Pilots can fly for 5 hours and 16 minutes within the 18 day working cycle, accumulating 94 hours and 48 minutes of flight time per rotation, or be limited to an average of 95 hours. With a 24 day working cycle, averaging 3 hours and 57 minutes per day, it is possible to accumulate the same number of hours of flight per rotation, as per regulations of a 28 day working cycle.

Furthermore, when working a 35 ON/OFF roster, it results in 6+1+6+1+6+1+6+1+6+1, which yields 30 flying days and 5 days of rest. Pilots will be able to fly an average of 3 hours and 10 minutes per day or perform the 28 day rotation 3 hours and 57 minutes per day and have continuous monitoring of the next 6 days of flying to maximize the number of hours per day be able to maintain within the 28 day cycle within the 95 hour limit. To understand tolerance zones, the same colour scheme was applied based on the hours of normal daily activities collected from Appendix 4.

Calculations are based on the average number of flying hours within both fleets per day after the collection of flight measurements (3h36min and 4h17min in the AW139 and AW189, which results in 3h57min) that can be multiplied by the number of working days to achieve the maximum hours permitted per rotation, respecting the 28 day cycle. Limits within the 21 and 35 day work rostering periods were calculated to determine the maximum permitted hours within each cycle. The results showed the daily hours needed to reach the cycle's maximum. **Table 38** displays the 21 ON/OFF rotation daily limit of 5 hours and 16 minutes, though pilots would experience higher exposure if they worked that many hours daily. In contrast, the 35 ON/OFF rotation has a daily limit of 3 hours and 10 minutes, with lower exposure expected if pilots adhere to this limit each day. When the phrase “not permitted” appears in **Table 37**, the limits of the 28 day cycle are exceeded based on the average flying hours per day. It also shows the number of flying hours per day in each roster that would lead to exceeding the cycle, allowing the colour scheme used above in the tolerance region to be applied according to the set reference values of the daily tolerance region. This creates a direct connection to daily limits within each rostering period.

The calculation is performed by multiplying the number of hours from decimal values by the number of days worked within the rotation, which is 18, 24, and 30 for the 21, 28, and 35 ON/OFF rotations, respectively. The value closest to the limit within the 28 day cycle would determine the total number of hours the pilot would accumulate in the same cycle, shown in **Table 38.** This would ensure the operator's pilot efficiency ratio in selecting the best roster scheme for operational demands.

Table 37 – Authors calculated Total of Flying Time per Rotation 21, 28, 35 ON /OFF

Conversion Min to Decimal	
Minutes	Decimal
6	0.1
12	0.2
18	0.3
24	0.4
30	0.5
36	0.6
42	0.7
48	0.8
54	0.9
60	1.0

Average Number of flying hours / day (decimal)	Average Total Flying Hours per day times the number o working days per rotation (having 1 day to rest after working 6 days straight)		
	21	28	35
	18	24	30
6.2	not permited	not permited	not permited
5.5	not permited	not permited	not permited
5.2*	94:48	not permited	not permited
4.1	73:48	not permited	not permited
3.9*	71:06	94:48	not permited
3.5	63:00	84:00	not permited
3.1*	57:00	76:00	95:00
*Based on exact minutes within the decimal interval			

Table 38 – Authors Calculated Average Hours per day to Maximise per Rotation Versus HNVrfED.

Average hours per day to maximize per Rotation Vs HNVrfED			
FLIGHT ACTIVITY in DAYS	21	28	35
	18	24	30
	Authors Recommended Flight Hours Limit /day		
Hours /Day (hh:mm)	05:16	03:57	03:10
Hours/Day (decimal)	5.2	3.9	3.1
Total Hours/ Rotation (hh:mm)	94:48	94:48	95:00

7.2 Discussion

Country constraints such as heavy road traffic, poor road conditions, tropical weather, and occasional shortages of essentials, like water and electricity, negatively impact family living standards, commute times, and healthcare access, which can range from poor to moderate. Consequently, previous flights may leave pilots feeling unwell-rested when reporting for duty, as they need at least 11 to 12 hours of rest after their last flight, ideally including 8 hours of uninterrupted sleep. Helicopter pilots must possess complex psychomotor skills; flying demands excellent coordination of hands and feet, as well as the ability to multitask using visual, verbal, and auditory cues. Exposure to vibration and sound at discomforting levels can impair these abilities and potentially harm the crew's health.

This research provides reasonable evidence that whole-body vibration (WBV) and substantial sound noise (SN) are significant factors contributing to pilot fatigue, affecting overall cognitive fatigue and psychomotor performance. Additionally, age plays a crucial role in recovery periods, as it influences accumulated daily fatigue through its degenerative effects on the body.

Concerns regarding the pilot's alertness and capability to safely conduct helicopter flights in regular and emergency situations remain contentious. While a pilot may trick their body into escaping the fatigue cycle, the long-term effects cannot be ignored; fatigue builds up over time. Additionally, the current pilot shortage, exacerbated by the global crises reported by Boeing and Airbus, means that no effective rostering scheme can be maintained. This research study identifies measures that can help helicopter pilots fly more safely, maintain better health, and have longer careers. Limiting the number of hours flown daily can improve operational rostering, ensuring that pilots are fit to fly safely and operate effectively.

Additionally, composite concerns arise with larger size and an increased number of emergency windows in both the AW139 and AW189; the author believes they have increased the noise and vibration experienced by crews and passengers. Modern helicopters may have reduced the cabin noise to some degree by replacing the heavy, ringing metal airframe with a self-damping composite shell. Be more efficient with less aluminium, more honeycomb cores and aeroelastic lay-ups which cancel hub loads at the blade before they reach the fuselage. Laminates offer the same stiffness as metal, at least 30% less weight, while adding 2–3 mm of extra damping without exceeding the original mass of the metal. The result may have been a 15 dB quieter cockpit and 40% lower whole-body vibration, all at no weight penalty.

Although the industry is increasingly adopting composites, noise and vibration issues still persist in helicopters. Cabin noise and vibration are closely linked: aerodynamic and mechanical sources produce sound levels that often surpass 80 dB and can reach 115 dB, while also causing airframe vibrations that reduce component lifespan and contribute to pilot fatigue and hearing loss. Traditional insulation methods add weight, which conflicts with the industry's 30-year goal of creating lighter, more fuel-efficient airframes, increasing range, and increasing payload for the offshore sector. Failing to achieve this could result in reduced payloads for operators and a decline in the acceptance of this helicopter type. Consequently, future research and designs must incorporate low-mass, multifunctional materials and active systems to reduce both acoustic energy (aiming for a 35 - 50 dB reduction) and structural vibration; without these advancements, the potential improvements in comfort, safety, and durability offered by modern, lighter helicopters with additional composite parts cannot be realised.

The author believes that newer helicopters may naturally transmit more vibration and noise to the crew and passengers due to the increase in the number and size of windows. The added fix from the manufacturer's initial design specifications may result in higher vibration with increased horsepower in each engine.

7.2.1 Result Comparison

With the established values in **Figure 41**, the calculation was performed using **Equations 12 and 14.** In **Table 39**, the author presents the estimated expected daily exposure value, calculated from manufacturing data and ISO 2631 recommendations, as explained in **Figures 41 and 42**. Additionally, the decibels to which pilots are exposed during each flight rotation, as recorded in Cruise Flight data, are provided in **Table 34** and **Graphics 1 and 2**. It was noticeable that the tolerance range was already out of the recommended zone for the 21 ON/OFF rotation roster. The rotation demonstrated that, per working day, in the 21 and 28 day ON/OFF rotation schemes, pilots would have an average of 5 hours and 16 minutes on the 21-day ON/OFF roster and an average of 3 hours and 57 minutes on the 28 day ON/OFF roster. Based on the tolerance range explained in **Figure 48**, the calculations in **Table 39** indicate that the risk range falls within operational tolerance (yellow). However, it is always working at the limit of the tolerance range.

Table 39 – Calculated HNVmfED based on average noise from manufacturers and WBV from ISO 2631. Source: Author´s and Creation based on WBV from ISO 2631 (ISO 2631-5, 2018).

$$HNVmfED = \left[10 \times \log\left(10^{\left(\frac{manfAvgND(dB1)}{10}\right)} + 10^{\left(\frac{manfAvgVD(dB2)}{10}\right)}\right)\right] \times TFT$$

HELICOPTER model	Average Sound Noise (SN) (dB)	Average WBV (dB)	**SN + WBV (dB)**	TFT (LIMIT HOURS / 4 Consecutive Weeks) (h) (NTA 15, PARTE E 15.050, b))	**HNV*mf* ED (dB)**	ROTATION SCHEME Nº OF DAYS ON (EX: 21 ON/OFF)	EST. EXP. VALUE HNV*mf* ED/ DAY (dB) (TOLERABLE)	ROTATION SCHEME Nº OF DAYS ON (EX: 28 ON/OFF)	EST. EXP. VALUE HNV*mf* ED/ DAY (dB) (ACCEPTABLE)
AW139	**95.10**	**95.73**	**98.44**	**95**	**9 351.49**	**18**	**519.53**	**24**	**389.65**
AW189	**95.91**	**95.73**	**98.83**	**95**	**9 388.97**	**18**	**521.61**	**24**	**391.21**
S-76C++	96.46	95.73	99.12	95	9 416.46	18	523.14	24	392.35
AS332L2	97.20	95.73	99.54	95	9 456.03	18	525.34	24	394.00
EC225	98.20	95.73	100.15	95	9 514.12	18	528.56	24	396.42
AVERAGE NUMBER OF HOURS FLOWN PER DAY IN EACH ROTATION SCHEME						**05:16**		**03:57**	
TOTAL NUMBER OF HOURS FLOWN PER ROTATION IN EACH SCHEME						**94 h 48 m**		**94 h 48 m**	

The result demonstrates that pilots could accumulate 94 hours and 48 minutes of flying time on the 21 day ON/OFF roster, precisely the same number of hours as the 28 day ON/OFF roster, as explained in **Tables 39 and 41**. The primary distinction lies in the amount of daily exposure and the associated risk of fatigue within each rotation.

A correlation must be established to compare the current findings and the ISO and manufacturers' data. **Table 40** presents the analyses of limitations presented in Teixeira´s study and the Tolerance range that reflects each rotation scheme of 21, 28, and 35 ON/OFF. A reference value was determined here regarding the limitations of the two sources of exposure (SN+WBV) and the total flight time for all five helicopter types. Although the focus shifted to the AW139 and AW189 for the remainder of the study, the data for the other helicopters remained unchanged, as only the AW139 and AW189 were field measured in flight.

Table 40 – ISO and Manufacture Values in Figure 41 or Table 39 with Tolerance Scale Figure 48

OPERATIONAL DAILY EXPOSURE (SN + WBV)												
HELICOPTER model	AUTHORS ACCEPTABLE REGION LIMITE *HVNmfED dBtotal /day* (LIMITED TO 3h57min)	AUTHORS TOLERABLE *REGION LIMIT HVNmfED dBtotal /day* (LIMITED TO 5h12min)	AUTHORS UNACCEPTABLE REGION LIMIT HVNmfED dBtotal/DAY (LIMITED TO 6h15min)	EXPOSURE LIMIT *dBtotal/rotation (ACCEPTABLE)*			EXPOSURE LIMITE *dBtotal/rotation* (TOLERABLE)			EXPOSURE LIMITE *dBtotal/rotation* (UNACCEPTABLE)		
				21	28	35	21	28	35	21	28	35
				18	24	30	18	24	30	18	24	30
AW139	383.90	511.87	610.31	6 910.26	9 213.68	11 517.10	9 213.68	12 284.90	15 356.13	10 985.54	14 647.38	18 309.23
AW189	385.44	513.92	612.75	6 937.95	9 250.60	11 563.25	9 250.60	12 334.14	15 417.67	11 029.57	14 706.09	18 382.61
S-76C++	386.57	515.43	614.55	6 958.27	9 277.69	11 597.11	9 277.69	12 370.25	15 462.82	11 061.86	14 749.15	18 436.44
AS332L2	388.20	517.59	617.13	6 987.51	9 316.68	11 645.85	9 316.68	12 422.24	15 527.80	11 108.35	14 811.14	18 513.92
EC225	390.58	520.77	620.92	7 030.43	9 373.91	11 717.38	9 373.91	12 498.54	15 623.18	11 176.58	14 902.11	18 627.64
Values presented are based on Auhtors calculated average exposure WBV + Noise (Cause of HL) limits and rotation schemes. Recalculated to a safer daily value and limited to 6h15 min of flight per day.												

The initial reference UNACCEPTABLE region, presented above the flight time limit of 6 hours and 15 minutes, is depicted in Figure 42, which establishes a correlation based on two sources of exposure: from manufacturer noise and ISO 2631 WBV inferior and superior values. This is based on values from **Figure 41** or **Table 39**. After analysing and correlating the **Daily Exposure Regions** shown in **Figure 47 b),** the **TOLERABLE** region was identified, with a difference of **minus 1 hour and 3 minutes**, setting the limit flight time at **5 hours and 12 minutes.** Additionally, the safe **ACCEPTABLE** region was **minus 1 hour and 15 minutes** from the TOLERABLE REGION, and the **flight time limit** was set at **3 hours and 57 minutes**.

Table 41 – Calculated HNVrfED in-flight measurements.

$HNVrfED = \left[10 \times \log\left(10^{\left(\frac{Real\ Flight\ Avg ND(dB1)}{10}\right)} + 10^{\left(\frac{Real\ Flight\ Avg VD(dB2)}{10}\right)}\right)\right] \times TFT$									
HELICOPTER model	Average Real Flight Sound Noise (SN) (dB)	Average Real Flight WBV (dB)	**In Flight SN + WBV (dB)**	TFT (LIMIT HOURS / 4 Consecutive Weeks) (h) (NTA 15, PARTE E 15.050, b))	**HNVrf ED (dB)**	ROTATION SCHEME Nº OF DAYS ON (EX: 21 ON/OFF)	EST. EXP. VALUE HNVrf ED/ DAY (dB) (TOLERABLE)	ROTATION SCHEME Nº OF DAYS ON (EX: 28 ON/OFF)	EST. EXP. VALUE HNVrfED/ DAY (dB) (ACCEPTABLE)
AW139	**101.31**	**97.13**	**102.93**	**95**	**9 758.15**	**18**	**542.12**	**24**	**406.59**
AW189	**103.06**	**100.85**	**106.08**	**95**	**9 985.21**	**18**	**554.73**	**24**	**416.05**
S-76C++	96.46	95.73	99.12	95	9 416.46	18	523.14	24	392.35
AS332L2	97.20	95.73	99.54	95	9 456.03	18	525.34	24	394.00
EC225	98.20	95.73	100.15	95	9 514.12	18	528.56	24	396.42
AVERAGE NUMBER OF HOURS FLOWN PER DAY IN EACH ROTATION SCHEME						**05:16**		**03:57**	
TOTAL NUMBER OF HOURS FLOWN PER ROTATION IN EACH SCHEME						**94 h 48 m**		**94 h 48 m**	

Focusing on the efficiency of production and flight services provided by pilots, the monthly (4 consecutive weeks) hour limitations were apparent. **It was evident that the AW139 on the 21 and 28 day ON/OFF roster scheme showed a change in exposure value within 95 hours of flying.** This meant flying at least 5 hours and 16 minutes each day, which would place the pilot's exposure above the author's ACCEPTABLE green range reference of 490.91 dB or below, above the TOLERABLE yellow range of 540.91 dB or below, and also above the TOLERABLE WITH LIMITATIONS, caution section, light orange reference of 590.91 dB or below on the total daily exposure range in **Figure 48**. This represented an increase in decibel exposure per rotation in both the 21 and 28 ON rosters. **It would represent a roster with a total exposure value showing an INCREASE of 51.21 dB in the 21 ON roster and an INCREASE of 2.85 dB per day, both from the ACCEPTABLE region. On the other roster with total exposure value, there was a DECREASE of 84.32 dB in the 28 ON roster and a DECREASE of 3.51 dB per day, both of which were outside the ACCEPTABLE region.**

For the **AW189 on the 21 and 28 day ON/OFF roster** scheme, the change of exposure value within 95 hours of flying, and 3 hours and 57 minutes per day of flying. It would be above the authors' ACCEPTABLE green range, above the TOLERABLE yellow range, and in the TOLERABLE WITH LIMITATIONS caution section on the total daily exposure range in **Figure 48**. This represented increased decibel exposure per rotation in the 21 and 28 ON rosters. **It would represent a roster with a total exposure value with an INCREASE of 63.82 dB in the 21 ON roster and an INCREASE of 3.55 dB per day**. **On the other roster, with total exposure value, there is a DECREASE of 74.86 dB in the 28 ON roster and a DECREASE of 3.12 dB per day, both of which are outside the ACCEPTABLE region.**

Between 21 and 28 days ON/OFF rostering schemes, the levels, as per the reference index mentioned above, are **revealed to be safer for pilots in the 28 ON/OFF roster**. **Calculations predict and demonstrate higher levels of operational safety, pilots' health, and career longevity[5], indicating expected lower fatigue related to SN and WBV, thereby increasing fitness to fly.** The average number of hours per day is noticeably lower. The author recommends operations with a low to medium average of flights per aircraft per day, or several crews to split services, several aircraft, or a combination of all three. This solution is highly recommended. Operators with large fleets and crews are advised to utilise the 28 or 35 ON/OFF schedule, as levels are lower, within the same number of hours permitted per rotation under the 28 day aeronautical regulation limitations.

If operators and pilots adhere to the limits specified in the aviation regulations of being able to fly 8 hours per day, to the reference limits detailed in ISO 2631, ISO 1999, and OSHA standards- while ignoring the fact that two combination sources exist and how both have a direct effect on pilots' fatigue levels- they will always face the risk of fatigue and illnesses when flying.

Additionally, if operators and pilots use the manufacturers' reported values and apply the inferior and superior limits from ISO 2631 when calculating combined sources, they still risk exposing pilots to increased fatigue and medium- to long-term illnesses. Based on the collected data, they would experience higher fatigue levels, and the operational safety latent risk would be higher.

[5] Career Longevity, the International Civil Aviation Organisation (ICAO) sets the career longevity for commercial helicopter pilots at 65 years for multi-pilot operations and 60 years for single-pilot operations. These are the global standards for international commercial air transport, but individual countries may have different regulations for domestic flights.

Tables 42, 43, 45, and 46 clarify the exposure levels for operators and pilots concerning the daily 8 hour limit and the four-week 95 hour limit for exposure doses when using two sources. They also present the average SN+WBV exposure dose calculated during pilots' 8 hour daily flying limit, in accordance with aviation regulations. Additionally, **Tables 43 and 46** show that exposure levels are determined based on horizontal and vertical correlations as the dB levels increase in **Figure 42**. This figure provides individual ISO 1999 exposure limit values for SN, ISO 2631 exposure limit values for WBV, and the combined-source value.

Table 42 – Calculation when using two Sources multiplied per 8 hour day flying

NOISE (SN) (dB1)	NOISE EXPOSURE LIMIT TIME/DAY (hh:mm)	WBV INFERIOR LIMIT (dB2)	WBV SUPERIOR LIMIT (dB2)	WBV EXPOSURE LIMITE TIME/DAY (hh:mm)	CALCULATED AVERAGE COMBINED SOURCES (SN+WBV INFERIOR LIMIT) (dB)	CALCULATED AVERAGE COMBINED SOURCES (SN+WBV SUPERIOR LIMIT) (dB)	SN+WBV EXPOSURE INFERIOR LIMIT *dBtotal/day (dB)*	SN+WBV EXPOSURE SUPERIOR LIMIT *dBtotal/day* (dB)	SN+WBV EXPOSURE Average. *dBtotal/day* (dB)
90	08:00	92.67	98.79	08:00	94.55	99.33	756.38	794.63	775.51
91	07:00	93.67	99.79	07:00	95.55	100.33	764.38	802.63	783.51
92	06:00	94.67	100.79	06:00	96.55	101.33	772.38	810.63	791.51
93	05:20	95.67	101.79	05:20	97.55	102.33	780.38	818.63	799.51
94	04:40	96.67	102.79	04:40	98.55	103.33	788.38	826.63	807.51
95	04:00	97.67	103.79	04:00	99.55	104.33	796.38	834.63	815.51
96	03:30	98.67	104.79	03:30	100.55	105.33	804.38	842.63	823.51
97	03:00	99.67	105.79	03:00	101.55	106.33	812.38	850.63	831.51
98	02:40	100.67	106.79	02:40	102.55	107.33	820.38	858.63	839.51
99	02:20	101.67	107.79	02:20	103.55	108.33	828.38	866.63	847.51
100	02:00	102.67	108.79	02:00	104.55	109.33	836.38	874.63	855.51

The SN+WBV exposure average per day is calculated and multiplied by the number of possible flying days in each rotation to determine the exposure limit for each roster scheme.

