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Analysis and evaluation of the Pilot Attentional Model

Par
Maryam Ghaderi

Unité académique d'Informatique et de Recherche Opérationnelle, Faculté des Arts et Sciences

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Présenté par

Maryam Ghaderi

A été évalué(e) par un jury composé des personnes suivantes

Abdelhakim Hafid
Président-rapporteur

Claude Frasson
Directeur de recherche

Dhanya Sridhar
Membre du jury

Résumé

Pendant les opérations de vol, les pilotes sont exposés à une variété de conditions émotionnelles, mentales et physiques qui peuvent affecter leurs performances et leur attention. Par conséquent, il est crucial de surveiller leur charge de travail et leurs niveaux d'attention pour maintenir la sécurité et l'efficacité de l'aviation, notamment dans les situations d'urgence. La charge de travail fait référence aux exigences cognitives et physiques imposées aux pilotes lors d'un vol. Des niveaux élevés de charge de travail peuvent entraîner une fatigue mentale, une attention réduite et une surcharge cognitive, ce qui peut entraver leur capacité à effectuer leurs tâches de manière efficace et efficiente. L'attention est un processus cognitif complexe qui limite la capacité de se concentrer et de comprendre tout en même temps. Dans les tâches de traitement de l'information visuelle, la vision humaine est la principale source du mécanisme d'attention visuelle. Le mode de distribution de l'attention d'un pilote a un impact significatif sur la quantité d'informations qu'il acquiert, car la vision est le canal le plus critique pour l'acquisition d'informations. Une mauvaise allocation des ressources attentionnelles peut amener les pilotes à négliger ou à oublier des paramètres spécifiques, ce qui entraîne des risques graves pour la sécurité des aéronefs. Ainsi, cette étude vise à étudier les niveaux d'attention des pilotes lors d'une procédure de décollage simulée, en mettant l'accent particulièrement sur les périodes critiques telles que les pannes de moteur. Pour ce faire, l'étude examine s'il existe une corrélation entre la dilatation de la pupille, mesurée à l'aide de la technologie de suivi oculaire, et les niveaux d'engagement, mesurés à l'aide de l'EEG. Les résultats indiquent que les changements de taille de la pupille sont effectivement corrélés aux changements d'activité de l'EEG, suggérant que la dilatation de la pupille peut être utilisée comme un indicateur fiable de l'engagement et de l'attention. Sur la base de ces résultats, la dilatation de la pupille et l'EEG peuvent être utilisés en combinaison pour examiner de manière globale le comportement des pilotes, car les deux mesures sont des indicateurs valides de l'engagement et de la charge cognitive. De plus, l'utilisation de ces mesures peut aider à identifier les périodes critiques où les niveaux d'attention des pilotes nécessitent une surveillance étroite pour garantir la sécurité et l'efficacité de l'aviation. Cette étude met en évidence l'importance de surveiller la charge de travail et les niveaux d'attention des pilotes et recommande d'utiliser les mesures de dilatation de la pupille et d'EEG pour évaluer la charge cognitive et l'engagement d'un pilote pendant les opérations de vol, améliorant ainsi la sécurité et l'efficacité de l'aviation.

Mots-clés: Charge de travail, Attention visuelle, Engagement, Évaluation de l'attention, Durée de fixation, Dilatation de la pupille, EEG

Abstract

During flight operations, pilots are exposed to a variety of emotional, mental, and physical conditions that can affect their performance and attention. Therefore, it is crucial to monitor their workload and attention levels to maintain aviation safety and efficiency, particularly in emergency situations. Workload refers to the cognitive and physical demands placed on pilots during a flight. High levels of workload can lead to mental fatigue, reduced attention, and cognitive overload, which can hinder their ability to perform their tasks effectively and efficiently.

Attention is a complex cognitive process that limits the ability to focus and comprehend everything simultaneously. In visual information processing tasks, human vision is the primary source of the visual attention mechanism. A pilot's attention distribution mode significantly impacts the amount of information they acquire, as vision is the most critical channel for information acquisition. Improper allocation of attention resources can cause pilots to overlook or forget specific parameters, resulting in severe risks to aircraft safety.

Thus, this study aims to investigate pilots' attention levels during a simulated takeoff procedure, with a specific focus on critical periods such as engine failures. To achieve this, the study examines whether there is a correlation between pupil dilation, measured using eye-tracking technology, and engagement levels, measured using EEG. The results indicate that changes in pupil size are indeed correlated with changes in EEG activity, suggesting that pupil dilation can be used as a reliable indicator of engagement and attention.

Based on these findings, pupil dilation and EEG can be used in combination to comprehensively examine pilot behavior since both measures are valid indicators of engagement and cognitive workload. Furthermore, using these measures can help identify critical periods where pilots' attention levels require close monitoring to ensure aviation safety and efficiency. This study emphasizes the significance of monitoring pilots' workload and attention levels and recommends using pupil dilation and EEG measures to assess a pilot's cognitive workload and engagement during flight operations, ultimately enhancing aviation safety and efficiency.

Keywords: Workload, Visual Attention, Engagement, Attention Assessment, Fixation Duration, Pupil dilation, EEG.

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List of acronyms and abbreviations

WL: Workload

CW: Cognitive workload

ECG: Electrocardiogram

EEG: Electroencephalogram

EF: Engine failure

HR: Heart rate

PD: Pupil dilation

ATC: air-traffic control

ICAO: International Civil Aviation Organization

VFR pilot

CRM: Crew Resource Management

EOG: electrooculography

ECG: electrocardiography

PIO: Pilot-induced oscillations

AOI: Areas of Interest

ND: Navigation Display

PFD: Primary Flight Display

E/WD: Engine/Warning Display

SD: System Display

SA: Situational Awareness

POG: Point of Gaze

FPOG: Fixation Point of Gaze

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Chapter 1- Introduction

Undoubtedly, air transportation has played a crucial role in enabling the extensive mobility of individuals and commodities worldwide. However, the most important aspect of air transportation has always been safety. As such, numerous efforts are continuously being made to ensure that the aviation industry remains as safe as possible.

One key concept that has received significant attention in the aviation industry over the past few decades is attention. This concept refers to the ability to maintain interest and focus on a particular task or idea while avoiding distractions. The ability to concentrate is especially important for pilots, as they need to process critical information selectively and quickly differentiate between important details and irrelevant noise. This is why concepts like situational awareness, mindfulness, and vigilance are crucial in the aviation industry. Furthermore, the lack of concentration can lead to inattention in the cabin. This can result in potentially dangerous situations and highlights the importance of maintaining focus and being alert at all times[1, 2].

On January 9, 2021, Sriwijaya Air Flight 182 took off from Jakarta's Soekarno–Hatta International Airport to Pontianak, with 62 people on board, including 50 passengers, 6 crew members, and 6 other personnel. Tragically, just four minutes after takeoff, the plane lost communication with air traffic control and subsequently went down into the Java Sea close to Laki Island.

The Indonesian National Transportation Safety Committee (NTSC) conducted an investigation into the crash and determined that it was caused by a combination of factors, including poor weather conditions, technical problems with the aircraft's auto throttle system, and errors by the pilot. According to the report, the pilot's lack of attention and situational awareness resulted in a loss of control of the aircraft, leading to a rapid descent and the eventual crash into the sea.

The investigation uncovered that the pilot did not adhere to proper procedures and failed to communicate effectively with the co-pilot during critical moments of the flight. The accident underscores the importance of adequate training, clear communication, and situational awareness in aviation, as well as the necessity of ongoing safety enhancements and analysis to prevent similar tragedies from happening in the future [2, 3].

1.1 Attention in Aviation

The conduct of aircrew members plays a vital role in ensuring aviation safety and smooth functioning, particularly in emergency situations. During takeoff, pilots are required to execute intricate operational protocols and closely observe flight instruments, which places a significant burden on their cognitive capacity. Elevated cognitive demands can result in perceptual distortions and miscalculations. Therefore, promptly rectifying deviations in parameters is essential to maintain optimal safety levels. [2].

Attention is a multifaceted and highly complex cognitive process that affects almost all human activities, including aviation. Pilots use attention to maintain focus on a certain idea or task and avoid distractions, allowing them to differentiate important information from unimportant noise and process information selectively. Workload refers to the cognitive and physical demands placed on pilots during a flight. Workload in aviation refers to the amount and complexity of tasks, responsibilities, and demands placed on pilots or aviation personnel during flight operations or other aviation-related activities. However, during periods of high workload, the available attention resource is often less than the need, and during periods of low workload, emotional issues and socializing may lead to distraction from primary tasks. Therefore, pilots' attention should be paid to one thing and withdrawn from another, and better workload management and planning are necessary to maintain attention [2, 4]. According to previous studies [5] it is possible to measure workload using EEG. EEG is a medical technique used to measure and record the electrical activity of the brain. EEG has been used in numerous research studies and is useful for examining cognitive, memory, and emotional functions related to the brain. More importantly, measuring attention status is also a critical application of EEG [5, 6].

The distribution of pilots' focus significantly impacts how they gather information, with vision being the primary channel for obtaining information. If attention resources are not allocated properly, certain parameters might be missed or forgotten, leading to serious risks in aircraft safety. To ensure safety and effectiveness, it is crucial for pilots, air traffic controllers, and other aviation professionals to maintain a high level of awareness about the situation and pay attention to details. Visual information is essential for both obtaining and transmitting data to the brain, allowing the brain to prioritize crucial visual information and process it efficiently [4]. Researches have demonstrated that when an individual concentrates on a visual stimulus, the dilator muscle contracts, causing the pupil to enlarge. This enlargement of the pupil is referred to as pupil dilation. Pupil dilation can serve as an indicator of attention and engagement across various contexts [7].

In summary, attention is a critical aspect of aviation that impacts safety, efficiency, and performance. Pilots must maintain focus and manage their attention resources to effectively monitor and manage flight factors, maintain situational awareness, and respond to potential threats and hazards. Better workload management and planning, as well as visual scanning strategies, can help pilots allocate attention resources effectively and maintain a high level of attention in critical situations.

1.2 Research hypotheses and objectives

Based on previous problems and investigations, we have developed the following hypotheses:

Hypothesis 1: Can we establish a baseline required level of attention for each flight phase and compare the real-time attention with it to identify deviations?

Hypothesis 2: Is it possible to measure pilots' attention in real-time during a takeoff experience using EEG?

Hypothesis 3: Is it possible to establish a correlation between the attention and the measured PD during a critical event?

Hypothesis 4: Is it possible to establish a correlation between the measured PD and the measured EEG during a critical event regarding the attention?

To confirm the validity of the hypothesis, our objectives will be as follows:

Objective 1: To establish a baseline level of required attention for each flight phase by conducting a focus group and use real-time attention measurements to identify deviations from this baseline. This will be achieved by collecting and analyzing data from the EEG headset, eye tracker, and during various flight phases using statistical analysis and correlation methods. The objective is to demonstrate the feasibility of this approach and provide insights into the potential benefits of establishing baseline attention levels for improving aviation safety and support Hypotheses 1.

Objective 2: To demonstrate the measurement of attention, we will create an environment in a flight simulator that can generate controlled changes in cognitive workload (CW) on demand. This will be achieved by integrating software that can introduce failures during a simulated flight.

Objective 3: To measure a pilot's attention, workload, and pupil dilation, we will utilize an EEG headset, and an eye tracker in conjunction with the previously mentioned software solution. Real-time monitoring, tracking, and saving of flight events and cognitive measurements will be implemented in the software, in addition to the requirements from Objective 1. Through the combination of Objective 1 and Objective 2, we aim to prove Hypothesis 1.

Objective 4: To establish a correlation between attention, workload, and pupil dilation, we will compare the data entries and curves extracted from experiments, including gaze point and EEG data, during a workload-intensive event. Statistical analysis and correlation methods will be used to determine the relationship and support Hypotheses 2 and 3.

❖ In our thesis, situated within the domain of computer science, the primary objective is to uncover the intricate relationships between engagement, attention, and workload through a data-driven approach. Differing from conventional machine learning projects that often center around prediction or classification tasks, our research follows a distinct path. The central aim is to develop a method capable of quantifying human engagement and subsequently explore its interplay with workload using pupil dilation. This is why we choose a data-driven approach instead of machine learning methods, aligning with the nature of our research objectives (Objective 1 and 4).

Objective 1 is to establish baseline attention levels for each flight phase, which will be achieved through **statistical analysis** and **correlation methods** (**Section 4.3.3**).

The central aim of objective 4 is to develop a formula capable of quantifying human engagement and subsequently explore its interplay with workload and pupil dilation (**Section 6.4.1**). To accomplish this, our research undergoes a preprocessing phase. We meticulously employ various data preprocessing techniques, including **normalization**, **uniqueness assessments**, **grouping**, **weighted calculations**, and **condition checks** (**Section 7.2**). Furthermore, a wide array of data **visualization tools**, ranging from **stack charts**, **line charts**, to **pie charts**, are utilized. We use diverse data visualization tools in my thesis to visually represent data, assess pilots work efficiency, analyze their visual attention, and distinguish between expert and non-expert pilots. For instance, stack charts are employed to display pilots' areas of interest at any given second, precisely identifying where their attention is focused. Line charts were used to reveal performance trends over time, such as workload, engagement, and pupil dilation. Understanding these efficiency indicators is crucial for enhancing aviation safety and performance. Additionally, comparing visual data between expert and non-expert pilots (**Section 7.2 and 7.3**). These methodologies collectively pave the way to unveil the intricate relationships between eye tracking data attributes like fixation and duration (**Section 7.2**) and EEG data, which allow the assessment of engagement and workload levels (**Section 7.3**). The results of this in-depth analysis will reveal patterns in the attention of pilots.

1.3 Research outline

Chapter 2: This section contains state-of-the-art research around attention in aviation. It covers various topics related to aviation and cognitive processes. It includes an introduction to the subject matter and probable causes of distractions and wrong decisions in aviation. Miscommunication, wrong information, and lack of situational awareness will be discussed in relation to poor decision-making. The section also covers workload and cognitive load, evaluating mental workload, and the role of emotions in aviation. Additionally, cognitive modeling and cognitive assistance in aviation will be explored. The chapter concludes with a discussion of data analysis and classification techniques used in aviation.

Chapter 3: This chapter discusses various topics related to workload and attention in aviation. It covers the concept of workload in aviation, including its impact on pilots and cabin crew, as well as mental overload and workload management techniques. The section also explores the topic of attention in aviation, including visual attention and engagement. Finally, the chapter concludes by emphasizing the importance of managing workload and attention for safe and efficient flight operations.

Chapter 4: This section discusses a focus group conducted as part of the research, including the methodology, study design, and rating scales used to measure workload and cognitive load in aviation. The section explores the subjects of the focus group and the results obtained, providing insights into the experiences of pilots and cabin crew with respect to workload and cognitive load. The importance of using standard rating scales in aviation research will also be highlighted. Furthermore, this section introduces the Attentional Task Model structure and reference model structure as frameworks for understanding cognitive processes in aviation. The design and components of the Attentional Task Model structure will be discussed, emphasizing the importance of understanding pilots' roles and responsibilities. These frameworks can be used to analyze and improve pilot performance, mitigate cognitive overload, and enhance attentional task performance. **This approach targets objective 1 and hypothesis 1 of the study.**

Chapter 5: This section details an aviation experiment conducted as part of a research study. It covers the equipment used, including eye-tracking and EEG systems, as well as the materials used in the experiment, which were aviation-related tasks. The section also explains the experiment environment and procedure, which involved participants completing tasks while their eye movements and brain activity were measured. The approach of conducting real-time experiments during actual flights enables the collection of data that is directly relevant to pilots' attention and workload during takeoff, which aligns with **objectives 2 and 3 of the study**. This approach also **supports hypothesis 2**, which posits that it is possible to measure pilots' attention in real-time during takeoff.

Chapter 6: This section focuses on visual attention and its relationship with attentional tasks in aviation. The chapter introduces the use of eye-tracking technology to measure visual attention and analyzes eye movement patterns during attentional tasks. The updated attentional task model, which was introduced in Chapter 4, is also will be discussed in this chapter. Attentional scores and the reference model are explored as means to assess cognitive workload and optimize attentional performance. Finally, the chapter examines engagement and its connection with attention in the context of aviation tasks. **This approach targets hypothesis 3 and 4 of the study as well as objective 3 and 4.**

Chapter 7: This section presents the results of a data analysis that explores the relationship between fixation duration, pupil dilation, and attention in aviation. The chapter provides an overview of the data features collected and discusses how fixation duration and pupil dilation relate to attention and task performance. The first objective of this chapter is to provide a comprehensive overview of the data, including its sources, format, and characteristics. The second objective of this chapter is to showcase the power of combining eye tracking and EEG data to gain a deeper understanding of the attention levels of pilots and distinguish expert pilots from novice ones. Like Chapter 6, this chapter also focuses on **hypotheses 3 and 4 of the study**, as well as **objectives 3 and 4**. The primary aim of this chapter is to address and examine these hypotheses and objectives in order to gain a deeper understanding of the research questions and goals outlined in hypotheses 3 and 4, as well as objectives 3 and 4 of the study.

Chapter 8: This section discusses the conclusion of the study, limitations, and the implications of the findings for future research and interventions to enhance attentional task performance in aviation.

Chapter 2- State of the Art

Air transport has played a major role in the broad-scale movement of individuals and facilitating these movements. It is noteworthy that military aviation account for a significant portion of these movements. The most important necessity in the field of aviation has always been safety. Thus, many efforts must be made to ensure the safety of aviation.

Pilots and members of air-traffic control (ATC), which send instruction, information and support from the ground, should work together to pilot a contemporary, high-velocity aircraft [8]. Operator's duty in traffic management centers, air traffic control rooms, and customer call centers involves complicated tasks to manage and solve [9]. However, despite many efforts and studies in the field of aviation, we are still witnessing miserable air accidents all around the world. This is why the existence of intelligent systems with the ability to intelligently assess and monitor emotional and cognitive status is an important research topic in this field.

These systems should consider issues such as cognitive load, communication, and emotional load. Moreover, they should be able to help various aspects of the system interacting with the operator, such as assisting, providing individual feedback, choosing the next decision, and so on [5]. These systems are designed with the goal of being able to intelligently adapt and evaluate the internal states of users, increase user performance and improve the interaction experience, with continuous analysis, forecasting and adaptation to the internal situation [5].

2.1 Probable causes of distraction and wrong decisions

There are several factors, which directly or indirectly are contributed to a pilot's level of attention, proper and timely decision-making, and therefore, aviation safety. Some factors such as Miscommunication, Workload and Cognitive load, and Emotions are those with a great impact on the attention of pilots and aviation safety.

2.1.1 Miscommunication

In 1950, the International Civil Aviation Organization (ICAO) chose English as the official language of aviation, emphasizing the importance of English proficiency for air traffic controllers as well as pilots. However, in some non-English countries, such as France and Italy, their own languages are still used for their domestic ATC [8]. Voice communication and its flexibility allow pilots and controllers to exchange large amounts of information rapidly in space. In aircraft operations, there are different types of communications. ATC communications play an important role in crisis management and achieving safety. Flexibility in ATC communications and instructions increases in emergency situations. Thus, this great flexibility is not always good. Flexibility can lead to ambiguity and, in rare cases, fatal consequences[8, 10].

There are usually several factors involved in plane crashes, and communication failures may not be the main cause. The aircraft can be saved from a fatal outcome by correct communication, and in contrast, miscommunication often could aggravate the situation. There are several crucial factors in how a breakdown in communication occurs and how various Englishes affected aviation safety. There are three *form* of ATC miscommunication *(wrong information, Lack of shared situation and* Loss of situation awareness)*, which* are explained here in details:

2.1.1.1 Wrong information

The wrong information is related to the situation when "due to a lack of" native sense "of English prepositions, incorrect information is passed between the controller and the pilot. The reason for this phenomenon is that English is usually used by international pilots for their communications. Thus, various usages of Englishes (variety of Englishes) by pilots and air traffic controllers and insufficient English proficiency and lack of "native sense" could cause miscommunication. For instance, a pilot may hear "two" as "to," while the controller meant "two" [8, 10].

2.1.1.2 Lack of shared situation

Failure of team members to create a shared understanding of situations leads to the lack of shared situation. For example, using "need priority" when a mechanical problem occurs instead of using "an emergency" builds the lack of shared situation because the controller may perceive it just as a problem rather than an emergency[8, 10].

2.1.1.3 Loss of situation awareness

The other issue is Cross-cultural resource management in the cockpit due to the increase in international operations. Cross-cultural communications refer to differences in accent and understanding of a language and most importantly, the use of English to speak to pilots and simultaneously speak in the local language with local pilots on an international flight with a multinational crew. Linguistic alienation exists in the wider communications of the cockpit and causes a serious menace to "situational awareness" and safety. For example, in the situation when an English voice alert may not be "noticeable" to pilots who are not fluent in English[8, 10].

2.2 Workload and cognitive load

Workload refers to the degree of subject dependency to the used capacity of resources [11]. Workload in aviation refers to the amount and complexity of tasks, responsibilities, and demands placed on pilots or aviation personnel during flight operations or other aviation-related activities. It includes factors such as flight planning, navigation, communication, systems monitoring, decision-making, and managing aircraft controls. Workload in aviation is typically measured by the quantity and intensity of cognitive and physical activities required. **Cognitive load (Mental Workload)** in aviation specifically focuses on the mental demands placed on pilots or aviation personnel while processing and retaining information. It relates to the working memory capacity required to absorb, understand, and apply knowledge or skills relevant to aviation tasks[9].

In aviation, the term **"Overload"** refers to a condition where a pilot is overwhelmed by the demands of the flying task or the information they need to process. It occurs when the pilot's cognitive, physical, or psychological capabilities are exceeded, resulting in a decreased ability to make effective decisions, maintain situational awareness, or properly execute flight maneuvers. **Mental overload in aviation occurs when the demands on pilots or aviation personnel exceed their capacity to effectively manage the workload, and cognitive load associated with their responsibilities**. It refers to a state where the available cognitive resources, attention, or physical capabilities of individuals are overwhelmed by the requirements of the situation or the complexity of the tasks at hand [11].

Mental overload has a direct impact on aviation safety [10]. Sometimes work processes are accompanied by stress, time pressure and disruption, resulting in wasted human resources and physical and safety problems. Therefore, mental overload due to increased work intensity reduces performance [10, 12].

On the other hand, in some special occasions such as military flights, It is necessary for pilots to fly in formation, control long-haul flights in remote and without any support, fly at night using night vision devices, and so on [10]. Therefore, in addition to using call signals in aircraft, aircraft detection systems are being developed to extract data from pilots' voices and increase safety [10]. These systems help users achieve high productivity by avoiding the stress and frustration of work that leads to errors, especially in dangerous situations [9, 10].

2.2.1 Cognitive load types

In multi-task flights, information must be sensed from several senses, and quickly integrated into action planning. Cognitive load is divided into three main types: load on situation awareness, load on information processing and load on decision-making[10]. In such flights, all three types of cognitive load exist simultaneously [10].

Load on situation awareness refers to the impact of factors such as workload, complexity, and distractions on a pilot's ability to understand his or her environment accurately. As a result, they may be less able to process important information and make timely decisions. **Load on information processing** refers to the amount and complexity of information that pilots must process while flying. **Load on decision-making** is the amount of cognitive demands placed on a pilot during flight operations. A pilot's cognitive resources, time pressure, the complexity of the situation, and availability of information are all factors that contribute to it [12]. Thus, processing large amounts of information challenges long-term memory, perception, attention, decision-making, and choice of next steps. High cognitive load among aviators is associated with severe time pressure as a significant stressor that can cause reactions such as changes in heart rate (increase and decrease), sweating, hypertension, fatigue and anxiety, and muscle tension [10].

2.2.2 Cognitive load factors

There are several factors related to cognitive load that are : Time pressure, intrinsic cognitive load (task difficulty), and Arousal.

2.2.2.1 Time pressure

Time pressure means the difference between the actual time required to perform a task and the time allotted to it. This difference causes many emotional reactions that activate the emotional components and indirectly affect the cognitive load. *F*or example*,* anxiety causes a person to devote more attention to resources and increasing cognitive load and time pressure[12].

2.2.2.2 Intrinsic cognitive load (task difficulty)

The number of components comprehended concurrently as well as the degree of elements interaction has a great effect on the cognitive load [12]. In other words, the number of items that should be remembered, as well as the difficulty of the task, interfere with performance [12].