Table 43 – Daily and Rostering Average Exposure based correlation of ISO and OSHA.

DAILY ACCUMULATED EXPOSURE & ROSTRING AVERAGE EXPOSURE BASED CORRELATION OF ISO & OSHA						
Total Daily Working Hours Limit for Pilots (h)	SN+WBV EXPOSURE INFERIOR LIMIT *dBtotal/day (dB)*	SN+WBV EXPOSURE SUPERIOR LIMIT *dBtotal/day* (dB)	SN+WBV EXPOSURE Average. *dBtotal/day* (dB)	SN+WBV EXPOSURE Average. dBtotal/Rotation (Based on the Limite of Flying 8 hours per day ignoring the combination of each source and how it affects fatigue on crews.		
				21	28	35
				18	24	30
8	756.38	794.63	775.51	13 959.09	18 612.12	23 265.16
8	764.38	802.63	783.51	14 103.09	18 804.12	23 505.16
8	772.38	810.63	791.51	14 247.09	18 996.12	23 745.16
8	780.38	818.63	799.51	14 391.09	19 188.12	23 985.16
8	788.38	826.63	807.51	14 535.09	19 380.12	24 225.16
8	796.38	834.63	815.51	14 679.09	19 572.12	24 465.16
8	804.38	842.63	823.51	14 823.09	19 764.12	24 705.16
8	812.38	850.63	831.51	14 967.09	19 956.12	24 945.16
8	820.38	858.63	839.51	15 111.09	20 148.12	25 185.16
8	828.38	866.63	847.51	15 255.09	20 340.12	25 425.16
8	836.38	874.63	855.51	15 399.09	20 532.12	25 665.16

Table 44 shows *that* no noticeable difference is revealed when comparing manufacturers' SN average values with those specified in ISO 2631.

Table 44 – Manufacture of Average value and ISO 2631 WBV average value stated in Figure 41

Authors Base Line Reference Adaptation of Average Limits based on Manufacturers Data, ISO 2631-2018 & Domingues Teixeira, 2020									
HELICOPTER model	Average Sound Noise (SN) (dB)	Average WBV (dB)	Average SN+WBV Total (dB)	TFT / 4 consecutive weeks (NTA 15 ANAC ANGOLA) (h)	HNV*mf* ED for 95 flight hrs/ 4 CONSECUTIVE WEEKS (dB)	21 DAYS ON/OFF	EXPOSURE VALUE HNV*mf* ED / DAY (dB)	28 DAYS ON/OFF	EXPOSURE VALUE HNVED / DAY (dB)
AW139	95.10	95.73	98.44	95	9 351.49	18	519.53	24	389.65
AW189	95.91	95.73	98.83	95	9 388.97	18	521.61	24	391.21

As shown in **Table 45**, the average 28 days calculated values are based on manufacturers' SN and ISO 2631 average values, which serve as the total exposure reference over 28 days.

Table 45 – Calculation when using two Sources multiplied per 95 hours limit per 28 day cycle of flying.

NOISE (SN) (dB1)	NOISE EXPOSURE LIMIT TIME/DAY (hh:mm)	WBV INFERIOR LIMIT (dB2)	WBV SUPERIOR LIMIT (dB2)	WBV EXPOSURE LIMITE TIME/DAY (hh:mm)	CALCULATED AVERAGE COMBINED SOURCES (SN+WBV INFERIOR LIMIT) (dB)	CALCULATED AVERAGE COMBINED SOURCES (SN+WBV SUPERIOR LIMIT) (dB)	Total 4 Consecutive Weeks Working Hours Limit for Pilots (h)	SN+WBV EXPOSURE LIMITE *inf. dBtotal/4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))* (dB)	SN+WBV EXPOSURE LIMITE *sup. dBtotal/4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))* (dB)
90	08:00	92.67	98.79	08:00	94.55	99.33	95	8 982.00	9 436.25
91	07:00	93.67	99.79	07:00	95.55	100.33	95	9 077.00	9 531.25
92	06:00	94.67	100.79	06:00	96.55	101.33	95	9 172.00	9 626.25
93	05:20	95.67	101.79	05:20	97.55	102.33	95	9 267.00	9 721.25
94	04:40	96.67	102.79	04:40	98.55	103.33	95	9 362.00	9 816.25
95	04:00	97.67	103.79	04:00	99.55	104.33	95	9 457.00	9 911.25
96	03:30	98.67	104.79	03:30	100.55	105.33	95	9 552.00	10 006.25
97	03:00	99.67	105.79	03:00	101.55	106.33	95	9 647.00	10 101.25
98	02:40	100.67	106.79	02:40	102.55	107.33	95	9 742.00	10 196.25
99	02:20	101.67	107.79	02:20	103.55	108.33	95	9 837.00	10 291.25
100	02:00	102.67	108.79	02:00	104.55	109.33	95	9 932.00	10 386.25

To determine the exposure limit for each roster scheme, the SN+WBV exposure average per 95 hours is used. This calculation is performed by dividing the 95 hours limit per 28 day cycle by the total number of flying days permitted in each rotation. When analysing the collected data, **Table 46** indicates that the AW139 (orange frame) and AW189 (purple frame) are within a specific exposure zone or higher.

Table 46 – Monthly and Rostering Average Exposure-based correlation ISO and OSHA.

4 CONSECUTIVE WEEKS (NTA 15, PARTE E 15.050, b)),ACCUMULATED EXPOSURE & ROSTRING AVERAGE EXPOSURE BASED CORRELATION OF ISO & OSHA						
Total 4 Consecutive Weeks Working Hours Limit for Pilots (h)	SN+WBV EXPOSURE LIMITE *inf. dBtotal/4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))* (dB)	SN+WBV EXPOSURE LIMITE *sup. dBtotal/4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))* (dB)	SN+WBV EXPOSURE Average. *dBtotal/4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))* (dB)	SN+WBV EXPOSURE Average. dBtotal/Rotation (Based on the Limit of Flying 95 hours per 4 Consecutive Weeks (NTA 15, PARTE E 15.050, b)), ignoring the combination of each source and how it affects fatigue on crews.		
				21	28	35
				18	24	30
95	8 982.00	9 436.25	9 209.12	511.62	383.71	306.97
95	9 077.00	9 531.25	9 304.12	516.90	387.67	310.14
95	9 172.00	9 626.25	9 399.12	522.17	391.63	313.30
95	9 267.00	9 721.25	9 494.12	527.45	395.59	316.47
95	9 362.00	9 816.25	9 589.12	532.73	399.55	319.64
95	9 457.00	9 911.25	9 684.12	538.01	403.51	322.80
95	9 552.00	10 006.25	9 779.12	543.28	407.46	325.97
95	9 647.00	10 101.25	9 874.12	548.56	411.42	329.14
95	9 742.00	10 196.25	9 969.12	553.84	415.38	332.30
95	9 837.00	10 291.25	10 064.12	559.12	419.34	335.47
95	9 932.00	10 386.25	10 159.12	564.40	423.30	338.64

NOTE: AW139 is within the orange rectangular data area, while AW189 is in the purple area.

Table 47, which presents the collected data, clearly shows values higher than the ISO 1999 standard. The SN exposure on the AW139 ranges from 99.28 dB to 103.35 dB, and on the AW189, it ranges from 101.65 dB to 104.48 dB. Compared within a zone region ISO 2631, the AW139 has an inferior limit of 92.07 dB and a superior limit of 102.19 dB for WBV. However, the AW189 has an inferior limit of 93.25 dB and a superior limit of 108.46 dB for WBV. Both SN and WBV values in both fleets are related to the cruise flight.

Table 47 – Exposure Value Positioning Correlation of AW139 and AW189 with Collected data and Tables 34, 44 and 46.

Limits based on the Author's Average Inferior Limit Collected Research Data, the Author's Adaptation of Domingues Teixeira, 2020									
HELICOPTER model	Average Sound Noise (SN) (dB)	Average WBV (dB)	Average SN+WBV Total (dB)	TFT / 4 consecutive weeks (NTA 15 ANAC ANGOLA) (h)	HNVmfED for 95 flight hrs/ 4 CONSECUTIVE WEEKS (dB)	21 DAYS ON/OFF	EXPOSURE VALUE HNVrf ED / DAY (dB)	28 DAYS ON/OFF	EXPOSURE VALUE HNVrf ED / DAY (dB)
AW139	99.28	92.07	100.04	95	9 503.45	18	527.97	24	395.98
AW189	101.65	93.25	102.23	95	9 712.11	18	539.56	24	404.67

Limits based on the Author's Average Superior Limit Collected Research Data, the Author's Adaptation of Domingues Teixeira, 2020									
HELICOPTER model	Average Sound Noise (SN) (dB)	Average WBV (dB)	Average SN+WBV Total (dB)	TFT / 4 consecutive weeks (NTA 15 ANAC ANGOLA) (h)	HNVmfED for 95 flight hrs/ 4 CONSECUTIVE WEEKS (dB)	21 DAYS ON/OFF	EXPOSURE VALUE HNVrf ED / DAY (dB)	28 DAYS ON/OFF	EXPOSURE VALUE HNVrf ED / DAY (dB)
AW139	103.35	102.19	105.82	95	10 052.48	18	558.47	24	418.85
AW189	104.48	108.46	109.92	95	10 442.37	18	580.13	24	435.10

For calculation purposes, the author sets the average value of both SN and WBV as the reference value for further analysis, as shown in **Table 48**.

Table 48 – Average In Flight SN+WBV reference value calculated from Table 47

Recommended Operation Reference Limits based on the Author's Average Collected Research Data, the Author's Adaptation of Domingues Teixeira, 2020									
HELICOPTER model	Average Sound Noise (SN) (dB)	Average WBV (dB)	Average SN+WBV Total (dB)	TFT / 4 consecutive weeks (NTA 15 ANAC ANGOLA) (h)	HNVmfED for 95 flight hrs/ 4 CONSECUTIVE WEEKS (dB)	21 DAYS ON/OFF	EXPOSURE VALUE HNVrf ED / DAY (dB)	28 DAYS ON/OFF	EXPOSURE VALUE HNVrf ED / DAY (dB)
AW139	101.31	97.13	102.93	95	9 758.15	18	542.12	24	406.59
AW189	103.06	100.85	106.08	95	9 985.21	18	554.73	24	416.05

Considering the results of **Tables 47 and 48**, the following **Tables 49 to 52** clarify the exposure limits for operations in AW139 and AW189 and are correlated with average real flight data collected. The SN+WBV daily exposure and the total for the most commonly used rostering patterns were calculated from average daily flight working hours. They also suggest **average daily flight times and accumulated decibel exposure values for pilot flying hours per rotation schemes for the AW139 and AW189 fleets**. This is based on an analysis of the most commonly used rostering patterns, specifically 21, 28, and 35 ON/OFF in offshore operations, as per the author's knowledge. **Table 49** presents a correlation of tolerance levels, adhering to the same colour scheme philosophy as above in **Figure 48**. The analysis also reflects the correlation between tolerance in the Operational Risk Condition and the **Daily Exposure Region within the Daily Rostering Average Exposure - AW139 Operational Risk Condition**. The calculation is based on the SN+WBV average exposure limit to maintain within the region's colour base, as referred to in **Figure 48** and determined by **Equations 11, 12 and 14.**

Table 49 – Daily and Rostering Average Exposure - AW139 Operational Risk Condition.

DAILY ACCUMULATED EXPOSURE & ROSTRING AVERAGE EXPOSURE BASED CORRELATION OF ISO & OSHA						
Total Daily Working Hours Limit for Pilots **AW139** (h in decimal) (Based on Average Real Flight Data Collected)	SN+WBV EXPOSURE LIMITE *inf. dBtotal/day* (dB)	SN+WBV EXPOSURE LIMITE *sup. dBtotal/day* (dB)	SN+WBV EXPOSURE Average. *dBtotal/day* (dB)	Based on Collected Real Flight Data using the combined two sources (SN+WBV) Exposure Average. (dB) total per Rotation Scheme		
				21	28	35
				18	24	30
6.2	620.23	656.06	638.14	11 486.54	15 315.38	19 144.23
5.5	550.20	581.99	566.09	10 189.67	13 586.23	16 982.79
5.2	520.19	550.24	535.22	9 633.87	**12 845.16**	16 056.45
4.1	410.15	433.84	422.00	7 595.94	**10 127.92**	12 659.89
3.9	390.14	412.68	401.41	7 225.40	**9 633.87**	12 042.34
3.5	350.13	370.35	360.24	6 484.34	**8 645.78**	10 807.23
3.1	310.11	328.03	319.07	5 743.27	7 657.69	11 167.47

Table 50 presents a correlation of tolerance levels, adhering to the same colour scheme philosophy as above. The analysis also reflects the correlation between tolerance in the Operational Risk Condition and the **Daily Exposure Region within the Monthly Rostering Average Exposure - AW139 Operational Risk Condition.**

Table 50 – Monthly and Rostering Average Exposure - AW139 Operational Risk Condition.

4 CONSECUTIVE WEEKS ACCUMULATED EXPOSURE & ROSTRING AVERAGE EXPOSURE BASED CORRELATION OF ISO & OSHA						
Total 4 Consecutive Weeks Working Hours Limit for Pilots **AW139** (h)	SN+WBV EXPOSURE LIMITE *inf. dBtotal/ 4 Consecutive Weeks* (dB)	SN+WBV EXPOSURE LIMITE *sup. dBtotal/ 4 Consecutive Weeks* (dB)	SN+WBV EXPOSURE Average. *dBtotal/ 4 Consecutive Weeks* (dB)	Based on Collected Real Flight Data using the Combined Two Sources (SN+WBV) Exposure Average and Compared with the Limit of Flying 95 hours per 4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))		
				21	28	35
				18	24	30
95	9 503.45	10 052.48	9 777.97	543.22	407.42	325.93
90	9 003.27	9 523.40	9 263.34	514.63	385.97	308.78
85	8 503.09	8 994.33	8 748.71	486.04	364.53	291.62
80	8 002.91	8 465.25	8 234.08	457.45	343.09	274.47
75	7 502.72	7 936.17	7 719.45	428.86	321.64	257.31
70	7 002.54	7 407.09	7 204.82	400.27	300.20	240.16

A **clear indication for the AW139 is that the optimal rostering is 28 ON/OFF**, which allows for better utilisation of the pilot's resources, particularly in terms of the time available to fly a day (3 hours and 57 minutes or 3.9) and per rotation (94h48min), concerning the salary paid from the operator's perspective. For the pilots, this **provides a more spaced-out exposure and a clear indication of reduced fatigue, thereby prolonging their health and career**. Pilots achieve **Psychological Stability in their Work/Family Relationships and as part of the National Workforce (by living in the country), which is an advantage with this roster**. Simultaneously, **it enables compliance with the operator's needs when flying an average of more than 3 hours and 57 minutes per day, and it balances the ON/OFF Analysis as referred to in Chapter VIII, Conclusion, Research Question IV,** and **Table 53**.

The analysis of **activities that require pilots to fly more than 95 hours per rotation, as well as the number of average hours per day needed for the operator being less than 3 hours and 57 minutes for 35 ON/OFF rotations**, is based on the premise that pilots would be able to add extra flying hours each day, **though limited to a maximum of 95 hours within four consecutive weeks of working days and in compliance with the regulation of a maximum of 6 working days followed by 1 day of rest.** For example: 6+1+6+1+6+1+6+1+6+1 = 35 days ON, with flying scheduled across a total of 30 days and 5 days of rest following each 6-day working period.

Table 51 compares tolerance levels, using the same colour scheme philosophy as above. The analysis also reflects the correlation between tolerance in the Operational Risk Condition and the **Daily Exposure Region within the Daily Rostering Average Exposure - AW189 Operational Risk Condition.** The calculation is based on the SN+WBV average exposure limit to maintain within the region's colour base, as referred to in **Figure 48** and determined by **Equations 11, 12 and 14.**

Table 51 – Daily and Rostering Average Exposure - AW189 Operational Risk Condition.

DAILY ACCUMULATED EXPOSURE & ROSTRING AVERAGE EXPOSURE BASED CORRELATION OF ISO & OSHA						
Total Daily Working Hours Limit for Pilots **AW189** (h in decimal) (Based on Average Real Flight Data Collected)	SN+WBV EXPOSURE LIMITE *inf.* *dBtotal/day* (dB)	SN+WBV EXPOSURE LIMITE *sup.* *dBtotal/day* (dB)	SN+WBV EXPOSURE Average. *dBtotal/day* (dB)	Based on Collected Real Flight Data using the combined two sources (SN+WBV) Exposure Average. (dB) total per Rotation Scheme		
				21	28	35
				18	24	30
6.2	633.84	681.50	657.67	11 838.10	15 784.14	19 730.17
5.5	562.28	604.56	583.42	10 501.54	14 002.06	17 502.57
5.2	531.61	571.58	551.60	9 928.73	**13 238.31**	16 547.88
4.1	419.15	450.67	434.91	7 828.42	**10 437.90**	13 047.37
3.9	398.71	428.69	413.70	7 446.55	**9 928.73**	12 410.91
3.5	357.81	384.72	371.27	6 682.80	**8 910.40**	11 138.00
3.1	316.92	340.75	328.84	5 919.05	7 892.07	9 865.08

Table 52 compares tolerance levels, using the established colour scheme philosophy. The analysis also reflects the correlation between tolerance in the Operational Risk Condition and the **Daily Exposure Region within the Four Consecutive weeks, or commonly said as the monthly Rostering Average Exposure - AW189 Operational Risk Condition.**

Table 52 – Monthly and Rostering Average Exposure - AW189 Operational Risk Condition.

4 CONSECUTIVE WEEKS ACCUMULATED EXPOSURE & ROSTRING AVERAGE EXPOSURE BASED CORRELATION OF ISO & OSHA						
Total 4 Consecutive Weeks Working Hours Limit for Pilots **AW189** (h)	SN+WBV EXPOSURE LIMITE *inf. dBtotal/4 Consecutive Weeks* (dB)	SN+WBV EXPOSURE LIMITE *sup. dBtotal/4 Consecutive Weeks* (dB)	SN+WBV EXPOSURE *Average. dBtotal/4 Consecutive Weeks* (dB)	Based on Collected Real Flight Data using the Combined Two Sources (SN+WBV) Exposure Average and Compared with the Limit of Flying 95 hours per 4 Consecutive Weeks (NTA 15, PARTE E 15.050, b))		
				21	28	35
				18	24	30
95	9 712.11	10 442.37	10 077.24	559.85	419.88	335.91
90	9 200.94	9 892.77	9 546.86	530.38	397.79	318.23
85	8 689.78	9 343.17	9 016.48	500.92	375.69	300.55
80	8 178.61	8 793.57	8 486.09	471.45	353.59	282.87
75	7 667.45	8 243.98	7 955.71	441.98	331.49	265.19
70	7 156.29	7 694.38	7 425.33	412.52	309.39	247.51

On the AW189, the same overview is observed as above on the AW139, **a clear indication that the best rostering is 28 ON/OFF** to better access the pilot's resources on time available to fly per rotation versus salary paid on the operator's point of view and for the pilots a more appropriate spaced-out exposure and a clear indication of diluted fatigue exposure prolonging pilots health and career but at the same time being able to comply with operators needs. **On the AW189, the use of the 21 ON/OFF is highly jeopardising for operators and pilots since it limits hours per week, and month or exposes pilots to regimes on the TOLERABLE WITH LIMITATION level daily that would guarantee higher levels of fatigue which resulting therefore higher levels of operational risk and lower longevity of operational pilots in the long term. Additionally, 21 day OFF period would not support overall physiological cell recovery, with possible long-term accumulated fatigue, resulting in acute lower back pain, discomfort, and both physiological and psychological fatigue, ultimately leading to pilot unfitness and/or impairment to fly.** Furthermore, limited to information about Operator Flight Activity being higher than 4 hours per day, Crews with higher exposure to HNVrfED, physiological fitness, and fatigue are affected in their work and family relationships with children below the age of 15 years, as well as in the national and expat workforce living outside the country (see **Table 53**).