2.2.2.3 Arousal

A functional state in a given task depends directly on his performance. Intentionally the ability to promptly recollect information in tasks involving short-term memory is higher during the morning; a time when lower arousal levels support automated processes. Conversely, the capacity for recalling information from long-term memory is improved during the evening, when heightened arousal levels promote more intricate semantic processing [12].

2.2.3 Evaluating mental workload

There are three main categories for evaluating mental workload: psychophysiological components, task performance measures, subjective measures.

2.2.3.1 Psychophysiological components

Changes in mental work are associated with changes in different states and bodily processes. However, the physical attempt has a profound effect on psycho-physiological measures and reflects changes in cognitive load only for activities that involve little physical attempt [12].

Psychological measures, especially those controlled by the autonomic nervous system, are affected by the difficulty of the task. For example, increased respiratory activity, increased cardiac activity, and elevated blood glucose levels are among the effects of high cognitive load [12].

2.2.3.2 Task performance measures

Within the performance measures methods, the overt behaviour and performance of individuals, especially response delay and response accuracy, reflects the extent of their mental work. Results revealed that the more workload increased, the more global performance decreased. In the situations of high workload conditions, the performance improved with training [12].

2.2.3.3 Subjective measures

The NASA-Task Load Index [13], the presented technique for subjective workload assessment [14] are techniques that are used for subjective mental workload. The first technique comprises Physical and Mental Demand, Temporal Demand, Effort, Performance and Frustration Level. The second technique comprises Mental Effort, Time Load, and Psychological Stress Load [12].

The effects of these factors on different cognitive load types is tested in [12]. According to the results of this study, there is a negative correlation between task performance and subjective load measures, while there is no correlation between these measures and differential heart rate. Furthermore, high temporal pressure and high task difficulty at the same time reduce mental performance and efficiency. In contrast, no effect is observed for time pressure by itself on load measures [12]. It seems that particular sensitivities of a given measure could be reflected by the effects of a single load factor on one of the load measures [12].

2.3 Emotions

There is a complex relationship between learning, decision making, performing and emotions [15]. Emotions can make decision-making easier or sometimes ruin it [16]. The high cognitive load, which may introduce emotions as a psychological factor, is the result of complicated tasks. Moreover, the experience of cognitive load might be influenced by personal feelings when important activities are taking place. This interference makes the detection of cognitive load more challenging [9].

Emotions are classified through valence and arousal. While arousal represents the excitement level related to a situation, the positive or negative emotional experience is represented by valence [16]. Moreover, while higher physiological arousal may cause a reduction in the decision time, forcing a quick decision and cause a greater challenge, having emotion regulation skills helps individuals decide with fewer challenges [16]. Therefore, the following are some of the possible effects that can be caused by a change in emotion:

(1) Motivation and attention, which are the results of positive emotions, may increase learning.

(2) Learning improves with the increase of cognitive processes (creativity and problem solving), which are the result of positive emotional states.

(3) In addition, negative emotions may cause various negative effects on the learning process [15].

2.4 Cognitive Modelling

Cognitive modelling of user behavior (user modelling) is a powerful tool for predicting and understanding the behavior of users [12]. The goal of most models in a controlled situation is to simulate the behavior of users than to examine individual performance in a complex task. One of the major challenges for cognitive modelling is to demonstrate individual user behavior. Several sources of variation are required to be dealt with for representation of individual behavior in naturalistic settings. Inter-individual differences (knowledge differences) and uncontrolled external factors of the situation are such sources that should be dealt with. For instance, various levels of experience and climate changes need to be considered for modelling pilot performance [16].

2.4.1 Levels of Cognitive modelling

There are higher-level and Lower-level cognitive modeling. The fast and easy development of models is facilitated by higher-level modelling frameworks such as GOMS and its various variants. Behavior is represented as principal actions of user such as pressing a key or moving a pedal. However, their modelling ability is sometimes limited and they are not always able to model detailed user behavior [12].

A user's cognitive structure can be described by GOMS based on four components: **Goals**, **Operators**, **Methods**, and **Selections** rules for choosing among competing methods for goals. GOMS generates both quantitative and qualitative forecasts regarding how individuals will interact with a proposed system [12].

On the other hand, user behavior has been represented by lower-level cognitive architectures. Lower-level cognitive architectures outline the fundamental building blocks of behavior. Soar, ACT-R and EPIC are examples of Lower-level cognitive architectures which allows for direct interaction with real-world systems and greater precision [12].

2.4.2 Pilots Cognitive Modeling

Pilots' cognitive dynamics have been modelled frequently using ACT-R [17]. It allows the cognitive models to be created based on particular task descriptions such as goal-directed hierarchical task analysis. Such that when task descriptions focus on situational awareness maintenance, a normative cognitive model is developed aiming to optimize situational awareness. Comparing normative models and individual pilot behavior can be used for deviation detection and making inferences about pilots' situational awareness [17].

2.5 Cognitive Assistance in Aviation

Despite the fact that most tasks are automated in most fields, current business and commercial aircraft still rely on pilots in case of emergency situations and when the system fails to function normally or satisfactorily. In this regards, SA maintenance is essential for pilots to be able to undertake manual control or intervene when needed [17]. Hence, there are some responsibilities associate with a pilot that should be considered. Responsibilities such as **Navigating responsibilities** (flight plan creation, performance consideration, altitude and weather conditions investigation), **Aviate responsibilities** (the actions of the pilot in the cockpit including monitoring and following cockpit instruments by working with steering, pedals, and lots of buttons, Checking weather conditions, the position of airplane and air traffic several times during the flight and determining any changes in the path when needed), **Communicate responsibilities (**Communicating with co-pilot and air traffic control by radio to be sure about a safe takeoff and landing, giving information and report about the flight after landing**) and finally Perceptions** (pilot perception of the plane, its reaction, observation of outside, the feeling and sensation).

To ensure accurate manual control of the aircraft, the pilot must grasp the aircraft's motion status. Both the visual and auditory systems are significant contributors to this perceptual process.

In attentional deafness reduces performance in the cockpit. In these situations, using cognitive assistance as a tool for verbal reminders is very useful. Thus, it is essential that the causes and consequences of overheard messages be considered for identifying the right information and the right timing for cognitive assistance in operations[16].

There are varieties of causes that depend on attentional and perceptual factors. Sometimes, they are possibly very complex for modelling missed alerts. In situations that a pilot fails to react to alerts, the alert is declared as missing. Investigating the reasons why the pilot does not pay attention to alerts or what information cannot be processed by them will help identify adequate support tools. For example, information about the content of messages and whether they have been processed or not, is a proper alternative to complex models for predicting user states [16].

Automation is another probable cause. Through automation, the role of pilots has shifted from hands-on flying to monitoring system displays, which is not matched to human cognitive abilities and assisted in processing of information that is more superficial. In addition, reducing the number of crew and performing operations with less crew (one pilot) causes higher complexity due to automation and an increase in the workload for the remaining crew. It also may enhance demands on pilots in commercial aircraft [17].

The consequences of an ignored or overheard message for the performance of pilots can be predicted using a cognitive model. As mentioned before, ACT-R is a universal and scientific proved cognitive architecture for producing models that representing processes in manual aircraft control, visual attention in the cockpit and the use of skill acquisition for flight management system. For model-based assistance, constitutes normative performance can be described using such descriptions of tasks and processes which are related to flight [16].

Out-of-the-loop problems are probable consequences of missed alert. Out-of-the-loop problems occur when pilots lack situational awareness. Situational awareness is steadily developed using the levels of projection, comprehension, and perception of a situation’s elements. Situation perception is impaired by missing critical alerts and this prevents the development of higher SA levels. Therefore, for preventing out-of-the-loop problems human-machine interfaces on the flight deck should be sure that messages are processed correctly and on time. Any insufficient response (Failed or delayed) to flight deck alerts could result in several fatal accidents [17].

2.6 Data analysis and classification

The study of intelligent systems and their ability to monitor and evaluate effectiveness and cognitive load is an important field of research. Therefore, several research studies are performed in the fields of human-computer interaction, artificial intelligence, neuroscience and cognition [18]. The use of Machine Learning allows the detection of cognitive load, the analysis and prediction of user experiences, and the assessment of patterns related to user experiences. Feature selection, Feature extraction, Normalization, and Classification techniques are examples of Machine-learning techniques, which are applied in this regard [9].

For example, as described in [9], cognitive load can be determined automatically from physiological responses and task performance, which can be recorded and analyzed using information such as audio and video streams, event data, and physiological data [9].

In another study, a Deep Long Term Memory is used for estimating emotions using multimodal Users Data [19]. User multimodal data, a deep multimodal architecture that uses deep learning, and the hierarchy of human memory is used in. Emotion estimation is extremely important in cognition of human behavior and in the modelling of users in simulation-based systems. There are several techniques to detect and classify users' emotions from data [19].

To design an effective emotions prediction model, all sources of data, which informs about the current situation of a user, should be considered [19]. Thus, considering the multimodality of the represented architecture and the integration of an explicit memory, best results were achieved in this study than to other architectures for prediction.

In another study , a Hybrid Deep Neural Networks is used for Socio-Moral Reasoning skills Prediction [20]. Socio-Moral Reasoning (SMR) is a socio-cognitive construct essential for decision-making, as well as social interaction adaptation. They proposed a simple but efficient way to integrate expert knowledge into deep neural networks architecture using the attentional mechanism. The achieved solution was best in their context due to the deep structures that can learn useful features from data, and also the a priori knowledge that can leverage unbalanced data [20].

Extracting mental information such as the polarity of emotions requires the consideration of user modeling (the representation of a person) as an important feature. A user-sensitive deep multimode structure that utilizes deep learning and user data are presented in [21]. The presented architecture comprises a combination of multiple Deep Neural Networks, Convolutional Neural Networks, LSTM-Auto-Encoder, and a Long Short-Term Memory (LSTM). The aim of this architecture is supporting the multimodality of data [21].

2.7 Conclusion

Attentional tasks are crucial for pilots as they play a critical role in ensuring flight safety. In this chapter, we have explored some of the factors that can lead to distraction and wrong decisions during attentional tasks. Miscommunication can occur due to wrong information, lack of shared situation, or loss of situation awareness. Workload and cognitive load can also lead to distraction and errors, and we have discussed the different types and factors of cognitive. Emotions can also affect pilots' attentional tasks, and we have briefly touched upon this topic.

To better understand pilots' cognitive processes during attentional tasks, we have also discussed cognitive modeling, including its levels and its application in aviation. Cognitive assistance can be helpful in supporting pilots in attentional tasks and improving flight safety.

Overall, this chapter highlighted the importance of understanding the factors that can affect pilots' attentional tasks and the need for effective cognitive assistance in aviation. By addressing these issues, we can work towards improving flight safety and reducing the likelihood of accidents due to distraction and errors during attentional tasks.

Chapter 3 - Workload and Attention

Behavior contains important factors for the failure or success of flight operations. Pilots are those who operate aircraft in various conditions. Pilots must perform a great many tasks correctly to be assured about the safety of the aircraft. When operating a plane, pilots are subjects to various events (Auditory, Visual, and Cognitive) which can lead to an overload of the mental availability of the brain resources (**the workload**). Therefore, in order to identify the probable risks during flight operations, the situational awareness of pilots is a key factor [11, 22]. Pilots usually perform competing tasks in a highly threatening and dynamic environment. At the same time, they have to keep a high **level of attention** to various environmental conditions and system instruments [11, 22]. These tasks are usually within the pilot's ability especially when they perform in isolation. However, when humans are faced with more than one of them and required to deal with multiple mental demands, the difficulty arises [23]. The immense and parallel number of tasks along with natural restrictions of cognitive processes cause an increase in critical stress for pilots and the workload changes into the **overload** in which mistakes can happen. Moreover, adverse environmental conditions and multi-missions cause increased workload and additional difficulties to pilots. Therefore, it is very important that the aircraft always be flown at the correct bank angle, speed, heading and altitude [22, 23].

On the other hand, the increasing use of automation in modern aircraft has necessitated the study of attention and vigilance for human factors, especially in aviation. A great deal of vigilance and attention is required for monitoring activity. This subject has been pursued by specialists in aviation for a few decades, in order to countermeasure effectively against repetitive types of aircraft accidents. Attention is considered as one of the foundations of risk management concepts. Without attention, we are not able to differentiate important information from unimportant ones. Therefore, attention is the capability to maintain interest and focus on a certain idea or task and avoiding distractions [1, 24]. Although there is not a universally accepted and standard definition for the term attention, psychologists are of the opinion that inherently, the amount of information that the brain can process is limited. Therefore, in order to have an effective function, we must filter or select particular information. In other words, **attention is the focus and maintenance of interest in a particular idea or task while avoiding distractions** [24].