The author acknowledges that there may be days when exposure limits are exceeded due to commercial or operational needs, but advises operators and pilots to monitor pilot fatigue when such exceedances occur frequently. As a pilot, the author based this research study on personal experiences, pilot verbal reports, and safety, focusing solely on the cruise flight phase. **It acknowledges that the approach phase of flight is more intense in terms of sound noise, whole-body vibration, and hand-arm vibration. Therefore, higher fatigue may be present due to the lack of take-off and approach measurements,** which can be attributed to main rotor and tail rotor blade flapping, high-speed blade tip vortices, engine regimes, gearbox, APU, and the pilot's contact with the collective, cyclic controls, and pedals. Additionally, **aerodynamic airflow through the fuselage and the pilot's postural position, which is influenced by factors such as height, weight, and age,** informs the findings. **Consequently, the study advises against yellow exposure regimes and strongly discourages light and dark orange regimes** for the average monthly daily flying limits.

7.3 Helicopter Pilot Verbal Report of Take-off and Approach Phase Sensation

After verbally consulting and interviewing helicopter pilots who fly the AW139 and/or AW189, with experience in the EC225, S76c++, AS332 L2, or other helicopter type ratings in offshore environments, regarding vibration and noise, the author felt it was relevant to include their personal experiences and opinions in this study.

The following questions were asked:

1. In your opinion, how do you compare the sensation of vibrations and noise on approach and take-off flying your current helicopter AW139 or AW189 relative to previous helicopters you flew in offshore environments like the S76C++, EC225, AS332L2 or others?
2. How would you account for the physiological fatigue level of your previous answer?

The following answers were given, and with their consent to add to this research study:

Rotor Wing Pilot 1, Captain, ATPL, flying experience in EC225, S76C++, currently flying AW139, with experience as Line Training Captain (LTC), former Director of Operational Safety (Safety Manager), and currently acting as the Nominated Person as the Director of Quality, Health, Safety and Environment (Quality Manager). In the first question, he stated the following personal opinion based on his experience: *"Regarding the comparison of the sensation in terms of vibrations and noise, in the EC225 Super Puma, we had higher noise than the AW139, but in terms of vibrations, we had fewer vibrations than in the AW139, especially on approach when reducing speed for landing."*

In the second question, the Captain stated the following personal opinion, *"In terms of fatigue, I would say they are similar, although the AW139 cockpit is more exposed to the sun, but in terms of fatigue, I would say they are similar."*

Rotor Wing Pilot 2, Captain, ATPL, flying experience in EC225, S76C++, with several years of Flight Instructor (FI) and Line Training Captain (LTC) experience, currently flying AW139 and acting as the Head of the Department of Crew Training (Crew Training Manager). In the first question, he stated the following personal opinion based on his experience: *"As for noise, I cannot say if there is more or less, but it is advisable that helicopter pilots in general use headphones with noise reduction for the sake of long-term protection which should always be pilots' biggest focus. As for vibrations, the AW139, despite the vibration reduction systems, maintains a large vibration when approaching at low speeds. I am referring to between 20 and 40 knots. This vibration level is quite high compared to helicopters I have previously flown."*
In the second question, the Captain stated the following personal opinion, *"Any vibration creates an increase in discomfort for the pilot and a consequent increase in stress and fatigue."*

Rotor Wing Pilot 3, Captain, ATPL, flying experience in EC225, AS332 L2, S76C++, AS365 N1, N2 & N3, currently flying AW139, with several years of Flight Instructor (FI) and Line Training Captain (LTC) experience. In the first question, he stated the following personal opinion based on his experience, *"Regarding the helicopters that I have previously flown, it does not matter if they are offshore or not, a total of around 12 helicopters, 12 types of helicopters, including French, Russian and American. The vibrations felt in the AW139 exceeded human imagination or capacity, and I am referring to the AW139 as being between 40 and 20 knots. An important detail is that the vibrations are so pronounced at the front, obviously for the crew and the passengers in the passenger cabin. The passengers feel it less, but it is a huge underload for the crew. To the point that the crew have to adopt individual procedures to even be able to see the approach point, due to the excessive vibrations that occur in this approach phase of flight, I repeat between 40 and 20 knots."*
In the second question, the Captain stated the following personal opinion, *"As for the levels of physiological fatigue, I consider it extremely worrying, and I say this for pilots who will have to fly this helicopter for a long time. I believe that with pilots flying this helicopter for many years, it will be obvious that the consequences will be felt much later. Preventive measures must be adopted so that the crews who fly this helicopter for a long time are not subjected to health problems, which worries me the most. Otherwise, I do not know if there will be pilots who will fly this aircraft for many years. The advice I have for pilots is to adopt preventive measures. Among them, I cannot define one specifically. However, I think that using the chair well, a cushion to sit on, and a special pilot cushion for the seat, among other measures, can reduce the amount of stress the body is subjected to, especially during this phase of flight. It does not mean the preventive measures will eliminate them, but they may eventually reduce the health problems. I cannot confirm this because all this requires studies and scientific data."*

Rotor Wing Pilot 4, Captain, ATPL, flying experience in EC225, S76C++, currently flying AW139, with experience as Line Training Captain (LTC). The first question stated the following personal opinion based on his experience, *"Comparing the vibration and noise sensations of the AW139, it is worth noting that during the approach, there is a very high level of vibration, compared to other aircraft I have flown. The* *noise is not as high, but the vibration is pronounced. This vibration generally occurs between 50 and 20 knots, and the crew feels the vibration level quite pronounced."*

In the second question, the Captain stated the following personal opinion, *"Regarding the level of physiological fatigue, we must say that, once exposed to this level of vibration with our hands and feet on the controls, we naturally develop a certain discomfort that translates into fatigue. Finally, it is worth mentioning that the time spent on the controls of the aircraft creates a very uncomfortable situation, and so it is true that this leads to a certain level of fatigue."*

Rotor Wing Pilot 5, Captain, ATPL, flying experience in EC225, S76C++, currently flying AW139, with experience as Line Training Captain (LTC). The first question stated the following personal opinion based on his experience, *"There is a mistake with this issue of vibration in the AW139 helicopter. For me, it is a question of the relationship between the engines and the structure. I think it is incompatible with the powerful engines it has installed concerning the aircraft's structure.*"

In the second question, the Captain stated the following personal opinion, *"I do not think it is perfect for crews; it is complicated in the case of the AW139; it is not very healthy for the crews because there are high levels of vibrations compared to previously flown aircraft. The power of the engines affects the structure, which implies a series of vibrations that can affect the health of the crew members themselves."*

Rotor Wing Pilot 6, Captain, ATPL, flying experience in EC225, AS365N3, currently flying AW139 and former Flight Operations Manager. In the first question, he stated the following personal opinion based on his experience, *"Although the AW139 is a more recent helicopter compared to the AS365N3 and H225, there is no comparison in terms of noise and vibration, as these are more evident in the AW139, during the final approach phase for landing, with speeds indicated between 40 and 20 knots, especially for those who do not have the AVCS installed."*

In the second question, the Captain stated the following personal opinion, *"Regarding the level of physiological fatigue, they are more evident on long flights above 5 hours and with more than four landings. It is worth mentioning that high vibrations are not only harmful to the pilot but also to the helicopter's equipment. We know that vibrations, noise and fatigue contribute to pilot's errors and, consequently, incidents and accidents."*

Rotor Wing Pilot 7, Captain, ATPL has flying experience in EC225 and several years of experience as a Flight Instructor (FI) and Line Training Captain (LTC), former deputy crew training manager. He is currently flying AW139. In the first question, he stated his personal opinion based on his experience: "I calculate that the AW139 vibrates more by around 15% since this is still the nature of helicopters. Regarding noise, I would go higher by 20 to 25 % in *all stages of the flight."*

In the second question, the Captain stated the following personal opinion, *"The consequence is evident. The moderate level also applies to physical fatigue."*

Rotor Wing Pilot 8, Captain, ATPL has flying experience in B412 and several years as a Line Training Captain (LTC), base manager, currently flying AW139 and AW189. The first question stated the following personal opinion based on his experience, *"When I am flying the AW139, I feel powerful vibrations during the landing portion as the aircraft is moving out of the translational lift. This is more prevalent on a CAT A offshore helideck or ground helideck landing than on a clear area landing, as you remain with the profile longer. I experience some of the same vibrations when flying the AW189; however, it is shorter during the landing profiles. Interestingly, I prefer to fly the AW139 on the cruise but the AW189 for take-off and landing. I have flown AW139 with and without the AVCS and find the system is more effective in the cruise than take-off and landing."*

In the second question, the Captain stated the following personal opinion, "*The AW189 has a large amount of cabin vibration that the AW139 during the cruise portion of a flight, so I often feel far more fatigued after several flights in an AW189, between 5 to 7 hours of flying per day. I wear a suitable noise-cancelling headset, so the noise does not bother me. I have had discussions with colleagues that fly the S92, and they have said that the aircraft is considerably noisier from a pilot's perspective; however, from a passenger's perspective, they have found the AW189 to be substantially more noisy."*

Rotor Wing Pilot 9, Captain, ATPL, who has flying experience in B412, B430, and B427, and several years as a Line Training Captain (LTC), is currently flying AW139 and AW189. In the first question, he stated his opinion based on his experience: *"If my memory serves me correctly, the AW139 in landing profile vibrates more than any helicopter I have flown. In cruise flight, it is smoother and has less cabin vibration than the AW189, but in saying this, all aircraft do differ, and I have found some AW189´s very smooth on the cruise and much quieter. Why this is? Comes down to maintenance or possibly newer aircraft."*

In the second question, the Captain stated the following personal opinion, *"Certainly, a smoother and quieter helicopter will induce less fatigue. I only feel fatigued if the air conditioning is not working, and I have become accustomed to the Leonardo Aircraft. You can reduce the stress of vibrations on the approach by coming into land holding above translation as long as possible, but it depends on headwind speed."*

Rotor Wing Pilot 10, Co-Pilot, CPL, flying experience in EC225, S76C++, currently flying AW139, In the first question, stated the following personal opinion based on his experience*: "In comparison to the S76C++, the AW has a similar flight profile of flight and vibrations, it already comes with the AVS (active vibration System) incorporated something that the Sikorsky did not have at the time, nor did I feel a significant improvement when it came to vibrations. It is a beautiful machine with modern systems; yes, it is more spacious and everything, but it leaves something to be desired regarding vibration and noise. As for the Super Puma, it was a machine that allowed us to reach up to 30 KIAS fully coupled; it had a different flight profile, vibrated much less, and even allowed us to reduce speed much faster. Regarding technology, It also had the AVCS (Active Vibration Control System), but in this case, it was much more noticeable, maybe due to the flight profile of the machine itself. The Sikorsky and the AW139 have their nose up when stationary hovering, so when we have to make an approach, we need to use more pitch up compared to the Puma. I* *believe it contributes a lot to vibrations. From what I have noticed on my offshore flights, the biggest vibrations occur between 15 KIAS and 25 KIAS. So much so that the technique we have used is not to stay exposed for too long at these speeds, thus not making a very slow approach but trying to pass this interval as quickly as possible."*

In the second question, the Co-Pilot stated the following personal opinion, *"Obviously, fatigue is much greater when you experience this type of situation in the medium/long term. Many pilots use special cushions to reduce the effect of vibrations. I have also used them in the past, but I always found it annoying for the simple fact of having to carry them every time I flew. Personally, I don't like carrying much weight. Worst of all is that there is the possibility that the system itself may not be well calibrated, which reduces its efficiency."*

Rotor Wing Pilot 11, Co-Pilot, CPL, flying experience in EC225, S76C++, currently flying AW139. In the first question, he stated the following personal opinion based on his experience, *"I can categorically state that there is no comparison regarding vibration in the final approach phase of the AW139 with the previous helicopters I have flown, in this case, the AS365 N3 and the imposing H225. Starting with the H225, a spectacular aircraft that, despite its large size, had a very advanced autopilot, which engaged approaches with the superior modes until practically the end of the approach. Offering a very stable and vibration-free approach to machine operation. The AS365N3, being an intermediate aircraft, was lighter and had great stability and comfort on approaches despite not having as advanced an autopilot as the previous helicopter mentioned. The N3 allowed stable approaches with vibrations that were normal to the helicopter's operability. Focusing on the appearance of the AW139, in comparison to the previous machines mentioned, there is no comparison, as despite offering innovative technology and proving to be a good machine in its intermediate category, it leaves something to be desired in the final phase of the approach, in terms of vibrations, especially in offshore approaches, you can feel a sudden change in vibrations which in certain cases can be frightening, as the helicopter leaves the normal operational vibration, increasing the vibration very sharply in such a way that the reading of the data on the panel MFD´s and PFD´s are almost impossible to read due to excessive shaking, which is very uncomfortable. Note that these vibrations in the AW139 vary from series to series. You feel the vibrations in older series much more than in more recent ones. In terms of take-offs and noise, I think there are no major aspects to consider since they all offer almost the same type of vibration at this stage. Except that in the case of noise, the H225, the highest category of all, made much more noise than the others."*

In the second question, the Co-Pilot stated the following personal opinion: "The most uncomfortable helicopter in certain critical flight phases, which will require much more concentration from pilots and leave pilots psychologically and physiologically more exhausted in situations involving several flights with landings, *is the AW139. I would consider the level high."*

Rotor Wing Pilot 12, Co-Pilot, CPL, flying experience in EC225, S76C++, currently flying AW139. In the first question, he stated the following personal opinion based on his experience, *"In comparison to other* *aircraft that I have flown, I would first like to point out that vibrations in aircraft during takeoff and landing can be influenced by several factors, among which we can list some. First, the rotors' state and the load's distribution inside the aircraft can also influence and cause some vibrations, the atmospheric conditions themselves, the type of surface of the runway or the helipad on which these same helicopters operate. During takeoff, especially in the transition phase from the ground to the air, some vibrations may be associated with the famous ground resonance. We also have the problem of balancing the main rotor, which can also cause some vibrations in helicopters. Now, speaking specifically about the AW139 in detriment or comparison to other aircraft, such as the S76 and the EC225 Super Puma, I can say that at the moment of take-off, at the moment of transition from the ground effect, at the moment when we are alone passing to the air cushion to park, the vibrations tend to decrease quickly and also at the moment of transition from stationary to the moment of gaining speed, it can provide us with certain stability at that moment of transition because we are on the air cushion. There, we have a smooth passage of the aircraft until it reaches the TDP at VTOSS. Consequently, at VY, we achieve VBROC at take-off and climb to the selected altitude to be able to continue our flight. Regarding the moment of landing, the manufacturer advises us that we should avoid landings with a tailwind as much as possible, at 180° from the rear of the aircraft, we should avoid 180° as much as possible, and consequently, we should also avoid landing from our right from the right to the left direction at 80° on our right, from right to left we should avoid landing with these winds in these directions. The recommended angle is 120° from left to right, and winds no higher than 15 knots. They advise that when we land, we should be facing the wind with winds of 120° from left to right and winds no higher than 15 knots because if we have winds from the right at 80°, we will have many vibrations when approaching, many vibrations indeed. In the AW139, when reducing speed for approach on the helideck, at the airport or on a heliport, when we go from 30 knots to 15 knots, we have a moment of exposure to very strong vibration, especially for machines of phase 6 and below, which have greater exposure to vibration. When we go from 30 knots to 15 knots, which is the LDP speed for helidecks, we have a huge exposure where we feel a vibration much higher than normal, and the structure of the aircraft itself enters into a very pronounced vibration. After passing this phase from 30 to 15 knots, the aircraft stabilises smoothly, and we can make our normal approach. Relatively or in comparison to the other aircraft I have flown, the S76 and EC225, I did not feel this vibration on the final approach or take-off. The vibration was reduced on take-off and final approach since the EC225, for example, already had the AVCS coupled, which is the anti-vibration control system. The AW helicopters from phase 7 onwards already have AVCS coupled, so there is already a reduction in this final phase of the approach. There is already a noticeable reduction in vibration; a certain vibration is felt, but not at the levels we feel in the helicopters in phase 6 below. Compared to the other aircraft, the AW139 vibrates more than the other aircraft I have flown previously.”*

In the second question, the Co-Pilot stated the following personal opinion, *"Regarding the level of physiological fatigue about the initial question, I can say that it is really tiring because the moment of landing, especially for us offshore pilots, is a critical moment, a moment in which all our effort and attention is focused on the approach, the parameters and everything else. When we fly these machines that have such high vibrations in the final phase, our body really feels that we are being worn out because the vibration is so* *great that the aircraft structure, the body structure of the crew feel the vibration as a whole, so it is really quite tiring and quite tiring in physiological terms. The vibration that the AW139 helicopters from phase 6 and below, I repeat, present, in phase seven and above is already slight. This vibration is not as pronounced as the other phases. In the other Sikorsky helicopters I flew and the EC225, we did not feel this physiological fatigue concerning the vibrations as much. There was a residual vibration but not the same proportion as the AW139 presents us now."*

Rotor Wing Pilot 13, Co-Pilot, CPL has flying experience in EC225 and AS332L2 and is currently flying AW139. In the first question, he stated the following personal opinion based on his experience, *"The AW139, during the deceleration phase and transition from wing to a rotor between 35 and 20 knots, suffers a significant increase in high-frequency vibration, which I think is of aerodynamic origin, which causes vision distortion and sensations of itching and disorientation in the inner ear. It requires an imperative, stabilised, and well-defined approach; also, due to the nose-up attitude that conditions the pilot to move horizontally, his visual attention is constantly between the landing point and the approach parameters, speed, height and pitch. During take-off, there is some vibration in the transition phase, but not as pronounced as in the deceleration phase. Compared to AS332 L2 and EC225, the disadvantage of AW139 is obvious for the following reasons: first, the Airbus Helicopters models, as they do not have a nose-up attitude during the deceleration phase, allow a more natural visual posture for the pilot, vertical scan between the touch point and instruments, as opposed to having the pilot move his head horizontally, providing sensations of disorientation increased by vibration. Second, the layout of the significant information in the Airbus genetics PFD is more compact in the sense that it is arranged to provide faster and better accuracy in reading the information as opposed to the AW139 where, for example, the radio altimeter reading is done in the lower right sector of the screen and the speed reading in the upper left sector of the screen, Airbus genetics projects the radio altimeter reading just below and within the artificial horizon window, with the visual field of the speedometer, variometer and altimeter. These are some examples, but there are more."*
In the second question, the Co-pilot stated the following personal opinion, *"Regarding the level of fatigue, it is undoubtedly more pronounced. As I said, it is unanimous among pilots and is attributed to the vibration level, whether in cruise or in the deceleration phase."*

Rotor Wing Pilot 14, Co-Pilot, CPL, flying experience in EC225, S76C++, currently flying AW189. In the first question, he stated the following personal opinion based on his experience, *"I have noticed without any doubt that today, in the current type, I am much more exposed to high levels of vibration compared to the two types I flew in the past, especially the EC225, which has an excellent vibration reduction system, I do not know if its because I currently fly a machine that already has a high number of hours, but the vibration level is very high, especially when approaching the aircraft for landing."*
In the second question, the Co-Pilot stated the following personal opinion: "Certainly, I believe that for us helicopter pilots, flying a type with a high level of vibration increases our physiological fatigue, as the

negative effects that vibration causes to humans are known, for example, spinal pain, which can affect the quality of *night rest that the pilot needs, working the next day with fatigue."*

Rotor Wing Pilot 15, Co-Pilot, CPL, flying experience in EC225, S76C++, currently flying AW189. In the first question, he stated the following personal opinion based on his experience, *"In my opinion, the EC225 has much lower vibration levels than the other two helicopters I have flown, the AW189 and the S76C++, both on approach and takeoff. I have flown in two environments, both onshore and offshore, and the vibration levels of the EC225 are much, much lower compared to the other two helicopters. On the other hand, the EC225 has the highest noise levels."*
In the second question, the Co-Pilot stated the following personal opinion, "*As for fatigue, I cannot compare because I only have a few hours on the AW189, but compared to the S76C++ and EC225, I can say that when flying the EC225, the physiological fatigue levels were much lower compared to the S76C++. I need more time with the AW189 to have a more solid basis for comparison."*

Rotor Wing Pilot 16, Co-Pilot, CPL, flying experience in S76C++, currently flying AW189. The first question stated the following personal opinion based on his experience, *"Regarding the two helicopters, in my opinion, the AW189 has low vibration and internal noise on approach and take-off, compared to the S76++."*
In the second question, the Co-pilot stated the following personal opinion: *"Therefore, the level of physiological fatigue in AW189 decreases. Furthermore, its spacious cabin provides incomparable comfort to the S76c++."*

In general, **most pilots shared the same personal opinion regarding a greater sensation of vibration. They associated higher fatigue levels with longer flights and when subjected to more consecutive take-offs and landings in their flight schedule. However, not all related the noise to the fatigue.** As an experienced pilot and former Safety Manager, **the author shares the same opinion while flying the AW189 versus the S76C++, as more vibration and noise are noticeable**. The author acknowledges that helicopters have several differences, for example, weight categories, a bigger cabine with higher passenger capacities, aerodynamic design, the use of composite materials, engine power, and also the number of blades, which all may play their part in the sensation and discomfort referred to above.