The research question addressed in section 3.1 concerns the way to manage the workload involved in piloting tasks. How can we identify the attentional tasks, which require full or moderate attention of the pilot? How can we prevent the pilot from a possible excess of workload (overload)? To answer these questions, we will analyze the conditions of workload in piloting tasks and the causes of the overload.

3.1 Workload in Aviation

As mentioned in chapter 2, in aviation, the **workload is** the load imposed on human operators while they are without the help of automation and have limited information-processing resources [10, 22]. Workload is usually divided into three general levels of intensity: ***low, medium*** *and* ***high***.

- During **low workload**, the only tasks that should be done are communicating and manipulating the flight controls.
- During **medium workload**, communicating, manipulating, and rule-based tasks need to be carried out.
- During **high workload**, pilots should deal with high cognitive demand, problem solving, rule-based tasks, communicating, and manipulating. The workload usually increases significantly during emergencies and abnormal situations [23].

The workload can result from task difficulty or multitasking, leading to a negative effect on pilots' performance and possible rise of mis operation. Controlling the airplane is also a demanding operation that needs high situation awareness and might increase pilot's mental workload [22]. Moreover, unexpected events that need two or more tasks and compete for attention may occur during flight [4]. This cause higher workloads, negatively influence pilots' performance and rise the probability of operating dangers [22].

In a transport flight, the **Takeoff** and **Landing phase**s are usually classified as high workload segments, while the **Cruise** phase is considered as the low workload phase. Therefore, pilot's workload is commonly considered as short periods of high workload and long periods of low workload [25, 26]. The increasing sophistication of transport aircraft has made the need for automation and the use of automation systems more apparent. The workload has reduced considerably due to the combination of automation and sophistication and direct manual-control. However, pilots should deal with a wide range of monitoring responsibilities. Moreover, in case of any malfunctions in automated systems, they should still be prepared to return to manual control [26].

There are a number of past articles that studied workload in aviation. For example, in [23] authors studied the impacts of increasing mental demands on the robustness of the allocation hierarchy and prioritization of aviate, navigate and communicate. Thirty-seven males and five females (total of 42 student pilots) were participating in this investigation. The participants joined to three workload groups: Level low (which only composed of communicating and manipulating the flight controls); Level medium (which composed of communicating, rule-based tasks and manipulating); and level high (which composed of communicating, rule-based tasks and manipulating, and problem solving/high cognitive demand). The main goal of this study was to express workload in terms of prioritization issues as well as the ability of participants to acknowledge and comprehend auditory messages with different lengths and in different workload environments. It is commented in this study that the increase in auditory input and mental workload has caused significant difficulties for participants in performing the main manipulation task. It has also caused a similar decline in prioritization. Furthermore, when pilots experienced a high mental workload, their ability to comprehend more than two chunks of auditory data declined quickly [23].

As another example,[22] presented a study on evaluating the relationship between operational performance and mental workload using eye-tracking. Their main purpose was to improve the training effectiveness of aviation safety and situational awareness by investigating cognitive effort's role in flight operations by examining the patterns and performance of pilots' eye movements in comparison with pilots' levels of mental stress. A total of 36 pilots with 320 to 2,920 hours of flight experience participated in this research. The results of this study showed that there is a significant relationship between the total fixation time of pilots on Right Multi-display, Altitude Indicators, Integration Control Panel and pilots’ subjective rating on NASA-TLX, and the performance of pilots during the operational time to perform tactical missions. In particular, longer total fixation time on Vertical Speed Indicator, Altitude Indicator, and Right and left multi-display, and shorter total fixation time on Air Speed Indicator was observed by pilots with high situational awareness who detected hydraulic malfunction compared with pilots who did not detect the signal of hydraulic malfunction[22].

3.1.1 Piloting Overload

Mental overload in piloting is a state of the brain in which the pilot has some difficulty to reason or decide an action in a task. Thus, overload in aviation can result in decreased performance, impaired decision-making, increased stress, and compromised flight safety [10]. Sometimes work processes are accompanied by stress, time pressure and disruption, resulting in wasted human resources and physical and safety problems. Therefore, mental overload due to increased work intensity reduces performance [12].

Pilots often make important decisions while they have very little time, are under stresses, and ambiguous information is available to them[22]. Flight safety and pilots responsibilities are not just arranging tasks in a serial order. Sometimes pilots should deal with many cognitive demands, which contain too many attributes. This usually results in mental overload. Even information with moderate levels of complexity can interfere with perceived workload and task management [23]. Moreover, it is important to investigate the relationships between attributes and their complexity to determine the workload levels and task difficulty [22, 23].

Several interruptions that occur on the flight deck, even routine and predictable ones, can affect mental workload, task difficulty, and also aircrew performance [23].

In a flight simulator or cockpit, pilots go through an endless stream of data. The data includes all communications between the air traffic controllers and pilots. In order to monitor, decide on aviation-related actions, and communicate to perform the assigned tasks, this data must be continuously and rapidly processed, understood, controlled, and prioritized [10]. On the other hand, in some special occasions such as military flights, it is necessary for pilots to fly information, control long-haul flights in remote and without any support, fly at night using night vision devices, and so on [10]. Thus, a significant amount of cognitive load is created in the aircraft [10]. The high cognitive load forces the individual to devote additional resources to entering information and it may reduce processing efficiency and performance [12].

3.1.2 Mental Health of Cabin Crews

During a flight, flight crews are subjected to particular health-related problems. Generally, unusual working hours, because of night work or shift work, may increase the risk of physical and mental problems [26].

Fatigue occurs for many reasons such as impairment of biorhythm, early start of work, night work, long time shifts, and long flying hours. Researches have shown that the stress and fatigue of cabin crews on international flights are less than on national flights. On national flights, an early starting or late ending of duties, irregularly structured duty schedules can be problematic. Subjective stressors are also impaired pilots performance [26]. Researches indicate that flight crews experience notably more depression, sleep problems, fatigue, and anxiety than the average population. They are especially affected by post-traumatic stress and anxiety after air accidents. Physical and cognitive overloads are the start of work stress in flights. Work-related emotionality are reflected in particular requirements such as the linguistic and cultural differences between passengers and cabin crews [26].

3.1.3 Classification of Piloting Tasks Involving Mental Overload

In this section, we classify Piloting tasks based on the periods of flight in which tasks are taking place, based on their cognitive categories as well as the primary cause of workload.

3.1.4.1 Periods of Flight Able to Generate Overload

During a flight, the pilot is faced to different situations, which require different levels of attention and workload. In the following, we review some of these situations.

Takeoff. During takeoff, pilots are faced with many tasks such as adjusting aircraft configuration, changing frequencies, looking for other traffic, radio calls, and flying the aircraft [27]. Moreover, the periods of taxiing, engine start, takeoff roll, lift-off, initial climb, and departure are times when pilots are deal with high workload. A safe takeoff is the key and most important task among all pilots' duties [28].

Flying an instrument approach. One of the highest workload situations that a pilot may face with, is flying an instrument approach. For the flight safety, it is essential that pilots make sure that they have fully prepared and briefed for the approach. They also need to be prepared for possible missed approach [27, 28].

Emergencies. Abnormal circumstances such as adverse weather, equipment malfunction, or emergency situations are other times that high workload occur. Emergencies always create high workload and stressful situations, whether it is a loss of communications or an engine failure [27, 29].

Busy airspace. Transition into tower-controlled airports might be a little intimidating especially for pilots whose flights are mostly done at non-towered airports. In tower-controlled airspaces, VFR pilots have the responsibility to fly the aircraft in accordance with ATC instructions and respond to radio calls. In addition, they have the responsibility of "see and avoid" [27, 29].

Landing. Descent, approach, landing, and any go-around situations are times that pilots should be prepared for a high workload because most accidents occur during landing. In this phases, pilots need to ensure they are at a proper speed, adjusting for wind, and on the glide path [27].

Lost procedures. Times exist when pilots are lost or unsure where they are. In such a situation, they should look for traffic while flying the aircraft, conserving their fuel, and locating their position [27].

3.1.4 Cognitive Classification of Tasks

Piloting tasks can be classified into several cognitive categories: Rule-based tasks, tasks with high cognitive demands, and communications tasks.

Rule-based tasks. There are some situations (tasks) such as fuel requirements, weather conditions, Aircraft systems, some navigation aspects, and being moved apart from other aircraft that pilots mostly deal with at the rule-based performance level. For this sort of information processing, the pilot does not need to stop and think about everything. They usually have been trained to manage these problems, have encountered them before, or have a procedure that explains the required actions in full detail [23, 30].

For non-automatic tasks, pre-packaged solutions are often used. Pre-packaged rules mean that there is some form of stored rules which have been obtained through experience or training. For instance, if (this situation happens) then (these actions should be done). This is why they are called rule-based tasks. An expert pilot compiles a mental script in which actions and reactions are anticipated to happen. The script consists of a set of knowledge and information about a series of interrelated particular events, their sequence, and the actions that are expected to occur in a specific way. Since pilots must use the right rule that corresponds to the situation and fly the aircraft at the same time, their mental workload will undoubtedly increase [23].

High cognitive demands. There are some occasions when pilots should interleave well prepared but multiple procedures and tasks. There are also times when pilots are not able to match symptoms and signs of a certain situation to available scripts. These are undesirable periods that may happen from time to time and are cognitively demanding for pilots. Thus, resorting to effortful, slow, and highly error-prone thinking process is inevitable when pilots are unable to find a solution using stored and known methods [23].

The most common interleaving tasks include monitoring. Pilots should periodically **stop** the continuous progress of ongoing tasks and focus on an event or case that needs to be monitored. However, performing a specific task and reminding the need to monitor at the same time, might be impossible if the ongoing task requires high levels of mental resources [23].

Communications. Pilots routinely discontinue flight deck tasks and redirect their attention to the intent of the instruction when ATC broadcast directions or any instruction to them. Although pilots may allocate less priority to communications in some circumstances, they are often ready to stop cockpit activities when they receive audio communications [23].

The big challenge is how to integrate the communications task into the hierarchy of tasks. It is beneficial to consider communications as a single task that is aside from other cockpit activities and may disrupt the other duties. The probability of an auditory display or a radio transmission seriously disturbing cockpit activities is dependent on the complexity, the length of its content, as well as the novelty carried by the message [23].

3.1.5 Temporality of Tasks Leading to Overload

High workload is the primary cause of attention distraction. Thus, having a deep knowledge on the factors that cause high workload is essential [11]. Four comprehensive factors, which usually have a direct effect on the workload, are as follows: Task difficulty, Number of tasks in series, Number of parallel tasks (tasks that are running concurrently, Task speed and available time for tasks.

Task Difficulty. One of the most effective factors on the workload is the difficulty of tasks which is easily perceived. In addition to other factors such as parallel tasks and time limitations, multiplying 2 by 2 is mentally easier than multiplying 468 by 731. These two tasks are considered as a low workload task and a high workload task, respectively. The more difficult the task is, the heavier processing is required [27].

Parallel tasks. In theory, it is said that pilots should be able to communicate and fly simultaneously. However, in reality, it depends on the amount of attention and control that each task needs. After a short period of practice, if both tasks require little attention and control, they can parallelly be performed without any interference. The problem arises when the tasks are not autonomous and require considerable amount of attention (the competition between tasks for the attention) [27].

Tasks in Series (Attention Switching). Although Simultaneous tasks compete for attention and other resources, it is not always possible to perform a single task at a time unless time permits. However, attention switching (switching from one task to another) should be avoided if it is possible because it consumes a huge amount of attention[27].

Time available for task (Speed of task). Obviously, doing a task with time pressure and control adds to the difficulty of doing the same task without considering time, and may lead to errors. In addition, awareness of the reduction time pressure will cause the pilot to pay attention to the considerations and consciousness of the seriousness of the time, and this itself will require additional attention [27].