More tests daily could be conducted to monitor the performance of helicopter pilots with the production of the presented equipment design and philosophy "PILVISOUVEX" (5.6.1 Equipment Design & Characteristics) to assess better and more precise measurements over a longer period of time by several pilots to provide information from exposure to Vibration and sound Noise.

A subject sample should be emphasised on a worldwide scale, with the contribution and participation of aviation advisors among all IOGP members. The focus shall be on a better understanding of cognitive fatigue, its effects on overall psychomotor performance, and its relation to flight safety, as well as its effectiveness in stressful events or emergencies among helicopter pilots operating in both onshore and offshore environments for the Oil and Gas and Wind Energy industries.

While large-scale testing may reveal surprising results, companies may worry about the broader economic impacts, particularly regarding insurance, salaries, and compensation, due to the ongoing or partial loss of pilots' ability to fly. The cost-benefit analysis of the hazard presented, along with the risk mitigation plans and countermeasures employed as part of FRMS, will undoubtedly benefit both the Oil and Gas and Wind Energy industries, as well as others, and enhance the safety and performance of helicopter pilots and operators.

The results are conclusive. More can be done to ensure effective and safer helicopter activities in the oil and gas and Wind Energy industries. To a certain extent, the author's profound conviction is that serious incidents and accidents may be prevented. The application of the presented measures referred to in this research study, the use of fresher crews to all onshore and offshore helicopter activities, applying the limited hours per day based on calculating HNV*rf*ED and rostering per type of hours limited per day (ideally 35, recommended 28, limited 21 days ON/OFF) will surely grant safer sky activities worldwide and longer and healthier pilots careers mitigating the shortage of experienced pilots.

To enhance pilots' quality performance, general companies' operational safety, and reduce human factor risk to a level As Low As Reasonably Achievable (ALARA), being both technically realistic and economically reasonable. *Operators should focus on improving training towards Human Factors (annual training). Emphasise 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 avoiding serious operational incidents and accidents, avoiding financial compensation or insurance claims and also towards SMS training in risk and hazard analysis. Training in Safety Management Systems (SMS) and Quality Management (QM) considerably impacts 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* (Teixeira, C., 2020)

Investment in developing equipment and software that can improve the FRMS (Fatigue Risk Management System) within their operations based on their hemisphere, environment, activity, and culture for all shift staff workers. Apart from the above-mentioned aspects in Teixeira´s study, regarding training and knowledge, the FRMS focuses primarily on Pilots, Flight Crews, Maintenance Staff, Flight Operations officers, the Operational Control Centre, and Dispatch personnel. Investment in workplace labour conditions can help staff´s health and awareness of their physical well-being.

7.4 Pilot Report on Vibration and Noise Sensation in Propeller and Jet Aircraft.

From verbally inquiring and interviewing aeroplane pilots about the vibration and noise of aeroplanes with propeller and jet engines, the author felt it necessary to include their personal experiences and opinions in this study.

The following questions were asked:

1. As a commercial or airline pilot with experience in aircraft with propeller and jet engines, can you describe your sensation of vibrations and noise in the cockpit and report how they affect your fatigue?
2. What is your opinion on the limit of hours that a crew member flying an aircraft with propeller engines can fly before feeling fatigued due to the vibrations and noise to which they are exposed?

The following answers were given, and with their verbal consent to add to this research study:

Fixed Wing Pilot 1, Captain, ATPL A, with flying experience in B-737NG, EMB-145, BE-1900D and F-50, the first question stated the following personal opinion based on his experience: *"Aircraft with propeller engines are similar to helicopters in terms of vibration and noise with initial more intense vibration until engines become synchronised with power. Older propeller aircraft without FADEC end up having more vibration and noise. The propeller engines are also more exposed than the jet engines, causing the noise to be louder. In jet engines, the nacelle muffles the noise. The louder the noise, the more tired the crew members become due to the high decibels to which they are exposed, regardless of the type of headsets you may have or of better quality, which may even have a noise-cancelling system for noise reduction. Engines are also closer to the cockpit and cause more vibrations; on long flights, they cause pilot fatigue due to the nuisance of noise."*

In the second question, the Captain stated the following personal opinion, *"I would say that after 1h30 minutes to 2 hours of flight on old propeller aeroplanes, the crew members end up feeling fatigued due to vibrations and noise, wanting to seek some physiological rest due to exposure. A sensation of wanting to have the relief of getting out of the plane and wanting to eliminate the fatigue and discomfort they feel."*

Fixed Wing Pilot 2, Captain, ATPL A with flying experience in B-737, B-732, B-777 and DHC-8, in the first question, stated the following personal opinion based on his experience, *"My experience with vibration in jet and propeller engine aircraft was that fatigue degraded was not felt at a physiological level. During my transition from jets to propeller aircraft, I had considerable negative hearing loss due to the noise and vibration exposure, which negatively affected" here referring ultimately on the body physiologically speaking."*

In the second question, the Captain stated the following personal opinion and sensation experienced*, "I felt that vibration and noise have a negative effect concerning the weekly and monthly limit. In my opinion, a* *pilot of an aircraft with propeller engines should not be exposed to more than 60 hours of flight per month, in this case, in the last 28 days and no more than 20 hours in the last 7 days. This is due to the limits prescribed in the Angolan Aeronautical Technical Regulations issued by ANAC Angola under NTA 15, which refer to the defined limits of maximum hours flown for domestic aircraft, and I believe that noise degrades the physiological condition of the crew."*

Fixed Wing Pilot 3, Co-Pilot, ATPL A, with flying experience in KA-200, KA-350, G-3, G-450, G-550, SL-601, DHC-8, and currently flying A220, in the first question, he stated the following personal opinion based on his experience, *"Vibration in propeller aircraft can vary, due to the direction of rotation of the engines, which serve in some aircraft to counteract the effect of torque on the longitudinal axis of that aircraft, thus reducing the vibration and noise felt inside the cockpit and passenger cabin. There are aircraft with two propellers per engine. In the case of the DCH-8, for example, the engine has large blades, six blades per engine, which create more resistance to air friction, depending on the power applied and its angle of attack, to produce thrust, thus causing more noise and vibration. In order to counteract vibration and noise, manufacturers end up establishing power and torque regimes that help to reduce the angle of attack on the blades, which in turn helps to reduce noise and vibration. However, the greater the angle of the propeller, the greater the vibration and noise produced. The disadvantages for the crews are that we end up having increased fatigue and stress since no one is used to working in an uncomfortable environment. Perhaps for this reason, among others, the industry ended up producing headphones with the so-called noise cancelling system. However, overall, the industry adapted and created mechanisms such as NVS (noise vibration system) on aircraft that reduce the noise and vibration inside the passenger cabin and cockpit. However, crew members always become exposed to noise and vibrations at uncomfortable levels, even with mitigation systems."*

In the second question, the Co-Pilot stated the following personal opinion and sensation: *"For example, on a flight from Luanda to Windhoek, lasting only 3 hours on the DCH-8, I ended up feeling quite physiologically fatigued due to the noise and vibrations felt in the cockpit."* No flight time limit was given, but a clear understanding of the severity of the issue was noted.

The author also assumes, based on the above experience shared by aeroplane pilots, that values may be above health and safety recommendations and that these tools may also be used by operators that utilise propeller-engine aeroplanes like KA-200, KA-350, B1900, DHC-8, and ATR 72 or similar aircrafts. The author acknowledges that a slight difference from helicopters and some changes may be required due to possible variations in WBV and Sound Noise exposure levels, which may be lower or higher; for this reason, the author presents **Equations 11,** Propeller Aeroplane Noise and Whole-Body Vibration Manufacture Estimated Exposure Dose (PANV*mf*ED) and the decomposition version in **Equation 12. The Equation 13,** Propeller Aeroplane Noise and Whole-Body Vibration Real Flight Estimated Exposure Dose (PANV*rf*ED) and the decomposition version in **Equation 14.**

7.4.1 Additional Research Contribution for Fixed Wing Operations

The following equations and their decomposed versions are presented for propeller engine aeroplanes:

$$PANVmfED = (dB_{total}) \times TFT \tag{11}$$

$$PANVmfED = \left[10 \times log\left(10^{\left(\frac{manf\ Avg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{manf\ AvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{12}$$

$$PANVrfED = (dB_{total}) \times TFT \tag{13}$$

$$PANVrfED = \left[10 \times log\left(10^{\left(\frac{Real\ Flight\ Avg\mathrm{ND}(dB1)}{10}\right)} + 10^{\left(\frac{Real\ Flight\ AvgVD(dB2)}{10}\right)}\right)\right] \times TFT \tag{14}$$

The new acronyms represent the following:

PANVmfED	Propeller Aeroplane Noise and Whole-Body Vibration Manufacture Estimated Exposure Dose
PANVrfED	Propeller Aeroplane Noise and Whole-Body Vibration Real Flight Estimated Exposure Dose

Adjustments to the safety risk analysis matrix regarding WBV and Sound Noise exposure, as well as the Operational Risk Condition due to Vibration and Noise Exposure tools, may be required or recreated for aeroplane propeller operations. The author acknowledges that further study is required within aeroplane operations.

Chapter VIII Conclusions

This chapter clarifies the objectives achieved, their contribution to the literature on the diminished gap, and their capacity to address the research questions and hypotheses. It comprehensively summarises the research study's conclusions, discusses its limitations, and recommends future research development.

The research conclusions are limited to male helicopter pilots, as only male pilots participated in the study. However, the author suggests that these results may apply to both male and female pilots. Twenty-five pilots used either AW139 or AW189. The study used 3-axis accelerometers and microphones embedded in recent Samsung and Apple smartphones. This resulted in the collection of 46 and 48 in-flight measurement sessions from the two sources, WBV and SN, respectively, which are the main factors influencing pilot fatigue in helicopter offshore environments. **Although the focus was on the cruise phase during in-field testing that lasted at least 30 seconds, evidence suggests that the approach phase generates more noise and vibration, potentially exceeding the average limits for the inferior and superior data.**

Research revealed that the **exposure of the crews had higher values in all in-field testing periods from the recommended levels for WBV and SN in ISO 2631-2018** and **ISO 1999-2013 and compared to manufacture values** (**Figure 47** - Manufacture & ISO Values vs Authors Calculated Average Exposure Limits), **for noise at Takeoff or Departure and Approach or Landing being above overflight or Cruise values**. Notably, higher probability values are observed during takeoff and approach, with manufacturers reporting increased readings.

The significant mechanical vibration and noise measured in this research provided clear evidence that the exceeding stress experienced by the crews can lead to muscle fatigue and health issues, including lower back pain and varying degrees of hearing loss, even when using active noise cancellation headsets. Furthermore, concerns have been raised concerning blood pressure, the circulatory system, and the skeletal system, among other examples cited. The uncomfortable sensations felt in the crew's bodies, combined with prolonged periods of flight each day, ranging from 3 hours 57 minutes to 5 hours 12 minutes for AW189 and AW139, contribute to the possible complex interaction between vibration, noise exposure, and postural overload experienced during flight. This scenario poses epidemiological evidence of an excessive risk of low back disorders, hearing loss, and/or other diseases among professional helicopter crew pilots.

The author believes that, based on the experiences and input of other more experienced pilots with higher flying hours, it is often considered that the daily flight time limit could be slightly extended. However, after reviewing research on side effects, body recovery, sleep cycles, and fatigue versus recovery, the author suggests that while exceptions may sometimes be justified due to unforeseen operational needs, they are generally not advisable. Extra time beyond the daily limit of **5 hours and 30 minutes, last level within the TOLERABLE REGION at 540.91 dB, should be avoided, and additional measures shall be established above this value until the limit of the TOLERABLE WITH LIMITATIONS REGION of 640.91 dB, which is equal to 6 hours and 15 minutes.**

Age significantly contributes to fatigue and prolongs recovery time. The evidence is somewhat questionable due to the small number of participants, which hinders a clear understanding. However, scientific research suggests that age plays a major role in fatigue, as our body cells gradually deteriorate over time. Further studies are still needed.

The best number of flying hours per day is between 4 and 6. Results demonstrate that, due to high values of exposure to vibration and sound noise, the **best number of hours per day is between 4 and 6 hours of flying**. **Precisely between 3 hours and 57 minutes to 6 hours and 15 minutes of flying per day on the AW189 and AW139, with the Ideal Flight Time Limit (IFTL) per day being 3 hours and 10 minutes, the recommended flight time with the Best Ratio Operator-Pilot (BROP) is 3 hours and 57 minutes and the Helicopter Maximum Flight Time (HMFT) or Daily Flight Time Limit (DFTL) is 6 hours and 15 minutes.**

The **solution should be approached in two forms**: **firstly**, by **operators** **imposing vibration and sound noise limits towards the human factor** effects on pilots, **with a possible future FDM output information with a combined link to FRMS** and **secondly**, by **crews'** **self-monitoring their fatigue levels with a conscious knowledge approach and self-reporting mechanism to FRMS**.

The author concludes that the **harm to pilots is cumulative and degenerative, and therefore irreparable, highlighting the significance of establishing a mandatory and minimum industry standard rostering system, ON/OFF**, and the vast **value of the necessary resting periods** that allow helicopter pilots' bodies to self-heal. **Sufficient evidence is presented** here, **revealing a high contribution indicator to the influence of the fatigue effect on helicopter pilots. Essential information offers fatigue risk management systems key insights into human factors. This helps reduce risk in operators' safety management systems and is vital for assessing the likelihood of pilot fatigue during investigations of serious incidents or accidents.**

Regarding the concerns with composite materials on helicopters, the author believes that the solution for the next generation of airframes must prioritise damping as a core design parameter, not merely an afterthought. Tailored viscoelastic composites—such as aramid/cork/foam-cored sandwiches, rubber-interleaved CFRP (Carbon Fibre-Reinforced Polymer) stacks, and aero-elastically tuned bearingless blades—may offer a way to reduce vibratory hub loads and interior sound levels by up to 30%, without the weight penalty associated with traditional add-on insulation. Still, each gram of damping layer must be justified by measurable increases in loss factor and fatigue life. The ideal composite material for each specific design is aircraft-specific and can only be selected after comparative testing that evaluates acoustic insertion loss, weight gain, and maintainability.

Once installed, maintenance considerations must be factored in, as these lightly loaded composites are susceptible to hidden delamination, moisture ingress, and micro-erosion, which can cause imbalance. The lifecycle and safety of each part will then depend on continuous NDT (ultrasonic, thermographic, and radiographic) inspections and predictive maintenance models that translate detected flaws into allowable flight hours before replacement or restoring airworthiness. Future helicopters should be as quiet and smooth as their composite damping systems allow, with integrated sensors enabling support, inspection, and repair to enhance overall feasibility.

8.1 Study Objectives & Diminished Gap Literature

In summary, the goal of enhancing pilot fatigue safety standards across the global offshore oil and gas industry was realised through an innovative approach to measuring vibration and noise exposure. This method supplied adequate data and guidance to improve pilot fatigue management and develop safer industry standards. Valuable insights were obtained from both the field measurement study and the survey. In this research work, the author **WAS ABLE TO**:

- Identify the average daily time limit for flying when vibration and noise exposure exceed international health standards and recommendations.
- Analytical data related to the Fatigue Risk Management System (FRMS) will help offshore helicopter operators better understand the appropriate rostering schemes based on intensity that should be implemented in each business activity.
- Develop a Helicopter Pilot Fatigue Risk Matrix as a quick risk-mitigating tool during the ON rotation period.
- Lastly, it contributed on the development and creation of a simplified mechanism, system, or tool to integrate into the operator's Safety Management System (SMS), enabling operators to manage exposure to vibration and noise values more effectively.

In this research work presented, the author **WAS NOT ABLE TO**:

- Identify offshore helicopter pilots' total daily exposure to vibration and sound noise exposure during a full day of work, up to a maximum of 8 hours of flight time.
  The author acknowledges the need for continuous monitoring of software or hardware that can be used throughout the entire flight period.
- Develop and create a simplified mechanism, system or tool to add to Helicopter Flight Data Monitoring (HFDM), which enables operators to control the exposure of vibration and sound noise values.
  The author recognises the importance of collaborating with an FDM service provider that can develop an algorithm to gather relevant information for operators to use alongside their FRMS.

Regarding the author's intent to reduce the gap between literature and scientific facts by addressing the research questions, the author **WAS ABLE TO ANSWER:**

- Is the fatigue experienced by helicopter pilots primarily attributable to exposure to whole-body vibrations and elevated noise levels generated by the rotor blades and engines, which collectively contribute to the overall impact?

The author emphasises that whole-body vibrations and excessive noise exposure are strong indicators of accumulated fatigue in helicopter pilots, which collectively contribute to the overall impact of fatigue and become more pronounced with age.

- How can the daily exposure doses of pilot vibration and noise be measured and quantified to identify trends in fatigue?
  The author recommends utilising the Safety Risk Analysis Matrix to evaluate vibration and sound exposure among helicopter pilots, in conjunction with Operational Risk Conditions Related to Vibration and Noise Exposure.
- Are measurements sufficient to identify and select the best rotation scheme ON/OFF scheme (21, 28 or 35) independently of the crew responsibility across flight exposure?
  According to the analysis, the measurements are sufficient to identify and select the best rotation, and the author recommends using the 28 ON/OFF for AW139 and AW189.

The author **WAS NOT ABLE TO ANSWER** and provide relevant information since further research study was required to:

- What is the exact exposure of WBV and SN of pilots performing flights with AW139 and AW189?
  The author acknowledges that the exposure is not fully characterised and recognises the importance of measuring the **flight take-off and approach phases** to understand helicopter vibration and noise patterns better; therefore, more research is required. As outlined in 7.1.1, the exposure dose timeframe relates to the total flight time (TFT). The author notes that these values could be significantly higher. However, if measured, the author believes the overall average vibration and noise are probably negligible, since a single takeoff and landing usually lasts less than 10 minutes combined, including the short final approach before and after the landing decision point (LDP), and the takeoff phases before and after the takeoff decision point (TDP). In contrast, during typical offshore flights with multiple landings and takeoffs, these values might become important for the above-recommended times.
- Can the FDM of the aircraft be correlated with the acquired data by direct measurement equipment on the pilot?
  The author recognises the importance of identifying the measuring signals. By utilising logarithmic calculations, one can obtain pertinent information about pilots' positions and, to a degree, discern their exposure patterns to sensor locations.
- If so, could a trustworthy pilot fatigue characterisation be made solely by the FDM?
  The author asserts that proper logarithmic calculations from specific sensors can extract pertinent information to determine the level of pilots' exposure and connect it to cumulative fatigue levels.

8.2 Answers to Research Questions

RQ I: Does the helicopter pilot's fatigue mainly result from exposure to whole-body vibrations and above-average noise levels from blades and engines?
YES, in general, exposure to whole-body vibrations and above-average noise from the blades and engines plays a significant role in the fatigue of helicopter pilots. The author acknowledges that they are not the sole contributors to the overall fatigue level. However, assumes they can confidently assert that more than half of it can be attributed to the WBV and SN experienced while flying, as fatigue accumulates. As a pilot, the author can also state that the overall fatigue level can range between 50 and 75% after a total of 4 hours or more of flying in a day, with up to 45 minute interval between two flights for refuelling, paperwork, and loading passengers and luggage by ground crews, resulting in a total of 4 to 6 landings and take-offs. Although it may not be the sole contributors.

H1: Prolonged periods of whole-body vibration can result in higher fatigue impacts in pilots.
YES, whole-body vibrations from the blades and engines that are felt on the pilot's body directly impact the pilot's fatigue. The research evidence clearly indicates a direct association between the number of hours flown and the pilot's exposure to more WBV, resulting in a greater overall impact on fatigue. Results are more likely to be present mainly after 4 hours of flying during the day.

H2: Prolonged periods of sound noise can result in pilot higher fatigue impacts due to hearing Loss.
YES, despite most pilots' headphones or headsets in flight being equipped with Active Noise Cancellation (ANC), above-average noise from the blades and engines directly impacts pilots' fatigue. Research evidence clearly identifies a direct association between the number of hours flown and the pilot's exposure to noise, resulting in increased overall fatigue, as total noise exposure combined with WBV exceeds health standard recommendations.

RQ II: What is the exact exposure of WBV and SN of pilots performing flights with AW139 and AW189?
The exact exposure to vibration and sound noise on the bodies of pilots performing flights with AW139 and AW189 is variable, as research has only focused on the most extended average exposure period in level and cruise flights. The take-off and approach phases were excluded due to their sensitive safety procedures. The author recognises that these phases experience more vibrations and noise from engine configurations, blade angles of attack, and the blade flapping effect. The author posits that some decisive factors on the aircraft side include the installed equipment, the aircraft's weight in flight, wind speed and direction, temperature, cloud conditions, and the aircraft's operational lifespan. Despite this lifespan, research indicates that even newer and relatively recent aircraft from both companies involved in the study still exhibit high values that pose some risk to pilots' health, leading to fatigue.
Conversely, the author suggests that several factors from the pilot's side are, the type of shoes worn (with or without rubber soles), the weight of the life jacket (with or without an oxygen bottle), belt strap tightness,

the headphones used (with ANC), recovery period need due to age, and the exposure ratio of height to weight, or body mass index (BMI).

H3: The average exposure range is within the recommended ISO 2631 and ISO 1999 standards.
NO, exposure is above the recommended in ISO 2631 and ISO 1999 standards. Results are conclusive in Chapter VI, as demonstrated in the initial, intermediate, and final research field tests. The author alerts to the excessive values identified, as a latent risk to the pilot’s health can be foreseen in medium to long-term scenarios. Further studies are still required.

H4: The average exposure range exceeds the recommended ISO 2631 and ISO 1999 standards.
YES, exposure is above the recommended level in the ISO 2631 and ISO 1999 standards. The results are conclusive. In Chapter VI, values demonstrate being above reference by 11.65 dB and 9.28 dB in Sound Noise exposure for the AW189 and AW139, with Peak values of 14.48 dB and 13.53 dB, respectively. Values demonstrate being above reference by 0.63 dB and below reference -0.60 dB in whole-body vibration exposure in the inferior limit and above reference by 9.71 dB and 3.4 dB in whole-body vibration exposure in the superior limit for both AW189 and AW139.

RQ III: Can daily pilot vibration and noise exposure doses be measured to identify fatigue trends?
NO, the exact vibration and sound noise exposure is measured daily on the bodies of pilots performing flights with the AW139 and AW189, as values are variable. The research only focuses on the longest average exposure period in levelled and cruise flights. Take-off and Approach phases were not included. The author acknowledges that these phases exhibit more vibrations and noise due to engine configurations, blade angle of attack, and blade flapping effects. Therefore, the author assumes that the average value from these two phases may increase the already high values presented in Chapter VI. The author also acknowledges that several factors may have a decisive role in the vibration and sound noise felt by pilots and that even the profile adopted by each pilot may vary and contribute to different values depending on the initial approach profile until descending to 500 feet in the Category A or Category B performance and the take-off profile after crossing 500 feet climbing.

H5: Yes, trends of fatigue may be foreseeable with more data.
YES, the trends of pilots' health effects may be foreseeable with more data from several years of data collection in both the northern and southern hemispheres. It will also play a significant role in identifying common illnesses that may correlate with helicopter pilots exposed to both sound noise and whole-body vibrations. Although the author acknowledges the high cost required to perform this type of research study, several operators would need to sponsor each other in the collection of the data for a typical study and share the insight obtained for the greater good of the working group, establishing a standardised approach that all operators can use through the enforcement of IOGP and Helioffshore members.

H6: No, fatigue trends cannot be foreseeable with more data.

The authors genuinely believe it is possible to be more predictive with additional data.

RQ IV: Are measurements sufficient to identify and select the best rotation scheme ON/OFF scheme, (21, 28 or 35) independently of the crew responsibility across flight exposure?

The research measurement data collected on the AW139 and AW189 flights enabled the quantification of the crews' average exposure to WBV and SN during cruise flights. These values can provide operators with a safe range for crews to create the best rostering scheme.

To identify the best company rostering, the author recommends that the operator analyse the flight activity and the number of crews available for rostering ON/OFF to understand which rostering system will best fit the company's needs. The author acknowledges that companies will always first analyse the benefits of safety versus the value spent in implementing the safety measures based on HNVrfED. Therefore, it must be cost-effective.

Crews and operators are not permitted to accept being scheduled or to schedule crews if the duty time exceeds 12 hours or the total flight time exceeds 8 hours during any rotation. Before each flight, crews must have an 11 hour rest period between flights. Crews are limited to 95 hours within 28 days and 900 hours within 12 months. Duty time and flight time may have further limitations based on the presentation time, which is 1 hour before the flight and is restricted to a number of landings per day. (DR. Nº141 NTA 15, 2022)

Crews typically have 6 days of flying and rest on the seventh day. (DR. Nº192 NTA 15, 2011)

The author genuinely believes that safety is assured in terms of cost-effectiveness and thus advises operators to evaluate the metrics. This will ensure improved crew fitness for flying while enhancing crews' occupational health, safety, environment and longevity.

H7: Bearing the industry's best practices and the Angolan Aviation Safety Regulations, 21 ON 21 OFF is the best rotation for pilots.

The 21 ON/OFF rostering rotation has advantages and disadvantages based on the national aviation safety regulations. In terms of operators, the benefit lies in the cost-benefit ratio of crew readiness, the limit of hours per month, the salaries paid, and the higher proficiency of ON scheduled crews. Rest days can be accumulated if the operator provides a valid reason to the National Civil Aviation Authority for up to three weeks. After this period, a mandatory three-day rest is required. Crews must not exceed a daily duty time of 12 hours or a total flight time of 8 hours during the rotation. If crews exceed these limits within the 21 day period, they will be granted a rest period when duty time exceeds the limit, or an additional day off if flight time is exceeded. Additionally, this research indicates that crews encounter higher levels of helicopter noise and vibrations, leading to increased physiological fatigue, particularly since only three days of rest are guaranteed, or no rest is provided, as noted above.

Crews will experience shorter time off from work, resulting in higher proficiency and less homesickness. In the author's opinion, time off with family is shorter but more suitable for families with children under 15, as they are likely to miss their parents more.

The author acknowledges that the 21 ON/OFF rostering may be suitable for operators with activity for each crew of no more than 4 hours of flight time per day and a duty time of 8 hours per day. The author also assumes that this rostering may result in a more equitable work-life balance for crews, leading to greater psychological stability and reduced stress and fatigue.

H8: Bearing the industry's best practices and the national Angolan Aviation laws, 28 ON 28 OFF is the best rotation for pilots.

Based on Angolan aeronautical safety regulations, the 28 ON/OFF rostering rotation has advantages and disadvantages. The crews based on this research study are less exposed to Helicopter Noise and Vibration, accumulating less physiological fatigue. Crews will experience a slightly longer time OFF from work. Resulting in medium average proficiency, slightly more homesick sensation, time OFF with family is slightly longer, more time for recovery from excess vibration and sound exposure, and a suitable period with families with children above the age of 15 years, where young adolescents will miss their parents less and become more independent, in the opinion of the author.

The author acknowledges that the 28 ON/OFF rostering may be suitable for operators with activity for each crew of more than 4 hours of flight time per day and a duty time of more than 8 hours per day. The author also assumes that this rostering may result in a slightly less equitable work-life balance for crews, leading to slightly less psychological stability and, consequently, slightly more stress or fatigue compared to the 21 ON/OFF rostering. On the other hand, the operators have crews on days with rest days in the ON period and higher OFF periods for crews.

H9: Bearing the industry's best practices and the national Angolan Aviation laws, 35 ON 35 OFF is the best rotation for pilots.

The 35 ON/OFF rostering rotation has advantages and disadvantages based on the Angolan aeronautical safety regulations. The crews based on this research study are much less exposed to Helicopter Noise and Vibration, accumulating less physiological fatigue. Crews will experience a longer time OFF from work, leading to lower average proficiency during the first 2 to 4 days of work. There will also be increased feelings of homesickness compared to the 28 ON/OFF system, and even more so compared to the 21 ON/OFF system. The extended time OFF with family allows for more recovery from exposure to excessive WBV and SN within the 35 ON cycle. It is also a less suitable period for families with children and adolescents under 18, as children will miss their parents more, while young adolescents will miss them less and become more independent, according to the author.

The author acknowledges that the 35 ON/OFF rostering may be suitable for operators who have activity for each crew of more than 6 hours of flight time per day, a duty time of more than 10 hours per day, and work with expatriates or non-residents of the country. Additionally, operators or crews may have to pay for airfares.

The author also assumes that this rostering may lead to an unreasonable work-life balance for crews, resulting in increased psychological instability and, consequently, greater stress and fatigue compared to the 21 or 28 ON/OFF rostering. On the other hand, the operators have crews on days with rest days during the ON period and have higher OFF periods for crews.

Based on the research study, research question IV, and hypotheses 7, 8, and 9 related to the comparison of ON/OFF rostering 21, 28, or 35, scientific facts from the reviewed literature and study presented, and bearing in mind that the total average per day is dependent on the helicopter type flown, the author assumes the best rostering is 28 ON/OFF rostering based on the comparison reasons in **Table 53** below.

Table 53 – ON/OFF Analysis.

	21 ON/OFF	28 ON/OFF	35 ON/OFF
Operator Flight Activity ≤4Hrs FT and 8H DT/ day	x	x	x
Operator Flight Activity ≥4H ≤6H FT and 8H DT/ day		x	x
Operator Flight Activity >6H FT and 10H DT/ day	Not Permitted		
AW139 Crews with lower exposure HVN*rf*ED		x	x
AW189 Crews with lower exposure HVN*rf*ED		x	x
Physiological Fitness/Fatigue		x	x
Work/Family Relationship children ≤15 yrs	x		
Work/Family Relationship children ≥15 yrs		x	x
Psychological Stability Work/Family Relationship	x	x	
Airfare paid by Operator or Crew	x	x	x
National Work Force (living in-country)	x	x	
National and expat workforce (living outside of the country)		x	x

FT= Flight Time; DT=Duty Time

RQ V: Is there any direct or indirect correlation associated with current HUMS or FDM installed equipment to identify an average or correct exposure to avoid adding new physical hardware equipment to measure vibration and noise pilot exposure?

The HUMS correlation was difficult to analyse because the data is sent to Leonardo's Manufacturing Server. All data is uploaded and collected by the manufacturer, limiting the maintenance team's insight to whether the parameters fall within the manufacturer's defined thresholds. Consequently, access is restricted, and any enquiries must be communicated and justified to the manufacturer. Given this situation and the nature of the company´s relationship, the author decided it was wise to limit requests and questions.

H10: The HUMS or FDM vibration data registered is comparably similar to data collected from crew exposure.

The author identifies similar data collected from the FDM, specifically while reading data related to longitudinal, lateral, and vertical accelerations. The author finds that further studies are necessary to confirm whether the data can be utilised more effectively or whether algorithms can be introduced to identify the similarities between cabin exposure experienced by pilots and the quality of value based on sensor distance. The percentage of energy transferred by absorption to crews should be measured, along with error patterns, using FDM data, which shall serve as the basis for reference and for the app measurements to identify differences in the error patterns. The author recommends undertaking this approach in a subsequent research study.

H11: The HUMS or FDM data registered can predict foreseeable fatigue trends without adding additional hardware or software to the aircraft, compared to data collected from crew exposure.
The author assumes that data gathered from the FDM on Longitudinal, Lateral, and Vertical Accelerations can be utilised to evaluate passage and pilot comfort, as well as pilot vibration exposure, depending on the sensor's distance and the signal correction applied in the calculation.

H12: Additional equipment must be added to aircraft to ensure foreseeable fatigue trends for crews.
The author believes that the data from the FDM on Longitudinal, Lateral, and Vertical Accelerations can help calculate potential fatigue trends based on vibration exposure measurements. However, it is also essential to measure sound to better identify the exposure discussed in this research study.

8.3 Limitations of the Research Study

This study has several **limitations when using multiple smartphones, and no specific equipment like that presented in Chapter V, Section 5.6, exists.**
The study was **limited to Angola, where two out of three companies conducted** the same offshore activity.

- The sample used in this study was limited because it only tested pilots flying for SonAir* and BestFly with several nationalities. (* GHC partnership pilots also.)
- Not all national helicopter operators were involved.
  NOTE: Currently, Heli Malongo is not providing offshore helicopter service flights and does not have either of the two aircraft types in this study, AW189 or AW139.

- The data was collected through field measurements, although **not all pilots were included, and only a small number of pilots were invited volunteers for this research study.**
- A total of 25 pilots participated in the field testing and 18 in the Survey.
- The **measurements were conducted when flight activity was below average due to offshore crew change reduction** by oil and gas operators and contracts being mainly MEDEVAC/SANEVAC and AD-HOC Flights.

The limitations of this study underscore the need for further research on the subject to deepen understanding of human factors, specifically fatigue levels, the impact of whole-body vibration (WBV) and noise on helicopter pilots, and the significance of age as a factor in future research.

8.4 Recommendations for Future Research Development

Building on the experimental research, additional studies could further establish the significance, reliability, and credibility of the connection between various illnesses that may evolve into diseases affecting helicopter pilots due to prolonged exposure to WBV and SN. Vibration and noise exposure have been linked to the development of chronic diseases. These physical stressors can trigger a series of physiological responses, especially with long-term exposure, affecting the nervous, cardiovascular, and immune systems and thereby increasing the body's vulnerability to pathogens. Pilots and air operators in this field may also offer comparable information and share safety insights through the International Oil and Gas Producers (IOGP) in their aviation safety committee biannual meetings or with HeliOffshore, resulting in unified standards throughout the industry. Demonstrating these effects would require evaluating numerous subjects over many years, and even then, it might result in a study that remains somewhat subjective. Many control factors are unpredictable, such as genetics, lifestyle, rest, and exercise, making it extremely difficult to manage all variables. Tracking millions of factors over time is unfeasible and costly, necessitating sophisticated monitoring tools, such as artificial intelligence, and devices like Apple and Samsung watches.

The **complexity of the human response to vibration is such that a solution to some specific problems may not be found in the literature**. **The only solution is experimental research to analyse and define the illness-disease causality, resulting in increased fatigue and performance degradation**. Therefore, **creating a phone app or hardware is essential, as presented in Chapter V, Section 5.6, “PILVISOUVEX”, which integrates software that allows pilots to self-monitor their exposure levels and provide such data for research purposes.** It shall be conducted in flight, preferably without pilot intervention. Ideally, it would serve as a personal device, allowing measurement of different genders and ages in this line of duty. Research data should be continuously available for study, investigation, and consultation on such problems over prolonged periods of years.

Recommendations for further research study:

(i) **A prospective interventional study calls for different conditions**. Ideally located in the Middle East, the European North Seas, the Asian Pacific, and the nations of Brazil, the United States, Mexico, Canada, Nigeria, the Ivory Coast, Namibia, Mozambique, Egypt, Libya, Malta, China, Malaysia, and Australia, where meteorological conditions vary and offshore activities exceed those in Angola. **The focus is on the following helicopter types: H160, H175, AW169, AW139, AW189, S92, and B525.** Improving understanding of exposure to vibration & noise levels, as well as related pilot fatigue, based on the body roundness index (BRI), which may offer a more precise assessment of your body shape and possible health risks than the classic BMI, is strongly recommended. The study's rationale encompasses weather conditions, various helicopter types, manufacturers with similar composite material percentages, and the daily flight schedule and hours flown by each pilot.

(ii) **A prospective interventional study in vibration when reading FDM data within the Longitudinal, Lateral and Vertical Accelerations to confirm if data can be used to identify the similarities between cabin exposure felt by pilots and the quality of value based on the distance of sensors.** The percentage of energy transferred to the crews and absorbed should be identified. Error patterns and FDM data shall serve as the basis of reference, and app measurements will be used to identify differences in the error pattern.

(iii) **A prospective interventional study in vibration dose exposure and associated pilot fatigue limitations of subjects within 28 and 35 ON / 28 and 35 OFF rotation schemes, and subjects exposed who may fly above 70 hours per rotation.** The study compares previous studies that reference subjects who may experience acute pain when exposed to accumulated fatigue in the lower back, knee, and elbow joints, as well as hearing loss due to excessive exposure to Vibration and Noise in helicopter pilots in offshore activities.

(iv) **A prospective interventional study in both the medical and engineering fields examines exposure to vibration and noise and the associated pilot sicknesses over a long-term career period of at least 10 to 20 years in offshore activities.** The study compares prior research that has referenced subjects with illnesses. A correlation may exist between the imbalance of normal cellular vibration and its impact on the body's functioning, potentially leading to premature incapacitation or work-related illnesses. This could result in diseases affecting the organs discussed in previous studies.

(v) **A prospective interventional study in both the composite material and engineering fields, which examines how new structural and aerodynamic designs affect the exposure to vibration and noise and the associated pilot absorbed linking to fatigue.** The study examines whether composite materials are actually increasing noise and vibration exposure for helicopter crews. A correlation may exist between less metallic material and more composite material, which may result in slightly higher vibration and noise impact on the crews, which could result in the premature incapacity of the pilot or potential work-related illnesses, leading to diseases in the organs affected by the vibration and sound noise discussed in previous studies.

Pilots possess a class I medical certificate/license and undergo comprehensive medical evaluations in multiple speciality areas, typically once a year, to confirm their fitness and clearance to fly. The information presented can significantly enhance factual information. It could equip this specialised occupational group with a thorough understanding of helicopter pilots' fatigue levels, operational flight fitness, and potential job-related health issues. Ultimately, increased awareness will lead to more comprehensive conclusions.

References

Abbate, C., Micali, E., Giorgianni, C., Munaò, F., & Brecciaroli, R. (2004). Affective Correlates of Occupational Exposure to Whole-Body Vibration. *Psychother and Psychosoma*, *73*, 375–379. https://doi.org/10.1159/000080391

Agrawal, S., Singh, K. K., & Sarkar, P. K. (2014). Impact damage on fibre-reinforced polymer matrix composite - A review. *Journal of Composite Materials*, *48*(3), 317–332. https://doi.org/10.1177/0021998312472217

Agustawestland. (2012). *EASA Type certificate datasheet AW139* (Issue 15). https://www.easa.europa.eu/system/files/dfu/EASA-TCDS-R.006_Agusta_AB139_and_AW139-15-23012012.pdf

Ahn, S. J., & Griffin, M. J. (2007). Effects of frequency, magnitude, damping, and direction on the discomfort of vertical whole-body mechanical shocks. *Journal of Sound and Vibration*, *311*(1–2), 485–497. https://doi.org/10.1016/j.jsv.2007.09.026

Alves-Pereira, M., & Castelo Branco, N. A. A. (2006). Vibroacoustic disease: Biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signalling. *Progress in Biophysics and Molecular Biology*, *93*(1–3), 256–279. https://doi.org/10.1016/j.pbiomolbio.2006.07.011

Andersson, R., Bermejo-García, J., Agujetas, R., Cronhjort, M., & Chilo, J. (2024). Smartphone IMU Sensors for Human Identification through Hip Joint Angle Analysis. *Sensors*, *24*(15). https://doi.org/10.3390/s24154769

Arianna Haffington. (2016). *THE SLEEP REVOLUTION TRANSFORMING YOUR LIFE ONE NIGHT AT A TIME (ISBN 9780753557211)*. Ebury Publishing.