3.1.6 Workload Management

Based on the previous study on classification of piloting tasks and different causes of workload it appears that Mental exercises, prioritization, planning, and scheduling tasks effectually have a great impact on workload management of Rule-based tasks, High cognitive demand tasks and difficult tasks. Time management, prioritization, planning as well as accepting assistance and delegating when required can help pilots to manage the workload during times of having parallel tasks, tasks in series (attention switching) or when the available time for the task is not enough [30].

Periods of flight when unexpected events may accrue and generate overload are times when workload management is very crucial. Methods that help a lot in managing the workload in these situations are awareness of unexpected events, accepting assistance and delegating when required and performing Cross-check, monitoring, and reviewing actions in a responsible way. Moreover, in these periods maintaining self-control in all circumstances as well as managing and recovering from variations, distractions, failures, and interruptions effectively is essential.

The process by which pilots prioritize and then perform more than two tasks that occur simultaneously and compete for attention, is consider as task management. Pilots usually give more priority to tasks at the top of the list than those below and first perform them. Typically, pilots should give priority to flying the aircraft and make sure that the aircraft is kept within the flight envelope which recommended by its manufacturer. The second and third priority is often given to navigation and communications tasks, respectively[2, 25] .

The prioritization process is not only related to periods of high workload and important cases, but also related to periods of low workload. During periods of low workload, non-essential tasks can easily distract pilots. Moreover, pilots may become unmotivated and lethargic in this period. Thus, prioritization, effort and attention are required to overcome both of these. Flight deck automatic systems can help pilots in prioritization process through warning lights, alarms, and display readouts [1].

Managing workload mainly involves being aware of **unexpected events** that may occur during flight, which can distract pilots from their essential duties. Even in situations that everything goes according to plan, workload management is essential. However, when **unexpected events** happen, workload management might become significantly difficult. Thus, pilots should always stay mentally "ahead" of the aircraft since their work environment is a dynamic environment that is likely to change rapidly [31]. Although pilots may have expectations about what might happen during the flight, they can never expect the flight to be exactly as scheduled. Thus, they need to be prepared for unexpected events. They should continuously assess the best course of action if an unexpected event should happen [31, 32]. Moreover, pilots might be distracted from their essential tasks for different reasons. This causes an error in managing and handling the aircraft. To avoid these some defenses such as cross-checking process and read-back or hear-back procedures can be done. These allow the ATC to make sure that pilots have received messages accurately [31]. Therefore, for managing the workload we suggest the **prioritization of tasks** and the practice of **mental exercises.**

The p**rioritization of tasks** is a dynamic process for pilots, which has a close connection with a large number of issues such as Situational Awareness, Crew Resource Management, Pilot Workload, Decision Making, Choice, Airmanship, Pilot Memory Aids, and Pilot Perception. Effective prioritization relies on adequate use of resources, sufficient practice, accurate knowledge, and task sharing [1].

There is often a trade-off between speed and accuracy and thus, effective prioritization can be a balance between these two. The matter of being both timely and accurate with task prioritization depends on the urgency and size of potential risk. Thus, understanding and utilization of risk assessments are crucial for managing operational threats. When speed is necessary, a lack of proper prioritization can increase the risk by delays in doing crucial and excessively useful tasks. When accuracy is necessary, a lack of proper prioritization can result in hidden errors based on false assumptions or analyses [30].

The ability of pilots to prioritize tasks successfully depends highly on several issues such as the availability of resources, the number and nature of threats, and also workload. Through an organization’s management system, pilots can address these issues[1, 29].

Mental exercises help pilots to manage their workload efficiently. Several evaluated alternatives are available to them and thus, they will have additional capacity to deal with emergency and abnormal situations [33, 34]. For efficiently handling the workload, pilots should:

- Maintain self-control in all circumstances.
- Manage time in a well-organized and competent way when performing tasks.

- Prioritize, plan, and schedule tasks effectually.
- Accept and offer assistance and delegate when required
- Cross-check, monitor, and review actions in a responsible way
- Manage and recover from variations, distractions, failures, and interruptions effectively.

3.1.7 Resource management

Crew Resource Management (CRM) is a subject that pilots practice, study, and discuss. This term aims to encompass the available resources to pilots, and the way they can manage them. Some examples of available resources for pilots are given below:

- Air Traffic Control (ATC)
- Both co-pilot(s) and cabin crew
- Maintenance personnel
- Ground personnel
- Pilots in other aircraft
- Administration
- On-board systems and automation

Pilots should draw from all of the above-mentioned resources to make sure that flights are operated efficiently and safely while managing the workload and minimizing errors [33, 35].

3.2 Attention in Aviation

The term attention is used in aviation for effective counteractions against repetitious aircraft accidents. Human beings' attention capacity is limited and they cannot pay attention to everything and understand everything simultaneously [1, 4]. All definitions of the term attention share the central theme that attention involves cognitive processes (concentration of thinking) on a subject or thought without considering other stimuli or thoughts [24].

Most of the time, during high workload the available attention resource is less than the need. Thus, attention should be intently managed. For instance, for a manually flown final turn, pilots visual attention need to be shared between the attitude, the airspeed, and the runway. However, it is not the only situation that causes distraction for pilots. Sometimes, during periods of low workload and when everything is as planned, emotional issues and socializing may lead to distraction from the primary tasks. During periods of low workload, pilots can easily become distracted by non-essential tasks such as socializing, or become lethargic and unmotivated. Therefore, without a distinct solution, pilots' attention should be paid to one thing and withdrawn from another thing. Nevertheless, it should be avoided to point out what the pilot has not done enough and advise to do more. This is only possible by better workload management and planning, not by simply saying pay more attention to the related task [2, 4].

3.2.1 Visual attention

In recent times, there has been extensive utilization of eye movement technology in research concerning pilot attention. Numerous researchers have explored whether indicators of eye movement can objectively mirror the patterns of attention allocation. Results of demonstrate that human gaze patterns can effectively indicate the distribution of attention. The authors employed eye movement data from the cruise and holding pattern stages to validate the pilots' attention distribution model, constructed using a combination of entropy-based methods. A different researcher [37], observed how pilots distributed their attention during various flight stages, utilizing measurements of eye movement parameters such as fixation, sweep, and pupil size. They highlighted the potential of these eye movement indicators to evaluate the impact of workload on pilots' flight performance. According to their findings, instances of elevated workload were associated with extended fixation duration, reduced sweep amplitude, and an increased pupil diameter among pilots.

Furthermore, the researchers examined the pilots' rate of fixation, the mean duration of fixation, and the proportion of time spent fixating within each Area of Interest (AOI) during the maneuvers conducted in the vicinity of the four intersections under investigation [38]. In addition, an analysis of eye-tracking information in aviation revealed that the allocation of pilots' visual attention proves valuable in situations of elevated workload or when identifying signs of fatigue, as well as when studying the flight conditions related to hypoxia and spatial disorientation [39].

The basis of the visual attention mechanism stems from the examination of human sight. It constitutes a vital psychological control system within the human visual system, governing the processing of visual information [40]. Visual engagements are intricately linked to nearly all human actions. Individuals purposefully concentrate on certain elements of information while disregarding others, effectively utilizing their restricted visual resources for information processing [40]. Evidently, vision stands out as the primary avenue for information perception, thus making pilots' distribution of attention a key factor in determining the extent of information assimilation [41, 42]. A judicious approach to scanning the visual field by a pilot can supply dependable and precise data about the aircraft's attitude, movement, and position. This, in turn, aids in averting and addressing instances of spatial disorientation [42]. Conversely, when attention resources are unevenly distributed among different instruments, resulting in the neglect or oversight of certain parameters, the overall safety of aircraft operations becomes significantly compromised [43]. Furthermore, pilots tend to exhibit more assertive behavior in post-congestion scenarios, showing increased focus towards the front area but reduced attention to the dashboard region [43].

For continuous tasks, such as specialized tasks, measuring and identifying sustained attention is crucial, particularly when the consequences of reduced attention can be severe. Engaging in attention-demanding tasks benefits from the brain's ability to focus on pertinent stimuli, locations, or actions in advance of their occurrence or execution.

3.2.2 Attention levels and Attention Types

In previous research on attention [2, 24], we have learned the importance of managing our attention effectively for our well-being. A number of studies have shown that multitasking can negatively impact performance. The findings provide a basis for developing interactive attention management systems that monitor and assist users [44, 45]. Nevertheless, even though attention significantly impacts user performance, existing techniques for attention classification have primarily concentrated on distinguishing various attention types, with minimal emphasis on distinguishing between distinct levels of attention (Especially in a range scale). A variety of sensors have been used in the past in order to measure attentional states, including electroencephalography (EEG), electrooculography (EOG), and electrocardiography (ECG) [6, 46]. In spite of their high accuracy, these devices are obtrusive and require a device to wear or electrodes to be attached to the skin, making them unsuitable for everyday use [44]. The other sensors for measuring attentional states is Eye tracking which is not obtrusive in nature.

Attention types

Focused attention: which is a state of focused attention in which an individual responds specifically to visual, auditory, or tactile cues.

Sustained Attention: which is continually responding to specific stimuli, such as reading a book, for an extended period of time is sustained attention.

Alternating Attention: which is the ability to switch focus from one task or part of a task to another, regardless of cognitive demands.

Selective Attention: **attention** selectively focused on one stimulus while suppressing others, like in the Cocktail Party Effect, where we attend to the voice of one person while minimizing the voice of another.

Divided Attention: which is the division of attention between different stimuli occurs simultaneously within the brain [47].

3.2.3 Engagement and Attention

Active involvement triggers heightened information processing (diminishing available attentional resources), providing a novel understanding of engagement and its fundamental neurophysiological characteristics.

There are two lines of research that describing attention:

Cognitive psychology models that encompass attention as a component of information processing propose the following: In existing psychological models, attention functions as a filter mechanism responsible for regulating the type and quantity of information that enters the working memory. This function is pivotal in preventing an overload of working memory, enabling the learner to focus on pertinent information. Only sensory data that successfully enters the working memory is processed, structured, and linked with pre-existing knowledge. As such, attention serves as a discriminative process for incoming sensory information, determining which elements will undergo further processing and have the opportunity to be learned. Consequently, attention plays a pivotal role in shaping the success of knowledge acquisition. Certain situations heavily rely on executive functions such as shifting, inhibition, or updating, necessitating an overarching, top-down control of attention. While much of the information processing is concealed, certain aspects of attentional procedures might be externally observable, such as visual orientation towards a specific stimulus, which enhances the efficiency of processing [48].

Engagement models involving attention as a component of behavioral aspects: Attention is frequently misconstrued as synonymous with engagement, although it actually constitutes only a segment of it. Engagement is a multi-dimensional overarching concept encompassing a range of factors crucial for achieving success in a given task. This encompasses evident actions, inner thought processes, and emotional responses. Subtle processes, such as dedicating effort to learning, grappling with complex information, and undertaking cognitive information processing, contribute to cognitive engagement. While cognitive engagement pertains to internal mechanisms by definition, only the emotional and behavioral components manifest in observable indicators. Nonetheless, all facets of engagement are tightly interconnected and do not manifest independently. Therefore, attention assumes a pivotal role as it can indicate particular processes that should, to some extent, surface in pilots' conduct [48].

3.2.4 Attentional span and capacity

Attention comprises various constituents, among them attention span, which denotes an individual's capacity to focus on a stimulus or object for a duration of time. This capability is also referred to as sustained attention or vigilance [49].

Sustained attention necessitates perseverance and drive. Consequently, individuals with limited attention spans might seem to lose interest or not invest adequate energy in tasks. Attention span develops as one gets older and is intertwined with, as well as influential in, various other aspects of functioning such as acquiring knowledge, memory, academic achievement, and comprehending and handling substantial volumes of information [49].

Studies have indicated that a child's sustained attention progresses steadily until the age of four, after which it experiences a significant surge between the ages of 4 and 6. Nonetheless, experts in childhood development commonly suggest that a reasonable attention span for a child can be estimated as two to three minutes per each year of their age.