Arora, N., & Grenier, S. G. (2013). Acute effects of whole body vibration on directionality and reaction time latency of trunk muscles: The importance of rest and implications for spine stability. *Journal of Electromyography and Kinesiology*, *23*(2), 394–401. https://doi.org/10.1016/j.jelekin.2012.10.018

Auffret, R., Delehaye, R. P., & Merges, P. J. (1980). *VERTEBRAL PAIN IN HELICOPTER PILOTS* (Issue April). https://ntrs.nasa.gov/citations/19800019542

Baig, H. A., Dorman, D. B., Bulka, B. A., Shivers, B. L., Chancey, V. C., & Winkelstein, B. A. (2014). Characterization of the frequency and muscle responses of the lumbar and thoracic spines of seated volunteers during sinusoidal whole body vibration. *Journal of Biomechanical Engineering*, *136*(10), 2–8. https://doi.org/10.1115/1.4027998

Balaskó, M., Sváb, E., Molnár, G., & Veres, I. (2005). Classification of defects in honeycomb composite structure of helicopter rotor blades. *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *542*(1–3), 45–51. https://doi.org/10.1016/j.nima.2005.01.010

Balaskó, M., Veres, I., Molnár, G., Balaskó, Z., & Sváb, E. (2004). Composite structure of helicopter rotor blades studied by neutron- and X-ray radiography. *Physica B: Condensed Matter*, *350*(1–3), 107–109. https://doi.org/10.1016/j.physb.2004.04.005

Ballard, M. T., Madison, A. M., & Chancey, V. C. (2020). *Human Response Effects to Whole-Body Vibration in Aviation: A Brief Review*. https://apps.dtic.mil/sti/tr/pdf/AD1098433.pdf

Blackman, C. G. (2019). *Whole Body Vibration of Military Aircrews on MH-60 Seahawk Helicopters: Risk Assessment in Relation to Lower Back Pain* [UNIVERSITY OF CALIFORNIA]. https://www.researchgate.net/publication/228976687_Whole_Body_Vibration_Exposure_for_MH-60S_Pilots

Bongers, P. M., Hulshof, C. T. J., Dljkstra, L., Boshuizen, H. C., Groenhout, H. J. M., & Valken, E. (1990). Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics*, *33*(8), 1007–1026. https://doi.org/10.1080/00140139008925309

Boshuizen, H. C., Bongers, P. M., & Hulshof, C. T. J. (1989). Back disorders and occupational exposure to whole-body vibration. *International Journal of Industrial Ergonomics*, *6*(1), 55–59. https://doi.org/10.1016/0169-8141(90)90050-C

Bovenzi, M. (1996). Low back pain disorders and exposure to whole-body vibration in the workplace. *Seminars in Perinatology*, *20*(1), 38–53. https://doi.org/10.1016/S0146-0005(96)80056-5

Burgess, M., & Molesworth, B. R. C. (2016). The Noise Reduction Provided by Aviation Headsets. *Acoustics Australia*, *44*(1), 95–99. https://doi.org/10.1007/s40857-016-0050-y

Campos, J., Ramkhalawansingh, R., & Pichora-Fuller, M. K. (2018). Hearing, self-motion perception, mobility, and aging. *Hearing Research*, *369*, 42–55. https://doi.org/10.1016/j.heares.2018.03.025

CAP 437. (2023). *Standards for offshore helicopter landing areas*. www.caa.co.uk/CAP437

CAP 1145. (2014). *Civil Aviation Authority-Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas*. https://www.caa.co.uk/our-work/publications/documents/content/cap1145/

Chap 14 - Manufacturing of fibre–polymer composite materials. (2012). In *Introduction to Aerospace Materials* (pp. 303–337). Elsevier. https://doi.org/10.1533/9780857095152.303

Chen, Y., Wickramasinghe, V., & Zimcik, D. G. (2011). Development of adaptive helicopter seat for aircrew vibration reduction. *Journal of Intelligent Material Systems and Structures*, *22*(5), 489–502. https://doi.org/10.1177/1045389X11400343

Cornelius, K. M., Redfern, M. S., & Steiner, L. J. (1994). Industrial Ergonomics Postural stability after whole-body vibration exposure. *International Journal of Industrial Ergonomics*, *13*, 343–351. https://doi.org/https://doi.org/10.1016/0169-8141(94)90091-4

Corporation, S. A. (2016a). *EASA Type Certificate data sheet S 76* (Issue 01). https://www2.lba.de/data/bb/Motoren/EN_0069_V02.pdf

Corporation, S. A. (2016b). *EASA TYPE-CERTIFICATE DATA SHEET FOR NOISE S-76 series* (Vol. 001, Issue 2).

https://www.bing.com/ck/a?!&&p=370c451d811cbd528df4c8c82bd9f902f2aa80b72015c1fa56fe672d57a718e6JmltdHM9MTc1OTk2ODAwMA&ptn=3&ver=2&hsh=4&fclid=1214bb85-f0ad-6827-1558-a965f11c69ad&psq=EASA+TYPE-CERTIFICATE+DATA+SHEET+FOR+NOISE+S-76+series+(Vol.+001%2c+Issue+2).&u=a1aHR0cHM6Ly93d3cuZWFzYS5ldXJvcGEuZXUvZW4vZG93bmxvYWRzLzE4MjczL2Vu

Cunningham, L. K., Docherty, S., & Tyler, A. W. (2010). Prevalence of Low Back Pain (LBP) in rotary wing aviation pilots. *Aviation Space and Environmental Medicine*, *81*(8), 774–778. https://doi.org/10.3357/ASEM.2736.2010

Curry, B. D., Bain, J. L. W., Yan, J. G., Zhang, L. L., Yamaguchi, M., Matloub, H. S., & Riley, D. A. (2002). Vibration injury damages arterial endothelial cells. *Muscle and Nerve*, *25*(4), 527–534. https://doi.org/10.1002/mus.10058

Das, M., Sahu, S., & Parhi, D. R. (2020). Composite materials and their damage detection using AI techniques for aerospace application: A brief review. *Materials Today: Proceedings*, *44*, 955–960. https://doi.org/10.1016/j.matpr.2020.11.005

Davies, D. P., Jenkins, S. L., & Belben, F. R. (2013). Survey of fatigue failures in helicopter components and some lessons learnt. *Engineering Failure Analysis*, *32*, 134–151. https://doi.org/10.1016/j.engfailanal.2013.03.005

D.D.L. CHUNG. (2001). Review Materials for vibration damping. *Material Science*, *36*, 5733–5737. https://doi.org/https://doi.org/10.1023/a:1012999616049

De Oliveira, C. G., Simpson, D. M., & Nadal, J. (2001). Lumbar back muscle activity of helicopter pilots and whole-body vibration. *Journal of Biomechanics*, *34*(10), 1309–1315. https://doi.org/10.1016/S0021-9290(01)00090-2

Diamanti, K., & Soutis, C. (2010). Structural health monitoring techniques for aircraft composite structures. *Progress in Aerospace Sciences*, *46*(8), 342–352. https://doi.org/10.1016/j.paerosci.2010.05.001

DIRECTIVE 2002/44/EC. (2002). DIRECTIVE 2002/44/EC Minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). *Official Journal of the European Communities*, *THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, 1–7. https://eur-lex.europa.eu/resource.html?uri=cellar:546a09c0-3ad1-4c07-bcd5-9c3dae6b1668.0004.02/DOC_1&format=PDF

DIRECTIVE 2003/10/EC. (2003). DIRECTIVE 2003/10/EC Minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). *Official Journal of the European Union*, 1–7. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003L0010

Doc 9859 Safety Management Manual (SMM) Fourth Edition, 1 (2018). https://omnisms.aero/wp-content/uploads/2019/08/ICAO-Doc-9859-SMM_Edition-4.pdf dos Santos, F. L. M., Peeters, B., Van der Auweraer, H., Góes, L. C. S., & Desmet, W. (2016). Vibration-based damage detection for a composite helicopter main rotor blade. *Case Studies in Mechanical Systems and Signal Processing*, *3*, 22–27. https://doi.org/10.1016/j.csmssp.2016.01.001

Dupuis, H., & Zerlett, G. (1987). Whole-body vibration and disorders of the spine. *International Archives of Int Arch Occup Environ Health*, *59*, 323–336. https://doi.org/10.1007/BF00405276

EASA Type Certificate DATA SHEET AW189. (2020). *AW189 Type Certificate Data Sheet EASA*. https://www.readkong.com/page/type-certificate-data-sheet-easa-2086581

E.J. Lovesey. (1979). *ENVIRONMENTAL EFFECTS UPON HELICOPTER CREW*. 1–13. https://dspace-erf.nlr.nl/server/api/core/bitstreams/618d2018-ea18-4738-9e8c-52922213d0b6/content

En–tong, W., Wei–xi, G., Wei, C., Xiao–li, M., Hui, X., & Jun, C. (2008). Detection of Early Noise–Induced Hearing Impairment in Pilots. *Journal of Otology*, *3*(2), 108–112. https://doi.org/10.1016/S1672-2930(08)50023-7

EU DIRECTIVE 2003/10/EC. (2003). *DIRECTIVE 2003/10/EC The minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)*. 1–7.

FAA - Nonmilitary Helicopter Urban Noise Study. (2004). *Nonmilitary Helicopter Urban Noise Study*. https://rosap.ntl.bts.gov/view/dot/9814

Fitzpatrick, D. T. (1988). An analysis of noise-induced hearing loss in army helicopter pilots. *Aviation Space and Environmental Medicine*, *59*(10), 937–941. https://doi.org/10.1016/0003-6870(89)90112-9

Fitzpatrick, & Daniel T. (1988). An Analysis of Noise-Induced Hearing Loss in Army Helicopter Pilots. *Aviation Space Environmental Medice*, *59(10) 937-941*, 1–6. https://apps.dtic.mil/sti/tr/pdf/ADA240778.pdf

Fletcher, A., & Dawson, D. (2001). Field-based validations of a work-related fatigue model based on hours of work. *Transportation Research Part F: Traffic Psychology and Behaviour*, *4*(1), 75–88. https://doi.org/10.1016/S1369-8478(01)00015-8

Gaydos, S. J. (2012). Low back pain: Considerations for rotary-wing aircrew. *Aviation Space and Environmental Medicine*, *83*(9), 879–889. https://doi.org/10.3357/ASEM.3274.2012

G.C. Mekalke; S.R. Basavarddi. (2019). Vibration Mitigation of Engine by Using Composite Materials. *International Journal of Engineering and Advanced Technology*, *8*(3), 194–196. https://www.researchgate.net/publication/331672715_Vibration_Mitigation_of_Engine_by_Using_Composite_Materials

George, A. R. (1978). Helicopter noise: State-of-the-art. *Journal of Aircraft*, *15*(11), 707–715. https://doi.org/10.2514/3.58436

Gilchrist, M. D. (2003). The fatigue performance of composite structural components. In *Fatigue in Composites* (pp. 593–620). Elsevier. https://doi.org/10.1533/9781855738577.5.591

Gradwell, D. P., & Rainford, D. J. (2015). *Ernsting´s Aviation and Space Medicine (ISBN 9781444179941)* (C. Press, Ed.; 5th ed.).

Gregory, K. B., Winn, W., Johnson, K., & Rosekind, M. R. (2010). Pilot fatigue survey: Exploring fatigue factors in air medical operations. *Air Medical Journal*, *29*(6), 309–319. https://doi.org/10.1016/j.amj.2010.07.002

Griffin, M. J. (1977). The Evaluation of Human Exposure To Helicopter Vibration. *Aeronautical Journal*, *81*(795), 110–123. https://doi.org/https://doi.org/10.1017/S0001924000032498

Grouios, G., Ziagkas, E., Loukovitis, A., Chatzinikolaou, K., & Koidou, E. (2023). Accelerometers in Our Pocket: Does Smartphone Accelerometer Technology Provide Accurate Data? *Sensors*, *23*(1). https://doi.org/10.3390/s23010192

Halmai, B., Holsgrove, T. P., Vine, S. J., Harris, D. J., & Williams, G. K. R. (2024). The after-effects of occupational whole-body vibration on human cognitive, visual, and motor function: A systematic review. *Applied Ergonomics*, *118*, 1–12. https://doi.org/10.1016/j.apergo.2024.104264

Hamernik, R. P., Ahroon, W. A., & Hsueh, K. D. (1991). *The energy spectrum of an impulse: Its relation to hearing loss*. http://acousticalsociety.org/content/terms.

Harrer, K. Y. D. M. M. E. D. E. N. G. M. (2005). *Whole Body Vibration Exposure for MH-60S Pilots*. https://www.researchgate.net/publication/228976687_Whole_Body_Vibration_Exposure_for_MH-60S_Pilots/link/5405cff70cf2c48563b1b824/download?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19

Harrison, M. F., Patrick Neary, J., Albert, W. J., Kuruganti, U., Croll, J. C., Carol Chancey, V., & Bumgardner, B. A. (2009). Measuring Neuromuscular Fatigue in Cervical Spinal Musculature of Military Helicopter Aircrew. *Military Medicine*, *174*(11), 1183–1189. https://doi.org/10.7205/milmed-d-00-7409

Hawkes, G. R., & Worsham, R. W. (1970). Time perception for helicopter vibration and noise patterns. *Journal of Psychology: Interdisciplinary and Applied*, *76*(1), 71–77. https://doi.org/10.1080/00223980.1970.9916822

Helicopters, A. (2014). *EASA Type Certificate Data Sheet for Noise Super Puma* (Vol. 001, Issue January). https://pt.scribd.com/document/517054635/EASA-TCDS-R-002-Airbus-Helicopters-SA330-AS332-EC225LP-12-07012014

Holder, T. C., Piazza, H., & Grappa, M. (2016). *EASA TYPE-CERTIFICATE DATA SHEET FOR NOISE AW139* (Vol. 001, Issue August). https://www.easa.europa.eu/en/downloads/7997/en

Hostens, I., & Ramon, H. (2003). Descriptive analysis of combine cabin vibrations and their effect on the human body. *Journal of Sound and Vibration*, *266*(3), 453–464. https://doi.org/10.1016/S0022-460X(03)00578-9

Hubbard, H. H., Lansing, D. L., & Runyan, H. L. (1971). A review of rotating blade noise technology. *Journal of Sound and Vibration*, *19*(3), 227–249. https://doi.org/10.1016/0022-460X(71)90686-9

Ibrahim, A., Eltawil, A., Eltawil, A., Na, Y., & El-Tawil, S. (2020). Accuracy limits of embedded smart device accelerometer sensors. *IEEE Transactions on Instrumentation and Measurement*, *69*(8), 5488–5496. https://doi.org/10.1109/TIM.2020.2964912

Ishimatsu, K., Meland, A., Hansen, T. A. S., Kåsin, J. I., & Wagstaff, A. S. (2016). Action slips during whole-body vibration. *Applied Ergonomics*, *55*, 241–247. https://doi.org/10.1016/j.apergo.2015.10.014

ISO 1999. (2013). *ISO 1999-2013 Acoustics-Estimation of noise-induced hearing loss(E)*. https://standards.iteh.ai/catalog/standards/sist/c7a43ade-865c-42b5-95fd-697f5f0365c4/Webwww.iso.orghttps://standards.iteh.ai/catalog/standards/sist/c7a43ade-865c-42b5-95fd-697f5f0365c4/

ISO 1999-2013. (2013). *ISO 1999-2013 Acoustics-Estimation of noise-induced hearing loss*. https://standards.iteh.ai/catalog/standards/sist/c7a43ade-865c-42b5-95fd-697f5f0365c4/Webwww.iso.orghttps://standards.iteh.ai/catalog/standards/sist/c7a43ade-865c-42b5-95fd-697f5f0365c4/

ISO 2631-5. (2018). ISO 2631-5 Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 5: Method for evaluation of vibration containing multiple shocks. In *Iso.Org*. https://standards.iteh.ai/catalog/standards/iso/7cc323db-d6e2-4be3-8776-e8f0ba4649c2/iso-2631-5-2018

ISO 9612. (2009). *ISO 9612-2009 Acoustics-Determination of occupational noise exposure-Engineering method*. https://standards.iteh.ai/catalog/standards/sist/cfaf73ce-cba2-4982-bd71-49641b4085df/iso-9612-2009

ISO-2631-1. (1997). *ISO-2631-1 Mechanical Vibration and Shock - Evaluation of Human exposure to whole-body vibration Part 1*. https://standards.iteh.ai/catalog/standards/sist/ca86d99a-070f-4d3e-a379-a4aa31d09132/iso-2631-1-1997

James, S. (2005). *Defining the Cockpit Noise Hazard, Aircrew Hearing Damage Risk and the Benefits Active Noise Reduction Headsets Can Provide*. https://apps.dtic.mil/sti/pdfs/ADA444706.pdf

Jaruchinda, P. T. T. P. S. H. P. (2005). Prevalence and an Analysis of Noise - Induced Hearing Loss in Army Helicopter Pilots and Aircraft Mechanics. *Journal Medicine Association Thailand*, *88*(10), 232–239. https://doi.org/10.1016/0003-6870(89)90112-9

Javed, A. R., Sarwar, M. U., Khan, S., Iwendi, C., Mittal, M., & Kumar, N. (2020). Analyzing the effectiveness and contribution of each axis of tri-axial accelerometer sensor for accurate activity recognition. *Sensors (Switzerland)*, *20*(8). https://doi.org/10.3390/s20082216

Jin, Y., Yu, L., & Yong, L. (2015). Vibration Reduction of a Bearingless Helicopter Rotor with Composite Tailored Couplings. *Procedia Engineering*, *99*, 1372–1379. https://doi.org/10.1016/j.proeng.2014.12.672

Kåsin, J. I., Mansfield, N., & Wagstaff, A. (2011). Whole body vibration in helicopters: Risk assessment in relation to low back pain. *Aviation Space and Environmental Medicine*, *82*(8), 790–796. https://doi.org/10.3357/ASEM.2982.2011

Kato, Y., Endo, H., & Kizuka, T. (2009). Mental fatigue and impaired response processes: Event-related brain potentials in a Go/No Go task. *International Journal of Psychophysiology*, *72*(2), 204–211. https://doi.org/10.1016/j.ijpsycho.2008.12.008

King, R. B., Saliba, A. J., Creed, D. C., & Brock, J. R. (1996). *Assessment of Noise Levels in and Around the Sikorsky S-7OA-9 Black Hawk Helicopter.* [DSTO Aeronautical and Maritime Research Laboratory]. https://apps.dtic.mil/sti/tr/pdf/ADA322052.pdf

Kittusamy, N. K., & Buchholz, B. (2004). Whole-body vibration and postural stress among operators of construction equipment: A literature review. *Journal of Safety Research*, *35*(3), 255–261. https://doi.org/10.1016/j.jsr.2004.03.014

Krajnak, K. (2018). Health effects associated with occupational exposure to hand-arm or whole body vibration. In *Journal of Toxicology and Environmental Health - Part B: Critical Reviews* (Vol. 21, Issue 5, pp. 320–334). Taylor and Francis Inc. https://doi.org/10.1080/10937404.2018.1557576

Kuronen, P., Toppila, E., Starck, J., Pääkkönen, R., & Sorri, M. J. (2004). Modelling the risk of noise-induced hearing loss among military pilots. *International Journal of Audiology*, *43*(43), 79–84. https://doi.org/10.1080/14992020400050013

Ladner, T. J. (1997). *BACK PAIN AND ENDURANCE TRAINING OF BACK MUSCLES: JUSTIFICATION FOR FURTHER STUDY IN HELICOPTER PILOTS* (Vol. 298) [UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON SCHOOL OF PUBLIC HEALTH]. https://apps.dtic.mil/sti/tr/pdf/ADA325683.pdf

Lang, G. T., & Harrigan, M. J. (2012). Changes in Hearing Thresholds as Measured by Decibels of Hearing Loss in British Army Air Corps Lynx and Apache Pilots. *Military Medicine*, *177*(11), 1431–1437. https://doi.org/10.7205/milmed-d-11-00409

Leonardo Helicopters. (2016). *EASA TYPE-CERTIFICATE DATA SHEET FOR NOISE AW189* (Vol. 001, Issue August). https://www.bing.com/ck/a?!&&p=0fcf92db974daef7f08403964c2799486937c7ba53a8e8a6026857ba234c728eJmltdHM9MTc1OTk2ODAwMA&ptn=3&ver=2&hsh=4&fclid=1214bb85-f0ad-6827-1558-a965f11c69ad&psq=EASA+TYPE-CERTIFICATE+DATA+SHEET+FOR+NOISE+AW189+&u=a1aHR0cHM6Ly93d3cuZWFzYS5ldXJvcGEuZXUvZW4vZG93bmxvYWRzLzE2ODU0L2Vu

Liu, M., Peng, L., Fan, Z., & Wang, D. (2019). *SOUND INSULATION AND MECHANICAL PROPERTIES OF WOOD DAMPING COMPOSITES*.

Lorist, M. M., Kernell, D., Meijman, T. F., & Zijdewind, I. (2002). Motor fatigue and cognitive task performance in humans. *Journal of Physiology*, *545*(1), 313–319. https://doi.org/10.1113/jphysiol.2002.027938

Lowson, M. V., & Ollerhead, J. B. (1969). A theoretical study of helicopter rotor noise. *Journal of Sound and Vibration*, *9*(2), 197–222. https://doi.org/10.1016/0022-460X(69)90028-5

Majumder, S., & Deen, M. J. (2019). Smartphone sensors for health monitoring and diagnosis. *Sensors (Switzerland)*, *19*(9), 2–45. https://doi.org/10.3390/s19092164

Malmivaara, A. A. T. H. L., & Hakkinen, U. (1995). Treatment of acute low back pain - bed rest, exercises, or ordinary activity? *THE NEW ENGLAND JOURNAL OF MEDICINE*, *332*, 351–355. https://doi.org/10.1097/00043764-199606000-00003

Mansfield, N. J. (2004). *Human Response to Vibration (ISBN 9780415282390)*. CRC Press 2004 - 10 - 28.

Mckinley, R. L., Bjorn, V. S., & Hall, J. A. (n.d.). *Improved Hearing Protection for Aviation Personnel*. http://www.rto.nato.int/abstracts.aps.

McMahon, T. W., & Newman, D. G. (2018). The differential effect of sustained operations on psychomotor skills of helicopter pilots. *Aerospace Medicine and Human Performance*, *89*(6), 496–502. https://doi.org/10.3357/AMHP.4895.2018

McReynolds, M. C. (2005). Noise-induced hearing loss. *Air Medical Journal*, *24*(2), 73–78. https://doi.org/10.1016/j.amj.2004.12.005

Min, J. B., Duffy, K. P., Choi, B. B., Provenza, A. J., & Kray, N. (2012). *Piezoelectric Vibration Damping Study for Rotating Composite Fan Blades*. https://ntrs.nasa.gov/api/citations/20120013823/downloads/20120013823.pdf

Morozov, E. V., Sylantiev, S. A., & Evseev, E. G. (2003). Impact damage tolerance of laminated composite helicopter blades. *Composite Structures*, *62*(3–4), 367–371. https://doi.org/10.1016/j.compstruct.2003.09.034

NIOSH. (1998). *NIOSH Publication No. 98-126, Criteria for a Recommended Standard, Occupational Noise Exposure, Revised Criteria 1998*. https://stacks.cdc.gov/view/cdc/6376

Noise-Occupational Exposure Limits in Canada, 1 (2023). https://www.ccohs.ca/oshanswers/phys_agents/noise/exposure_can.pdf

Noise-Occupational Exposure Limits in Canada CCOHS Noise Noise-Occupational Exposure Limits in Canada, 1 (1990). https://www.ccohs.ca/oshanswers/phys_agents/noise/exposure_can.pdf

NTA 15 - Gestão da Fadiga, 1 (2022). https://doc.anac.ao/share/s/WfoCShw3QLOVjU_8J03D8w

NTA 15 - Limites dos Tempos de Serviço do Pessoal Aeronáutico 2011, 1 (2011). Diario da Republica de Angola, 1 série - nº192 de 5 de outubro de 2011

Occupational Noise Exposure, Revised Criteria 1998 (NIOSH Publication No. 98-126), Pub. L. No. nº 98-126, NIOSH 1 (1998). https://stacks.cdc.gov/view/cdc/6376

Odilyn, L., Maria, S., & Farassat, F. (1999). *Two-Dimensional Fourier Transform Analysis Of Helicopter Flyover Noise* (Issue April). https://ntrs.nasa.gov/api/citations/20040086754/downloads/20040086754.pdf

Okunribido, O. O., Magnusson, M., & Pope, M. H. (2008). The role of whole body vibration, posture and manual materials handling as risk factors for low back pain in occupational drivers. *Ergonomics*, *51*(3), 308–329. https://doi.org/10.1080/00140130701637262

OSHA. (2020). *Subpart G — Occupational Health and Environmental Control*. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.95

Owen, J. P. (1995). Noise induced hearing loss in military helicopter aircrew--a review of the evidence. *Journal of the Royal Army Medical Corps*, *141*(2), 98–101. https://doi.org/10.1136/jramc-141-02-08

Panjabi, M. M., Andersson, G. B. J., Jorneus, L., Hult, E., & Mattsson, L. (1986). In vivo measurements of spinal column vibrations. *Journal of Bone and Joint Surgery - Series A*, *68*(5), 695–702. https://doi.org/10.2106/00004623-198668050-00009

Pawar, P. M., & Ganguli, R. (2007). On the effect of progressive damage on composite helicopter rotor system behavior. *Composite Structures*, *78*(3), 410–423. https://doi.org/10.1016/j.compstruct.2005.11.043

Pei, L., Jiao, S., Chen, R., Liu, J., Chen, W., Kuusniemi, H., Tenhunen, T., Kröger, T., Chen, Y., Leppäkoski, H., & Takala, J. (2010, September). *Motion recognition assisted indoor wireless navigation on a mobile phone*. https://www.researchgate.net/publication/261876649

Peng, L., Song, B., Wang, J., & Wang, D. (2015). Mechanic and acoustic properties of the sound-absorbing material made from natural fiber and polyester. *Advances in Materials Science and Engineering*, *2015*, 5. https://doi.org/10.1155/2015/274913

Phillips, A. S. (2011). *The scope of back pain in Navy helicopter pilots* [Master Thesis, Naval Postgraduate School]. http://hdl.handle.net/10945/5795

Phillips, J., Forrester, B., & Brown, K. (1996). Low Back Pain Prevention and Management. *AAOHN JOURNAL*, *44*(1), 40–50. https://doi.org/10.1177/216507999604400110

Piňosová, M., Andrejiová, M., Badida, M., & Moravec, M. (2018). Analysis and Evaluation of Risks from Exposure to Noise in a Working Environment. *Acta Mechanica Slovaca*, *22*(3), 44–52. https://doi.org/10.21496/ams.2018.026

Pope, M. H., Wilder, D. G., Jorneus, L., Broman, H., Svensson, M., & Andersson, G. (1987). The response of the seated human to sinusoidal vibration and impact. *Journal of Biomechanical Engineering*, *109*(4), 279–284. https://doi.org/10.1115/1.3138681

Pope, M. H., Wilder, D. G., Seroussi, R. E., & Donnermeyer, D. D. (1985). *The Effects of Helicopter Vibration on the Spinal System*. https://apps.dtic.mil/sti/tr/pdf/ADA181434.pdf

Rabinowitz, Y. G., Breitbach, J. E., & Warner, C. H. (2009). Managing Aviator Fatigue in a Deployed Environment: The Relationship Between Fatigue and Neurocognitive Functioning. *Military Medicine*, *174*(4), 358–362. https://doi.org/10.7205/milmed-d-01-5008

Reinhart, R. O. (2008). *Basic Flight Physiology (ISBN 978-0-07-149488-5)* (third edit). Mc Graw Hill.

Rivera, J. A., Aguilar, E., Cárdenas, D., Elizalde, H., & Probst, O. (2016). Progressive failure analysis for thin-walled composite beams under fatigue loads. *Composite Structures*, *154*, 79–91. https://doi.org/10.1016/j.compstruct.2016.07.026

S, M. A. M. A. Z. M. I. G. M. N. Y. M. I. (2009). *Investigation on Sound Absorption of Rice-Husk Reinforced Composite*. 19–22. https://doi.org/10.46335/IJIES.2021.6.6.5

Santos, B. R., Larivière, C., Delisle, A., Plamondon, A., Boileau, P. É., & Imbeau, D. (2008). A laboratory study to quantify the biomechanical responses to whole-body vibration: The influence on balance, reflex response, muscular activity and fatigue. *International Journal of Industrial Ergonomics*, *38*(7–8), 626–639. https://doi.org/10.1016/j.ergon.2008.01.015

Savage, R., Billing, D., Furnell, A., Netto, K., & Aisbett, B. (2015). Whole-body vibration and occupational physical performance: a review. *International Archives of Occupational and Environmental Health*, *89*(2), 181–197. https://doi.org/10.1007/s00420-015-1062-x

Seidel, H., Bastek, R., Brauer, D., Buchholz, C., Meister, A., Metz, A. M., & Rothe, R. (1980). On human response to prolonged repeated whole-body vibration. *Ergonomics*, *23*(3), 191–211. https://doi.org/10.1080/00140138008924734

Shappell, S. A., & Wiegmann, D. A. (2000). *The Human Factors Analysis and Classification System – HFACS*. https://commons.erau.edu/cgi/viewcontent.cgi?article=1777&context=publication

Shen, J., Li, X., & Yan, X. (2021). Mechanical and Acoustic Properties of Jute Fiber-Reinforced Polypropylene Composites. *ACS Omega*, *6*(46), 31154–31160. https://doi.org/10.1021/acsomega.1c04605

Silva, G. V. da. (2018). Helicopter Pilots and Low Back Pain: How to Manage the Risk Factors? *Ergonomics International Journal*, *2*(1), 1–11. https://doi.org/10.23880/eoij-16000130

Singh, P. P., & Nath, G. (2021). Noise Reduction Analysis through Biomaterial Based Acoustic Material. *Indian Journal of Pure & Applied Physics*, *59*, 429–436. https://pdfs.semanticscholar.org/e116/4e6da5fde32c70f382190d6d49d793e9c9c5.pdf

Sirevaag, E. J., Kramer, A. F., Wickens, C. D., Reisweber, M., Strayer, D. L., & Grenell, J. F. (1993). Assessment of pilot performance and mental workload in rotary wing aircraft. *Ergonomics*, *36*(9), 1121–1140. https://doi.org/10.1080/00140139308967983

Smith, D., & Leggat, P. (2005). Whole-body vibration: health effects, measurement and minimization. Professional Safety. *Professional Safety*, *50*(July), 35–40. https://aeasseincludes.assp.org/professionalsafety/pastissues/050/07/030705as.pdf

Smith, S. C. S. C. J. (2019). *Vibration Exposure Characterization and health risk assessment of the UH-60L Blackhawk*. https://apps.dtic.mil/sti/pdfs/AD1082363.pdf

Snecma, Airbus Helicopters, Sikorsky Aircraft, Bell Helicopter, AgustaWestland, Turbomeca, Marenco Swisshelicopter, ASA, DLR, ONERA, & JAXA. (2015). *Helicopter Noise Reduction Technology* (Issue April). https://www.icao.int/environmental-protection/Documents/Helicopter_Noise_Reduction_Technology_Status_Report_April_2015.pdf

Sneddon, A., Mearns, K., & Flin, R. (2013). Stress, fatigue, situation awareness and safety in offshore drilling crews. *Safety Science*, *56*, 80–88. https://doi.org/10.1016/j.ssci.2012.05.027

Stave, A. (1973). EFFECTS OF HELICOPTER NOISE AND VIBRATION ON PILOT PERFORMANC. In *ペインクリニック学会治療指針２* (Vol. 4, Issue 1). https://doi.org/.1037//0033-2909.I26.1.78

Tang, X., & Yan, X. (2020). A review on the damping properties of fiber reinforced polymer composites. In *Journal of Industrial Textiles* (Vol. 49, Issue 6, pp. 693–721). SAGE Publications Ltd. https://doi.org/10.1177/1528083718795914

Teixeira, C. L. D. (2020). *HELICOPTER PILOT ROSTERING ON/OFF SCHEDULE SCHEME IN ANGOLA OIL AND GAS OFFSHORE INDUSTRY Fatigue in Offshore Helicopter Pilots* [Master Dissertation, ISEC]. https://comum.rcaap.pt/entities/publication/8a4b9daf-e9f0-4a15-a14a-30e837733d3f

Truszczynska, A., Lewkowicz, R., Truszczynski, O., Rapala, K., & Wojtkowiak, M. (2012). Back pain in Polish military helicopter pilots. *International Journal of Occupational Medicine and Environmental Health*, *25*(3), 258–264. https://doi.org/10.2478/S13382-012-0033-7

U.S. DHEW. (1972). *OCCUPATIONAL EXPOSURE TO NOISE* (Issue U. S. DEPARTMENT OF HEALTH. EDUCATION, AND WELFARE Health Services and Mental Health Administration National Institute for Occupational Safety and Health). https://stacks.cdc.gov/view/cdc/19325

Wan, A. S., Xu, Y. G., Xue, L. H., Xu, M. R., & Xiong, J. J. (2021). Finite element modeling and fatigue life prediction of helicopter composite tail structure under multipoint coordinated loading spectrum. *Composite Structures*, *255*, 1–12. https://doi.org/10.1016/j.compstruct.2020.112900

Wannenburg, J., & Malekian, R. (2017). Physical Activity Recognition from Smartphone Accelerometer Data for User Context Awareness Sensing. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *47*(12), 3142–3149. https://doi.org/10.1109/TSMC.2016.2562509

Yan, J., Lee, J. C., Lee, C. W., Kang, D. W., Kang, Y. J., & Ahn, S. H. (n.d.). *SOUNDPROOF EFFECT OF NANOCLAY REINFORCED POLYPROPYLENE COMPOSITES*. https://www.semanticscholar.org/paper/SOUNDPROOF-EFFECT-OF-NANOCLAY-REINFORCED-COMPOSITES-Yan-Lee/d829307fe2fe93b4237faf8880b970d9c8d87b80

Yin, J., van der Wall, B. G., & Oerlemans, S. (2008). Acoustic wind tunnel tests on helicopter tail rotor noise (HeliNOVI). *Journal of the American Helicopter Society*, *53*(3), 226–239. https://doi.org/10.4050/JAHS.53.226

Zadoń, H., Nowakowska-Lipiec, K., & Michnik, R. (2021). A sitting or standing position – which one exerts more loads on the musculoskeletal system of the lumbar spine? Comparative tests based on the methods of mathematical modelling. *Acta of Bioengineering and Biomechanics*, *23*(1), 1–17. https://doi.org/10.37190/ABB-01762-2020-01

Zaman, I., Latif, A., Tobi, M., Manshoor, B., Khalid, A., Amri, N., & Amin, M. (2016). NEW APPROACH OF DYNAMIC VIBRATION ABSORBER MADE FROM NATURAL FIBRES COMPOSITE. *ARPN Journal of Engineering and Applied Sciences*, *11*(4), 2308–2313. https://core.ac.uk/download/pdf/42956231.pdf

Zhu, X., Kim, B.-J., Wang, Q., & Wu, Q. (2014). *Recent Advances in the Sound Insulation Properties of Bio-based Materials*. https://bioresources.cnr.ncsu.edu/wp-content/uploads/2016/06/BioRes_09_1_Review_c_Zhu_Wu_Recent_Advan_Sound_Transm_Props_Biobased_4744.pdf

Appendices

In the Appendices, the following information is provided to support the above research study: Pre-Notice Letter of Questionnaire, Questionnaire, Conversion Table from Acceleration to Decibel, In-Flight Data from measurement collection and 360° Overview of Pilots' Positioning while Flying on Controls.

Appendix 1: Pre-Notice Letter of Questionnaire

Pre-Notice Letter

I am a helicopter offshore pilot attending a PhD program in Structural Integrity in Aircraft at Atlântica Instituto Universitário in Lisbon, Portugal. I am developing a research study for a thesis on offshore pilot fatigue. This Questionnaire aims to obtain relevant information regarding fatigue risk in the offshore industry. The data gathered will help mitigate fatigue analysis.

Your participation is essential!

Please answer the following questionnaire. It takes no more than 5 minutes. All answers are anonymous and aimed at academic purposes.

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

Appendix 2: Questionnaire

Prior or Post-Flight Field-Testing Questionnaire

I – DEMOGRAPHIC INFORMATION

1. Gender:

◯ Female ◯ Male

2. Age (years):

______

3. Weight (kg):

______

4. Height (cm):

______

II – PROFESSIONAL INFORMATION

5. Pilot license:

◯ Commercial Pilot (CPL(H)) ◯ Airline Transport Pilot (ATPL (H))

6. Medical license Class 1:

◯ Annually fit ◯ Annually fit (with restrictions)

7. Helicopter Type Rated (select the one that you mostly fly when double-rated):

◯ AW169 ◯ H160 ◯ AW139 ◯ S76 ◯ AW189 ◯ H175 ◯ S92 ◯ OTHER

8. Helicopter Type Rated if dual rated on other type):

◯ AW169 ◯ H160 ◯ AW139 ◯ S76 ◯ AW189 ◯ H175 ◯ S92 ◯ OTHER

9. Valid type rating at the time:

◯ With Type rating Valid ◯ Without type rating Valid

10. Current number of hours on type mostly flown? (Your best estimate is fine)

____

11. Current number of TOTAL hours? (Your best estimate is fine)

____

12. Main role in the organisation?
   - ◯ Co-pilot
   - ◯ Captain
   - ◯ Instructor (LTC/TRI/TRE)
   - ◯ Pilot with added Administrative or Managing functions

13. Headphones or Headsets used in flight are equipped with Active Noise Cancellation?
   - ◯ Yes
   - ◯ No
   - ◯ Don’t Know

III - SLEEP QUALITY AND FATIGUE

(NEMSPA Sleep and Fatigue Survey, Questions 8 - 15 (Gregory et al., 2010))