There are different patterns of cognitive function changes across the lifespan, according to studies on cognitive ageing. Over the course of life, crystallized intelligence, which pertains to knowledge-based skills, remains relatively stable. As opposed to fluid intelligence, which is associated with cognitive processes such as working memory, processing speed, and long-term memory, fluid intelligence demonstrates a significant decline in early adulthood and continues linearly over the years [47]. There is, however, one exception to this pattern: older adults perform worse on executive functions due to frontal lobe atrophy. It suggests that cognitive processes involving the prefrontal cortex decline earlier and in a greater degree than those involving other regions of the brain [50]. Those cognitive processes supported by the frontal lobe would decline at an earlier age and to a greater extent than those supported by other regions that are not frontal [47]. To explain the decline in cognitive function associated with ageing, this hypothesis integrated previous theories that focused on executive functions such as attentional capacity and inhibition [48]. There is a strong connection between cognitive aging and attention, which is a process of executive control supported largely by the frontal lobes and may be affected by aging. In addition to affecting other cognitive functions, attention contributes to the decline of memory and reasoning. The effects of attention on aging, however, have been studied in a variety of ways, and the results have been mixed. The process of attention helps maintain goal-directed behavior despite competing distractions. Three aspects of executive attention can be identified: selectivity, intensity, and executive attention. The impact of aging on executive attention has been investigated by using paradigms such as dual-tasking or task switching [49]. Visual search tasks and visuospatial orienting tasks have been used to investigate the selectivity aspect of attention. A study focusing on visual search found that older adults exhibited significantly slower conjunction search than younger adults, despite displaying no decline in feature search [48].

3.3 Conclusion

The mental workload experienced by pilots is the burden imposed when they have limited information-processing resources, time constraints, and are under stress. It is often categorized as low, medium, or high intensity and can occur during various flight phases, such as Takeoff and Landing, as well as during emergency and busy airspace situations, due to high cognitive demands, difficult tasks, parallel tasks, and limited time available for task completion. Managing workload effectively is crucial in aviation to ensure safe and efficient flight operations. Methods such as being aware of unexpected events, minimizing distractions, mental exercises, and prioritization can be employed to manage workload in different situations and from various causes.

The impact of workload and attention on pilots and cabin crew can lead to fatigue and mental health issues, which can adversely affect their performance and decision-making abilities. Therefore, understanding the impact of workload on pilots and cabin crew, and identifying the types and levels of attention required during different flight phases, is essential for effective aviation human factors management.

Measuring and assessing workload and attention can be done using techniques such as EEG and eye tracking. To address this issue, it is important to first break down the flight into different phases and determine the probable workload and required attention for each phase. However, to gain a comprehensive understanding of the unique workload and attention demands of a specific flight, establishing a baseline specific to that flight is essential. This can be achieved through a **focus group** comprising expert pilots who can provide insights into the probable workload and required attention for each flight phase.

Conducting real-time experiments to collect attention and workload data during actual flights allows for comparison with the baseline attention data gathered from the focus group. Any deviation from the baseline can be identified, and appropriate measures can be taken to address workload and attention-related issues to ensure optimal performance and safety in aviation operations. Taking a proactive approach to managing workload and attention in aviation, including gathering baseline data from expert pilots and conducting real-time experiments, can provide valuable insights and help identify potential deviations that may impact pilots' attention levels. This information can then be used to develop effective interventions and strategies for mitigating workload-related challenges and optimizing attention management in aviation operations. By prioritizing workload and attention management, safety, efficiency, and overall performance in the aviation industry can be improved. In the next chapter, we will concentrate on the study of a focus group on attention.

Chapter 4 - Focus group and Attentional Tasks Model

Managing workload and attention in aviation is crucial for ensuring safe and efficient flight operations. High workload and lack of attention can lead to fatigue, mental health issues, and ultimately impact pilots' performance and decision-making abilities. To effectively manage workload and attention, it is important to understand their impact on pilots and cabin crew, as well as identify the types and levels of attention required during different flight phases.

To address this issue, the first step is to break down the flight into different phases and determine the probable workload and required attention for each phase. However, in order to gain a comprehensive understanding of the unique workload and attention demands of a specific flight, establishing a baseline specific to that flight is essential. This can be achieved through a focus group discussion with expert pilots who can provide insights into the probable workload and required attention for each flight phase. This chapter explores hypothesis 1 and objective 1, which aims to establish baseline attention levels for each flight phase and identify real-time deviations. It demonstrates the feasibility of this approach and emphasizes the potential benefits it holds for enhancing aviation safety through the establishment of baseline attention levels.

In this chapter, the main objective is to provide attentional scores for all flight tasks, allowing for a classification of tasks based on their attentional scores. To determine these scores, several meetings were conducted and finally, a focus group discussion was held with a group of pilots, including participants from CAE and Bombardier. Each participant brought their unique piloting experience and knowledge, leading to a detailed and in-depth discussion that gathered information about the subject, taking into account all aspects. This information is crucial for modeling pilots' attention and determining a baseline level of workload and required task attention.

4.1 Study Design

Focus groups are an established mechanism and a form of group interview that capitalizes on communication between research participants for generating or collecting data across mixed-method, quantitative, qualitative and methodologies [51]. Group interaction is used as part of the method in focus groups. In focus groups, participants are encouraged to talk to one another instead of the researcher asking each person to respond to a question in turn. They ask questions, exchange anecdotes and comment on each other’s' points of view and experiences. This method can be used to examine what people think, how they think and why they think that way. It means that this method is useful for exploring people's experiences and knowledge [52].

Classification of tasks that require attention taking into consideration needs information about tasks and the amount of contribution of each effective causes of high workload on that task. In this regard, we needed a survey to gather the required information. The data preparation process was relatively long due to the high importance and sensitivity of its results. We had to make sure we chose the right scales as references and use the right definitions for each phase or question to be easily understandable for all participants. Moreover, the number and explanation of options for each question was highly controversial and finally was approved after several changes. The explanation of the options had to be defined carefully and sensitively in such a way that prevent any bias. Between October 2021 and March 2022, we organized multiple meetings involving a teammate from UQAM University, Benoit from Bombardier, and Hamdi. Additionally, on 1 March 2022, we conducted a dry run with the same participants. Finally, on 25 March 2022, we held a focus group discussion with 9 participants from Bombardier and CAE. The focus group was conducted in Zoom. The aims of this discussion were to gather some information about the required amount of attention for flight phases from the beginning to the end of the flight. This information is very important to model the pilots' attention and used to determine a baseline level of workload and required task attention as well as their contributors.

The structure of the focus group is explained in detail in section 4.4 (Focus Group Structure and Content). For each flight phase, we have some information and using them, we will classify tasks based on the amount of attention that is required for each of them. The details of how we will use this information to calculate the Attentional score of each task is explained in this chapter.

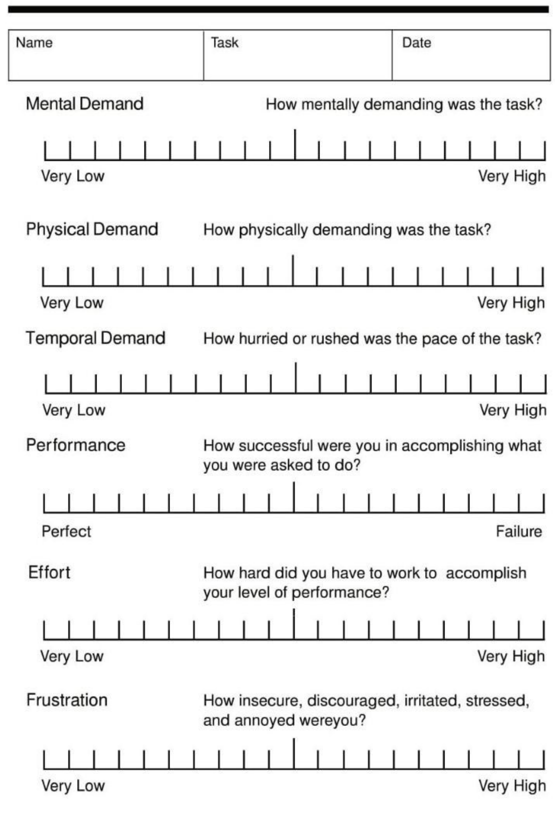
4.2 Standard rating scales

We needed to use standard rating scales to design an accurate, reliable and referable survey. Therefore, the first step was studying workload and handling qualities assessment tools. The rating scales that are considered for the survey are NASA Task Loading Index, Modified Cooper Harper, Bedford, and PIO. A brief explanation of each rating scale is given in the following subsections. For assessment purposes, we utilized the NASA Task Loading Index (NASA-TLX) and the Bedford Rating Scale, from the previous set of scales. The reason for selecting these particular scales will be explained in the following sections.

4.2.1 NASA TASK LOADING INDEX

The NASA Task Loading Index is a rating scale that provides a workload score based on participant feedback regarding their self-assessed efficiency. Six major subscales that are used by participants are physical demand, mental demand, performance, temporal demand, frustration, and effort [53].

The NASA TLX scale has actually two stages: in the first stage, the workload is split into the six subscales mentioned earlier. Each subscale ranges from 'very low' to 'very high'. In this stage, participants decide where their efficiency fit into the scale. Finally, in this stage, a rating between the range of 0 to 100 is generated which referred to as the "raw TLX" score. Figure 1 shows the paper handout form for calculating the raw score. The second stage of the TLX rating scale comprises comparing the workload sources. The six mentioned subscales should be compared to each other in such a way that the user decides which subscale is more relevant to workload. Then a weighted score is set up for each subscale based on the summation of the number of times that subscale was selected. After that, the weighted score of each subscale is multiplied by the related scale score and then divided by fifteen to create a final workload score ranging from 0 to 100. A zero final workload score means a very low workload and a 100 final workload score means a very high workload [54, 55].



Name	Task	Date

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low Very High

Figure 1. The paper handout form for calculating the raw score in The NASA TLX scale [53].

4.2.2 Modified Cooper Harper

The modified Cooper Harper scale [56] is a unidimensional measure of aircraft handling qualities that elicit pilot mental workload using a decision tree. This rating scale is still widely used by pilots all over the world. This scale is used to achieve pilots' ratings of the ability to control or manage aircraft. In this scale, it is assumed that the level of difficulty to control an aircraft and pilot workload have a direct relationship. The Cooper-Harper scale is a decision tree ranging from 1 to 10. In this scale,1 means 'excellent' and 10 means 'major deficiencies'. Pilots follow the decision tree and any time they arrive at a value, they should give feedback on both performance and the workload. Here performance means the accuracy of aircraft control achieved by the pilot, and the workload means the amount of mental and physical effort required to achieve the desired level of performance [56].

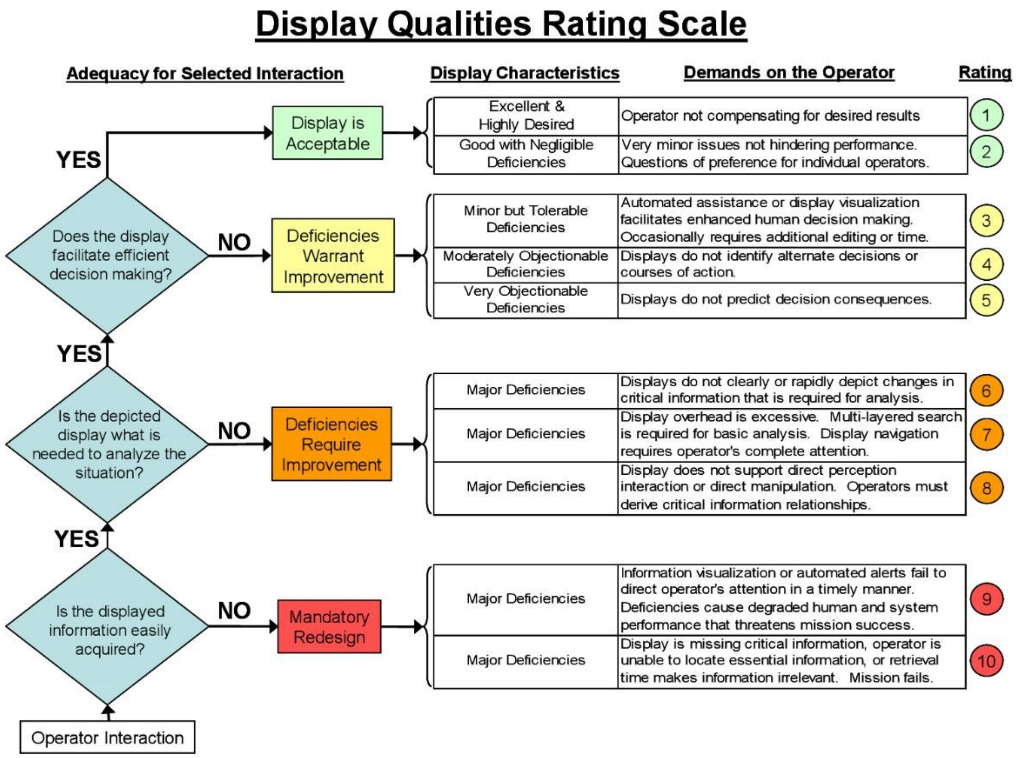


Figure 2 . The modified Cooper Harper scale [53].

4.2.3 Bedford Scale

Bedford Scale [53] is another workload assessment, which was developed by the RAE Bedford (Royal Aircraft Establishment of Bedford).This scale aims to move from gathering feedback of pilots toward a more quantitative approach. Half a decade of work was done on correlating pilots' viewpoint of workload with their heart rate, which leads to developing an improved means to measure pilots' workload. This scale defines workload as an integrated physical and mental effort that is needed for satisfying the apperceive requirements of a certain flight task [53].

The Bedford Scale is a decision tree ranging from 1 to 10. In this scale, 1 is referred as 'workload insignificant' and 10 referred as 'pilot unable to apply sufficient effort'. A pilot follows the decision tree from bottom to top, first answers general 'yes or no' questions and after that answers more descriptive and specific choices to designate a final rating [53, 57].

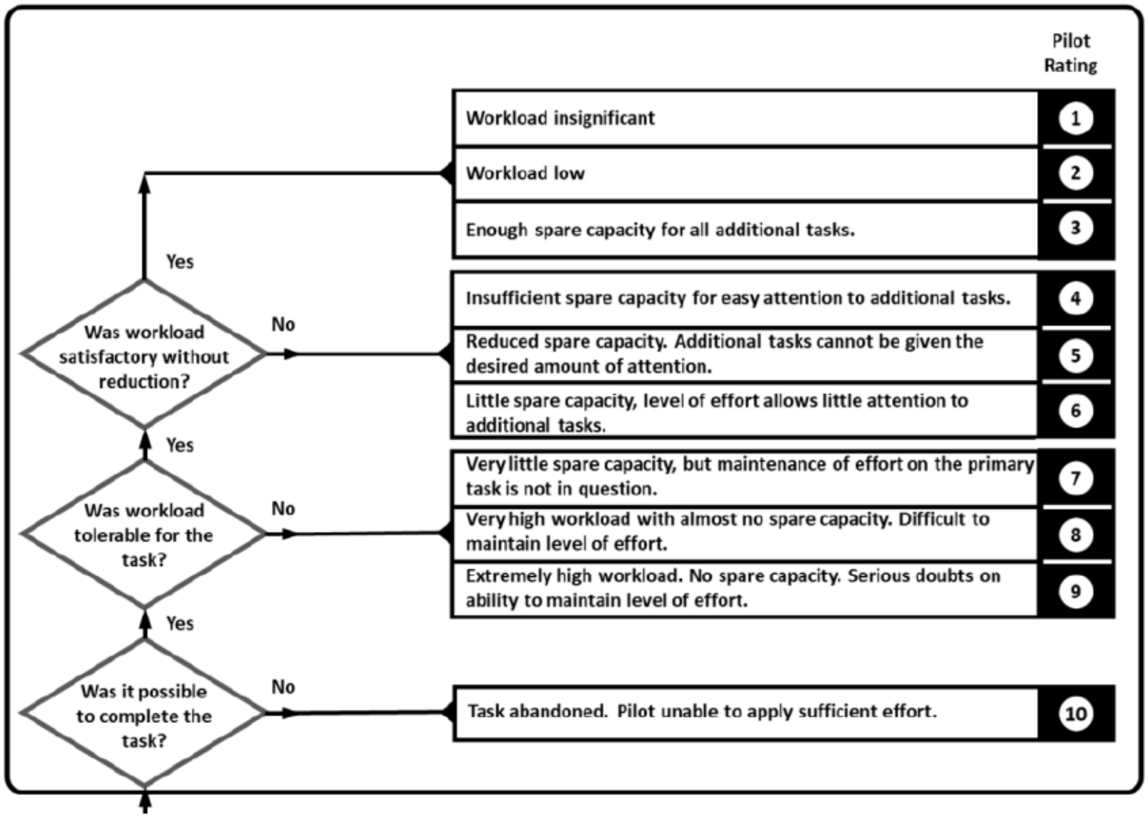


Figure 3. The Bedford Scale [55].

4.2.4 PIO Scale

Pilot-induced oscillations are sources that always cause pilot frustration. Pilot-induced oscillations are commonly described as uncontrollable or sustained oscillations that comes from pilots' efforts to control the aircraft [58]. Although PIOs are mostly connected to beginner pilots who apply inordinate control inputs, they may have effects on all types of aircraft aviators [58].

Similar to other scales, the PIO rating scale has also used a decision tree format. Pilots start from the bottom by answering some yes or no questions. This scale provides some rating descriptions to help pilots match their experience to the proper rating [58].

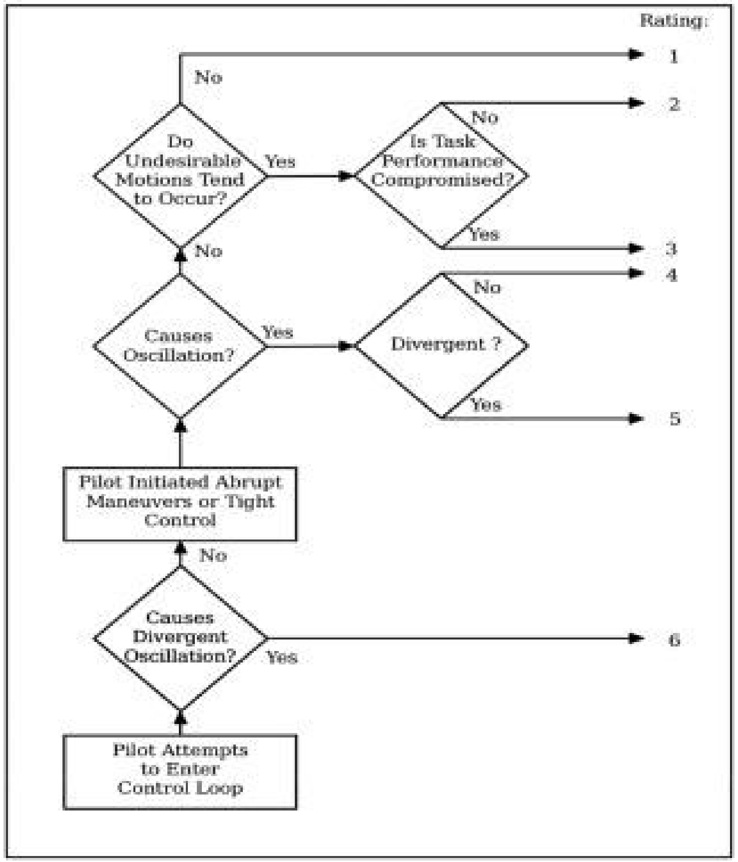


Figure 4. The PIO Scale [53]

Table 1. The PIO Scale descriptions [53]

Description	**Numerical Rating**
No tendency for pilot to induce undesirable motions.	1
Undesirable motions end to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.	2
Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort.	3
Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.	4
Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must open loop by relasing or freezing the stick.	5
Disturbance or normal pilot control may cause divergent oscillation. Pilot must open control loop by releasing or freezing the stick.	6

We conducted a thorough comparison of the four previous rating scales, examining their subscales, measurement targets, number of phases, phase descriptions, scale ranges, execution times, and important considerations. After studying the rankings and comparing the information, we have decided to utilize two specific rating scales: the NASA Task Loading Index (NASA-TLX) and the Bedford Rating Scale. We consider the structure of the NASA TLX rating scale as the main structure of our questions, and used the concepts of Bedford rating scale for collaborating the scales.

4.3 Focus Group

4.3.1 Focus Group Subjects

The focus group was conducted by students from the University of Montreal and UQAM. Participants included pilots from CAE[1] and Bombardier [2] (our partners). Each participant has unique experience and knowledge and this variety made the discussion detailed and in-depth and led to gathering information about the subject taking into account all aspects.

4.3.2 Focus Group Structure and Content

This focus group survey was designed to gather some information about the required amount of attention for flight phases from the beginning to the end of the flight. Using the information obtained from this survey, we have proceeded to an in-depth analysis of the workload, attention, the causes of distractions and wrong decisions, which leads to a classification of attentional tasks.

The survey is composed of blocks of tasks from the beginning to the end of takeoff. Participants need to answer some questions related to each block of tasks based on their experience with the typical tasks performed during the flight phase. One of the important steps in designing the survey was studying workload and handling qualities assessment tools in order to find and use standard rating scales to design an accurate, reliable and referable survey. Figure 1 shows the focus group structure for a typical flight phase. The rating scales that are considered for the survey are NASA Task Loading Index and Bedford rating scale based on the information achieved during studying about the scales [53, 54]. Therefore, the questions in the survey are inspired by Bedford rating scale and NASA TLX rating scale. We consider the structure of the NASA TLX rating scale as the main structure of our questions and used the concepts of Bedford rating scale for collaborating the scales [59].

[1] CAE Inc. is a Canadian manufacturer of simulation technologies, modelling technologies and training services to airlines, aircraft manufacturers, healthcare specialists, and defence customers.

[2] Bombardier Inc. is a Canadian business jet manufacturer.

There are 5 main important and affective factors (Mental Demand, Physical Demand, Effort, Stress and Available Time) on the workload and the required level of attention for each block of tasks. Each of these factors is composed of 6 options from not existence of that factor to the extremely existence of that factor. For example, the options we have for mental demand of a typical block of tasks are: No mental demand, Slight mental demand, Moderate mental demand, high Mental demand, very high mental demand, Extreme mental demand (table 1).

Table 2. A typical block of tasks and their options, as well as their raw scores.

No mental Demand	**Slight mental Demand**	**Moderate Mental Demand**	**High Mental demand**	**Very High Mental demand**	**Extreme Mental demand**
0%	20%	40%	60%	80%	100%

In addition to the above five factors, some other task characteristics may contribute to the workload of each phase. Thus, focus group participants were asked to select the main contributing factors for the related phase. The list of the contributed task characteristics are as follow:

- Tasks difficulty
- Time Pressure
- Number of tasks in each phase
- Task interruption
- External factors
- Frustration
- Boredom
- Precision

Finally, the participants were asked to choose the type of task that contributes the most to the workload of the related phase. Different type of task that contributes to the workload are **Aviate**, **Navigate**, **Communicate**, and **Manage**.

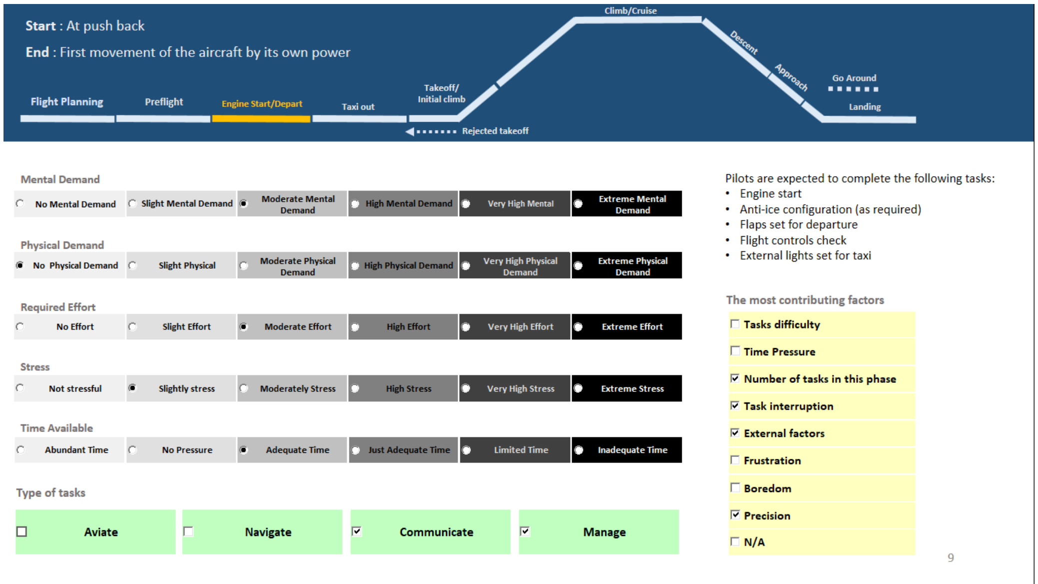


Figure 5. Focus group structure for a typical flight phase.