14. How many consecutive DAY shifts do you typically work?

   ◯ 1 or 2 ◯ 3 or 4 ◯ 5 or 6 ◯ 7 ◯ greater than 7

15. 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

16. 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

17. 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

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

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

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

   ◯ Never ◯ rarely ◯ occasionally ◯ somewhat frequently ◯ frequently

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

   ◯ Yes ◯ No

21. 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

Appendix 3: Conversion Table from Acceleration to Decibel

Conversion Formula from Acceleration to Decibel															
dB	m/s^2	dB	m/s^2	dB	m/s^2	dB	m/s^2	dB	m/s^2	dB	m/s^2	dB	m/s^2	dB	m/s^2
120	9.81	115	5.52	110	3.10	105	1.74	100	0.98	95	0.55	**90**	**0.31**	85	0.17
119.95	9.75	114.95	5.48	109.95	3.08	104.95	1.73	**99.95**	**0.98**	**94.95**	**0.55**	89.95	0.31	84.95	0.17
119.9	9.70	114.9	5.45	109.9	3.07	104.9	1.72	**99.9**	**0.97**	94.9	0.55	89.9	0.31	84.9	0.17
119.85	9.64	114.85	5.42	109.85	3.05	104.85	1.71	99.85	0.96	94.85	0.54	89.85	0.30	84.85	0.17
119.8	9.59	114.8	5.39	109.8	3.03	104.8	1.70	**99.8**	**0.96**	**94.8**	**0.54**	89.8	0.30	84.8	0.17
119.75	9.53	114.75	5.36	109.75	3.01	104.75	1.69	99.75	0.95	94.75	0.54	89.75	0.30	**84.75**	**0.17**
119.7	9.48	114.7	5.33	109.7	3.00	104.7	1.69	**99.7**	**0.95**	94.7	0.53	**89.7**	**0.30**	84.7	0.17
119.65	9.42	114.65	5.30	109.65	2.98	104.65	1.68	99.65	0.94	**94.65**	**0.53**	89.65	0.30	84.65	0.17
119.6	9.37	114.6	5.27	109.6	2.96	104.6	1.67	**99.6**	**0.94**	94.6	0.53	89.6	0.30	84.6	0.17
119.55	9.31	114.55	5.24	109.55	2.95	104.55	1.66	99.55	0.93	94.55	0.52	89.55	0.29	84.55	0.17
119.5	9.26	114.5	5.21	109.5	2.93	104.5	1.65	**99.5**	**0.93**	**94.5**	**0.52**	89.5	0.29	84.5	0.16
119.45	9.21	114.45	5.18	109.45	2.91	104.45	1.64	99.45	0.92	94.45	0.52	89.45	0.29	84.45	0.16
119.4	9.16	114.4	5.15	109.4	2.90	104.4	1.63	**99.4**	**0.92**	94.4	0.51	**89.4**	**0.29**	84.4	0.16
119.35	9.10	114.35	5.12	109.35	2.88	104.35	1.62	99.35	0.91	94.35	0.51	89.35	0.29	84.35	0.16
119.3	9.05	114.3	5.09	109.3	2.86	104.3	1.61	**99.3**	**0.91**	**94.3**	**0.51**	89.3	0.29	84.3	0.16
119.25	9.00	114.25	5.06	109.25	2.85	**104.25**	**1.60**	**99.25**	**0.90**	94.25	0.51	89.25	0.28	84.25	0.16
119.2	8.95	114.2	5.03	109.2	2.83	**104.2**	**1.59**	99.2	0.89	94.2	0.50	89.2	0.28	**84.2**	**0.16**
119.15	8.90	114.15	5.00	109.15	2.81	**104.15**	**1.58**	**99.15**	**0.89**	**94.15**	**0.50**	89.15	0.28	84.15	0.16
119.1	8.84	114.1	4.97	109.1	2.80	**104.1**	**1.57**	99.1	0.88	94.1	0.50	**89.1**	**0.28**	84.1	0.16
119.05	8.79	114.05	4.95	109.05	2.78	**104.05**	**1.56**	**99.05**	**0.88**	94.05	0.49	89.05	0.28	84.05	0.16
119	8.74	114	4.92	109	2.76	104	1.55	99	0.87	94	0.49	89	0.28	84	0.16
118.95	8.69	113.95	4.89	108.95	2.75	**103.95**	**1.55**	**98.95**	**0.87**	**93.95**	**0.49**	88.95	0.27	83.95	0.15
118.9	8.64	113.9	4.86	108.9	2.73	**103.9**	**1.54**	98.9	0.86	93.9	0.49	88.9	0.27	83.9	0.15
118.85	8.59	113.85	4.83	108.85	2.72	**103.85**	**1.53**	**98.85**	**0.86**	93.85	0.48	88.85	0.27	83.85	0.15
118.8	8.54	113.8	4.80	108.8	2.70	**103.8**	**1.52**	98.8	0.85	**93.8**	**0.48**	**88.8**	**0.27**	83.8	0.15
118.75	8.50	113.75	4.78	108.75	2.69	**103.75**	**1.51**	**98.75**	**0.85**	93.75	0.48	88.75	0.27	83.75	0.15
118.7	8.45	113.7	4.75	108.7	2.67	**103.7**	**1.50**	98.7	0.84	93.7	0.47	88.7	0.27	83.7	0.15
118.65	8.40	113.65	4.72	108.65	2.66	**103.65**	**1.49**	**98.65**	**0.84**	93.65	0.47	88.65	0.27	83.65	0.15
118.6	8.35	113.6	4.70	108.6	2.64	103.6	1.48	98.6	0.83	**93.6**	**0.47**	88.6	0.26	**83.6**	**0.15**
118.55	8.30	113.55	4.67	108.55	2.63	**103.55**	**1.48**	**98.55**	**0.83**	93.55	0.47	88.55	0.26	83.55	0.15
118.5	8.25	113.5	4.64	108.5	2.61	**103.5**	**1.47**	98.5	0.83	93.5	0.46	88.5	0.26	83.5	0.15
118.45	8.21	113.45	4.61	108.45	2.60	**103.45**	**1.46**	98.45	0.82	93.45	0.46	**88.45**	**0.26**	83.45	0.15
118.4	8.16	113.4	4.59	108.4	2.58	**103.4**	**1.45**	**98.4**	**0.82**	**93.4**	**0.46**	88.4	0.26	83.4	0.15
118.35	8.11	113.35	4.56	108.35	2.57	**103.35**	**1.44**	98.35	0.81	93.35	0.46	88.35	0.26	83.35	0.14
118.3	8.07	113.3	4.54	108.3	2.55	103.3	1.43	**98.3**	**0.81**	93.3	0.45	88.3	0.26	83.3	0.14
118.25	8.02	113.25	4.51	108.25	2.54	**103.25**	**1.43**	98.25	0.80	93.25	0.45	88.25	0.25	83.25	0.14
118.2	7.97	113.2	4.48	108.2	2.52	**103.2**	**1.42**	**98.2**	**0.80**	**93.2**	**0.45**	88.2	0.25	83.2	0.14
118.15	7.93	113.15	4.46	108.15	2.51	**103.15**	**1.41**	98.15	0.79	93.15	0.45	88.15	0.25	83.15	0.14

118.1	7.88	113.1	4.43	108.1	2.49	**103.1**	**1.40**	**98.1**	**0.79**	93.1	0.44	**88.1**	**0.25**	83.1	0.14
118.05	7.84	113.05	4.41	108.05	2.48	103.05	1.39	98.05	0.78	93.05	0.44	88.05	0.25	**83.05**	**0.14**
118	7.79	113	4.38	108	2.46	**103**	**1.39**	**98**	**0.78**	**93**	**0.44**	88	0.25	83	0.14
117.95	7.75	112.95	4.36	107.95	2.45	**102.95**	**1.38**	97.95	0.77	92.95	0.44	87.95	0.25	82.95	0.14
117.9	7.70	112.9	4.33	107.9	2.44	**102.9**	**1.37**	**97.9**	**0.77**	92.9	0.43	87.9	0.24	82.9	0.14
117.85	7.66	112.85	4.31	107.85	2.42	**102.85**	**1.36**	97.85	0.77	92.85	0.43	87.85	0.24	82.85	0.14
117.8	7.61	112.8	4.28	107.8	2.41	102.8	1.35	97.8	0.76	**92.8**	**0.43**	87.8	0.24	82.8	0.14
117.75	7.57	112.75	4.26	107.75	2.39	**102.75**	**1.35**	**97.75**	**0.76**	92.75	0.43	87.75	0.24	82.75	0.13
117.7	7.53	112.7	4.23	107.7	2.38	**102.7**	**1.34**	97.7	0.75	92.7	0.42	**87.7**	**0.24**	82.7	0.13
117.65	7.48	112.65	4.21	107.65	2.37	**102.65**	**1.33**	**97.65**	**0.75**	92.65	0.42	87.65	0.24	82.65	0.13
117.6	7.44	112.6	4.18	107.6	2.35	102.6	1.32	97.6	0.74	**92.6**	**0.42**	87.6	0.24	82.6	0.13
117.55	7.40	112.55	4.16	107.55	2.34	**102.55**	**1.32**	**97.55**	**0.74**	92.55	0.42	87.55	0.23	82.55	0.13
117.5	7.36	112.5	4.14	107.5	2.33	**102.5**	**1.31**	97.5	0.74	92.5	0.41	87.5	0.23	82.5	0.13
117.45	7.31	112.45	4.11	107.45	2.31	**102.45**	**1.30**	97.45	0.73	92.45	0.41	87.45	0.23	82.45	0.13
117.4	7.27	112.4	4.09	107.4	2.30	102.4	1.29	**97.4**	**0.73**	**92.4**	**0.41**	**87.4**	**0.23**	**82.4**	**0.13**
117.35	7.23	112.35	4.07	107.35	2.29	**102.35**	**1.29**	97.35	0.72	92.35	0.41	87.35	0.23	82.35	0.13
117.3	7.19	112.3	4.04	107.3	2.27	**102.3**	**1.28**	**97.3**	**0.72**	92.3	0.40	87.3	0.23	82.3	0.13
117.25	7.15	112.25	4.02	107.25	2.26	**102.25**	**1.27**	97.25	0.71	92.25	0.40	87.25	0.23	82.25	0.13
117.2	7.11	112.2	4.00	107.2	2.25	102.2	1.26	**97.2**	**0.71**	**92.2**	**0.40**	87.2	0.22	82.2	0.13
117.15	7.07	112.15	3.97	107.15	2.23	**102.15**	**1.26**	97.15	0.71	92.15	0.40	87.15	0.22	82.15	0.13
117.1	7.03	112.1	3.95	107.1	2.22	**102.1**	**1.25**	97.1	0.70	92.1	0.40	87.1	0.22	82.1	0.12
117.05	6.99	112.05	3.93	107.05	2.21	102.05	1.24	**97.05**	**0.70**	92.05	0.39	87.05	0.22	82.05	0.12
117	6.94	112	3.91	107	2.20	**102**	**1.24**	97	0.69	92	0.39	**87**	**0.22**	82	0.12
116.95	6.91	111.95	3.88	106.95	2.18	**101.95**	**1.23**	**96.95**	**0.69**	**91.95**	**0.39**	86.95	0.22	81.95	0.12
116.9	6.87	111.9	3.86	106.9	2.17	**101.9**	**1.22**	96.9	0.69	91.9	0.39	86.9	0.22	81.9	0.12
116.85	6.83	111.85	3.84	106.85	2.16	101.85	1.21	96.85	0.68	91.85	0.38	86.85	0.22	81.85	0.12
116.8	6.79	111.8	3.82	106.8	2.15	**101.8**	**1.21**	**96.8**	**0.68**	91.8	0.38	86.8	0.21	81.8	0.12
116.75	6.75	111.75	3.79	106.75	2.13	**101.75**	**1.20**	96.75	0.67	**91.75**	**0.38**	86.75	0.21	81.75	0.12
116.7	6.71	111.7	3.77	106.7	2.12	101.7	1.19	**96.7**	**0.67**	91.7	0.38	86.7	0.21	**81.7**	**0.12**
116.65	6.67	111.65	3.75	106.65	2.11	**101.65**	**1.19**	96.65	0.67	91.65	0.38	86.65	0.21	81.65	0.12
116.6	6.63	111.6	3.73	106.6	2.10	101.6	1.18	96.6	0.66	91.6	0.37	**86.6**	**0.21**	81.6	0.12
116.55	6.59	111.55	3.71	106.55	2.09	101.55	1.17	**96.55**	**0.66**	91.55	0.37	86.55	0.21	81.55	0.12
116.5	6.56	111.5	3.69	106.5	2.07	**101.5**	**1.17**	96.5	0.66	**91.5**	**0.37**	86.5	0.21	81.5	0.12
116.45	6.52	111.45	3.67	106.45	2.06	101.45	1.16	96.45	0.65	91.45	0.37	86.45	0.21	81.45	0.12
116.4	6.48	111.4	3.64	106.4	2.05	101.4	1.15	**96.4**	**0.65**	91.4	0.36	86.4	0.20	81.4	0.12
116.35	6.44	111.35	3.62	106.35	2.04	**101.35**	**1.15**	96.35	0.64	91.35	0.36	86.35	0.20	81.35	0.11
116.3	6.41	111.3	3.60	106.3	2.03	101.3	1.14	**96.3**	**0.64**	**91.3**	**0.36**	86.3	0.20	81.3	0.11
116.25	6.37	111.25	3.58	106.25	2.01	101.25	1.13	96.25	0.64	91.25	0.36	86.25	0.20	81.25	0.11
116.2	6.33	111.2	3.56	106.2	2.00	101.2	1.13	96.2	0.63	91.2	0.36	86.2	0.20	81.2	0.11
116.15	6.30	111.15	3.54	106.15	1.99	101.15	1.12	**96.15**	**0.63**	91.15	0.35	**86.15**	**0.20**	81.15	0.11
116.1	6.26	111.1	3.52	106.1	1.98	101.1	1.11	96.1	0.63	91.1	0.35	86.1	0.20	81.1	0.11
116.05	6.23	111.05	3.50	106.05	1.97	**101.05**	**1.11**	96.05	0.62	**91.05**	**0.35**	86.05	0.20	81.05	0.11
116	6.19	111	3.48	106	1.96	**101**	**1.10**	**96**	**0.62**	91	0.35	86	0.20	81	0.11

115.95	6.15	110.95	3.46	105.95	1.95	100.95	1.09	95.95	0.62	90.95	0.35	85.95	0.19	**80.95**	**0.11**
115.9	6.12	110.9	3.44	105.9	1.93	**100.9**	**1.09**	95.9	0.61	90.9	0.34	85.9	0.19	80.9	0.11
115.85	6.08	110.85	3.42	105.85	1.92	100.85	1.08	**95.85**	**0.61**	90.85	0.34	85.85	0.19	80.85	0.11
115.8	6.05	110.8	3.40	105.8	1.91	**100.8**	**1.08**	95.8	0.60	**90.8**	**0.34**	85.8	0.19	80.8	0.11
115.75	6.01	110.75	3.38	**105.75**	**1.90**	**100.75**	**1.07**	**95.75**	**0.60**	90.75	0.34	85.75	0.19	80.75	0.11
115.7	5.98	110.7	3.36	105.7	1.89	100.7	1.06	95.7	0.60	90.7	0.34	**85.7**	**0.19**	80.7	0.11
115.65	5.95	110.65	3.34	105.65	1.88	**100.65**	**1.06**	95.65	0.59	90.65	0.33	85.65	0.19	80.65	0.11
115.6	5.91	110.6	3.32	105.6	1.87	100.6	1.05	**95.6**	**0.59**	90.6	0.33	85.6	0.19	80.6	0.11
115.55	5.88	110.55	3.30	105.55	1.86	**100.55**	**1.05**	95.55	0.59	**90.55**	**0.33**	85.55	0.19	80.55	0.10
115.5	5.84	110.5	3.29	105.5	1.85	**100.5**	**1.04**	95.5	0.58	90.5	0.33	85.5	0.18	80.5	0.10
115.45	5.81	110.45	3.27	105.45	1.84	100.45	1.03	**95.45**	**0.58**	90.45	0.33	85.45	0.18	80.45	0.10
115.4	5.78	110.4	3.25	105.4	1.83	**100.4**	**1.03**	95.4	0.58	90.4	0.32	85.4	0.18	80.4	0.10
115.35	5.74	110.35	3.23	105.35	1.82	100.35	1.02	95.35	0.57	90.35	0.32	85.35	0.18	80.35	0.10
115.3	5.71	110.3	3.21	105.3	1.81	**100.3**	**1.02**	**95.3**	**0.57**	90.3	0.32	85.3	0.18	**80.3**	**0.10**
115.25	5.68	110.25	3.19	105.25	1.80	**100.25**	**1.01**	95.25	0.57	**90.25**	**0.32**	**85.25**	**0.18**	80.25	0.10
115.2	5.65	110.2	3.17	105.2	1.79	100.2	1.00	95.2	0.56	90.2	0.32	85.2	0.18	80.2	0.10
115.15	5.61	110.15	3.16	105.15	1.77	**100.15**	**1.00**	**95.15**	**0.56**	90.15	0.32	85.15	0.18	80.15	0.10
115.1	5.58	110.1	3.14	105.1	1.76	100.1	0.99	95.1	0.56	90.1	0.31	85.1	0.18	80.1	0.10
115.05	5.55	110.05	3.12	105.05	1.75	**100.05**	**0.99**	95.05	0.55	90.05	0.31	85.05	0.18	80.05	0.10

Appendix 4: In Flight Data

Offshore Commercial Flights Initial Analysis on AW189

Table 54 – Data Collection and Analysis Initial phase on AW189

confidential data removed

Offshore Commercial Flights Intermediate Analysis on AW189

Table 55 – Data Collection and Analysis Intermediate phase on AW189

confidential data removed

Offshore Commercial Flights Final Analysis on AW189

Table 56 – Data Collection and Analysis Final phase on AW189

confidential data removed

Offshore Commercial Flights Initial Analysis on AW139

Table 57 – Data Collection and Analysis Initial phase on AW139

confidential data removed

Offshore Commercial Flights Intermediate Analysis on AW139

Table 58 – Data Collection and Analysis Intermediate phase on AW139

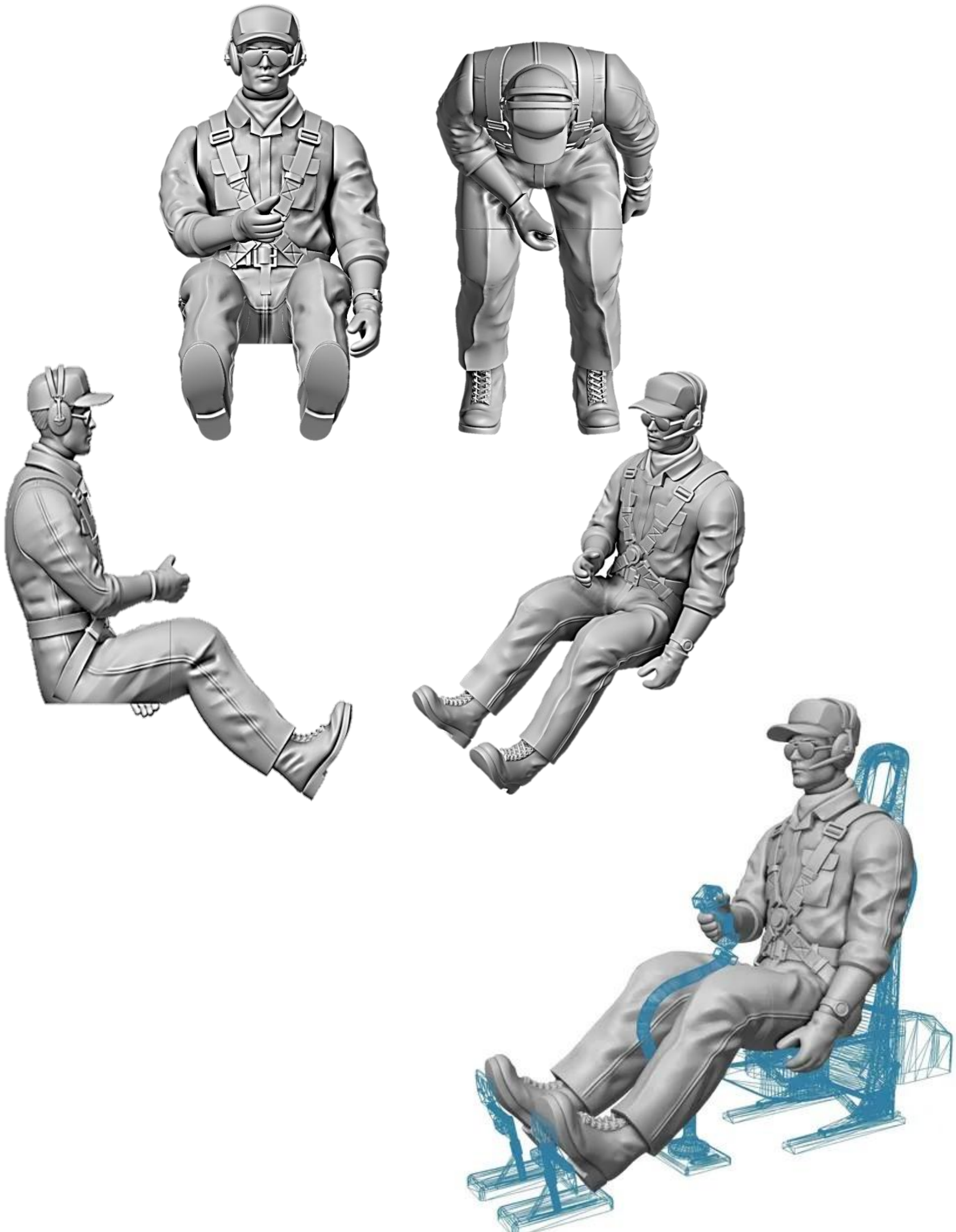
confidential data removed

Offshore Commercial Flights Final Analysis on AW139

Table 59 – Data Collection and Analysis Final phase on AW139

confidential data removed

Appendix 5: 360° Overview of Pilots Positioning while Flying on Controls (Source: Adaptation "Helicopter Sky Worker" from designer Max Grueter)



Website: www.cults3d.com

https://cults3d.com/en/3d-model/art/copter-pilot?srsltid=AfmBOorEzOO-ZeWBbbORkXqR-d_NwGNXgD0Bb3mZowcfo2eYcwmCtbKI