In order to evaluate the workload in a uniform way, we have suggested a scenario that has supported the discussions. Questions were answered with the following scenario in mind:

"The flight is planned to depart from the typically busy Chicago O'Hare airport (KORD) and land at Montreal Pierre-Elliot Trudeau (CYUL). The aircraft is a A320 or similar fly by wire aircraft. For this particular day, we are expecting light rain and wind."

"Still at Chicago O'Hare, the aircraft is rolling on the runway for takeoff. Before reaching V1, one of the aircraft tires burst. The rejected takeoff procedure is initiated."

"The aircraft is in short final (the last section of the final approach and fairly close to the runway) at Montréal Pierre-Elliot Trudeau airport. Just before reaching minimums, an unexpected airport vehicle enters the runway. The Go Around procedure is initiated."

4.3.3 Data analysis and Computing Attentional Scores

The data was gained from the focus group discussion with participants from CAE and Bombardier. The option that is selected by participants for each factor is referred to as the raw score (table 2). The first step after receiving the data from the focus group meeting was data preprocessing in order to normalize the data and find missing data. Then, the attention dataset was generated using the focus group data. The next step was calculating a weight for each factor.

We used the "Relief-based feature selection method" [60] in order to compute weights for each factor. All weights are normalized between zero and one. The Relief algorithm is initially designed to calculate a score for each feature. Feature scores can be used as feature weights or scores to sort and choose top-scoring features for feature selection. A filter-method approach that is sensitive to feature interactions is used in the Relief algorithm. This algorithm is designed based on identifying the differences in feature values between the nearest neighboring sample pairs [60].

After calculating weights for all factors, the next step was to multiply the raw score of each factor by its weight to get the final score of each factor. We have done this process for all Rating factors, main contributing factors as well as different type of tasks. To do so, I assigned a weight to each factor which gained from the Relief-based feature selection method. In regards to the main contributing factors and different type of tasks, whether these factors or types of tasks are involved in the workload of each block is determined by 0 and 1. In such a way that if they are selected, they get a raw score of 1 and if they are not selected they get a raw score of 0. Same as the rating factors, the next step was multiplying the raw scores by weights to get the final scores and then transfer it into the scale of 0-100 to be in the same scale as the rating factors. Then, in each group, I have added them together and divided them by the number of item in each group [59].

Eventually, I had 7 scores between 0 and 100. The final attentional score for each block of tasks was computed by adding these 7 scores and dividing them by 7. Finally, I normalized the scores between 1 to 10. This procedure was repeated for each block of tasks (flight phase).

4.3.4 Discussion and Results

The results of our analysis are shown in figures 6-9. Apart from having a specific attentional score for each phase, it is essential to know the importance of each factor and its effects on the workload and available resources. Thus, the importance of each factor calculated using the focus group data. It should be noted that the colors in the figures hold no significance. The meaning is conveyed through the percentages, and all evaluations are conducted based on these percentages. Figure 6 shows the importance of rating factors. As we can see, “Mental Demand” and “Available Time” are factors with highest impact on workload and required level of attention (24% and 26% respectively). The next two factors with highest important percentage are “Effort” and “Stress” with 22% and 19% importance respectively. As expected, “Physical demand” is a factor with lowest impact on the attention with only 9% of importance.

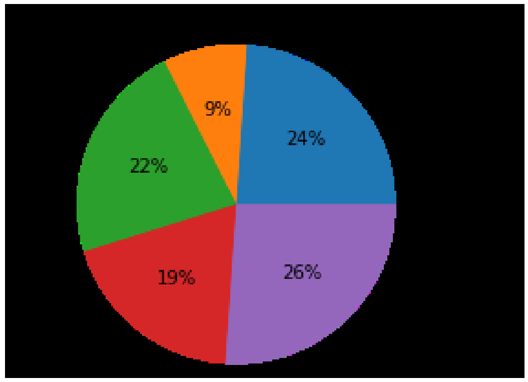


Figure 6. Importance of Rating Factors.

The importance of type of tasks is shown in figure 7. As it is shown in the chart, “Mange” and “Communicate” type of tasks are those, which involve in almost all flight phases and are the most important type of task with 27% importance. The other two types of tasks are, “Navigate”, and “Aviate” which do not involve in all phase and though have less importance compared to “Mange” and “Communicate” (24 % and 21% respectively).

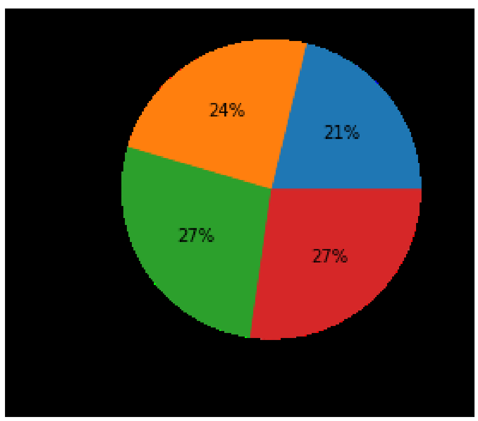


Figure 7. Importance of different Type of Tasks.

Figure 8 illustrated the importance of contributing factors. Results show that “External factors” with 20% importance has the highest impact on the workload and attention. The other three contributing factors that have the highest impact after the external factor, are “Number of Tasks”, “Task Interruption” and “Precision” with 18% importance. “Time pressure” is the next contributing factor with considerable impact on the workload and attention (14%). Other factors have an impact of less than ten percent.

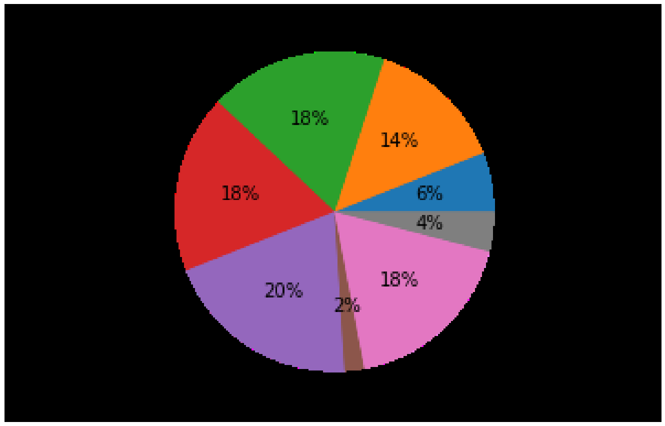


Figure 8. Importance of contributing factors.

Figure 9 shows the final attentional scores for all phases from beginning to the end of flight. As it is shown, the attentional score for the first phase (preflight) is 1. The “Rejected Takeoff” and “Go Around” are phases with most strategic tasks and highest attentional scores (9 and 10 respectively). The score for other phases fluctuates between 1 to 6. The attentional scores for each phase are presented in table 3.

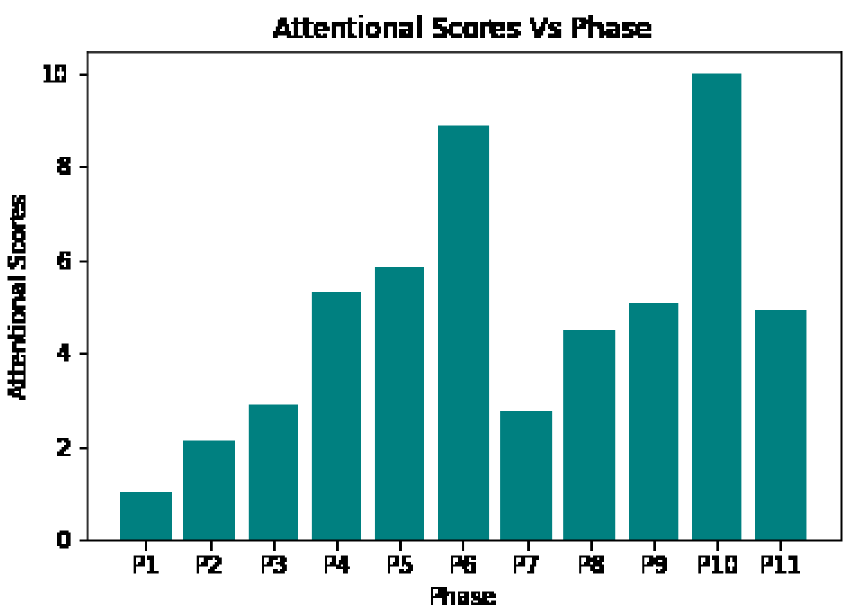


Figure 9. Final attentional scores.

Table 3. Phases' explanation and their attentional scores.

# Phase	Phase name	Attentional score
P 1	Flight Planning	1
P 2	Preflight	2
P 3	Engine Start/Depart	3
P 4	Taxi out	5
P 5	Takeoff/Initial climb	6
P 6	Rejected takeoff	9
P 7	Climb/Cruise	3
P 8	Descent	5
P 9	Approach	5
P10	Go Around	10
P11	Landing	5

Using the responses of participants alongside the results gained from these responses, we can see that the required level of attention for each phase is directly related to the presence of important factors. The higher probability of existence of rating factors, more contributing factors and more types of tasks involved in a phase, indicates the existence of a high workload in that phase and therefore the need for a higher level of attention (Attentional score) in that phase. It is obvious that the importance of each factor certainly has a significant effect on the workload of that phase. Undoubtedly, the "Available Time" and "Physical Demand" with the same existence rate do not have the same effect on the workload and level of attention required for a phase. For instance, the phase 10 (Go around) with the highest attentional score (10) is a phase that the existence rate of all rating factors is 80% (except "Physical Demand" rate which is 20%), 7 out of 8 of contributing factors and all types of tasks are involved in it.

4.4 Attentional Tasks Model

The human is an essential factor for the success or failure of flight operations. Pilots are those who operate aircraft in various industries. Pilot's responsibilities vary from day to day and they must perform a great many tasks correctly if the safety of their aircraft is to be assured. Therefore, their situational awareness is the key factor to identify the potential risk during flight operations. Any normal aircraft flight comprises different main parts such as takeoff, climb, cruise, descent, and landing. Each of these parts comprise of specific tasks, which require different level of attention [11, 22].

The objective of this section is to establish an attentional task model for piloting tasks. This model should be derived from the piloting model encompassing all tasks. Additionally, the model should incorporate focus group data and attention scores as a baseline for establishing the expected attention scores for each piloting task, which will be included in the reference model. The significance of this model lies in its ability to prevent errors and mitigate potential consequences on the aircraft and its passengers that may arise from neglecting critical attentional tasks. The list of tasks to be performed in each block is shown in figure 10.

Figure 10. List of tasks to be performed in each block

4.4.1 Attentional Task Model Structure

In order to provide predicted attentional measurements with each task of the reference model's list of actions we have defined an Attentional Task Model. The actions represent tasks that the pilot should perform to achieve a certain goal (whether that is a takeoff, cruise, or landing).

The main objective of this **Attentional Task Model** is to provide attentional scores for all flight tasks. These scores will be used for comparing the expected actions received by the Reference Model (section 4.4.2), which is updated by the Attentional Task Model, and the executed actions that are logged by the X-Plane Simulator (see figure 11).

To better understanding the structure of the Attentional Model, the inputs that will be used for the Attentional Task Model are briefly explained in this section, in order to provide basic knowledge about them. As it is shown in figure 10, the Attentional Task Model is composed of two inputs: The Reference Model (section 4.4.2) and the Focus Group's Data, and one output: the updated Reference Model by attentional scores. The output of the Attentional Task Model has the same format as the Reference Model plus a score of attention for each task (figure 11). In the reference model, tasks are considered as single actions that run sequentially. However, it was not possible to consider them like this for the focus group. In the focus group, pilots should answer some questions based on their experiences. If we want to consider each task as a single action and ask 7 questions for each of them, two problems may occurs: 1. In this case, the focus group will be very long and the accuracy of the participants' responses will probably decrease, 2. More importantly, answering questions for a single task is meaningless for pilots. Thus, we decided to have blocks of tasks instead of single tasks to address these problems. Therefore, as it is shown in figure 11, we divided all tasks into 11 blocks of tasks. Finally, an attentional score will be computed for each block of tasks using the focus group's data. The computed attentional score of each block is assigned to all tasks in that block.

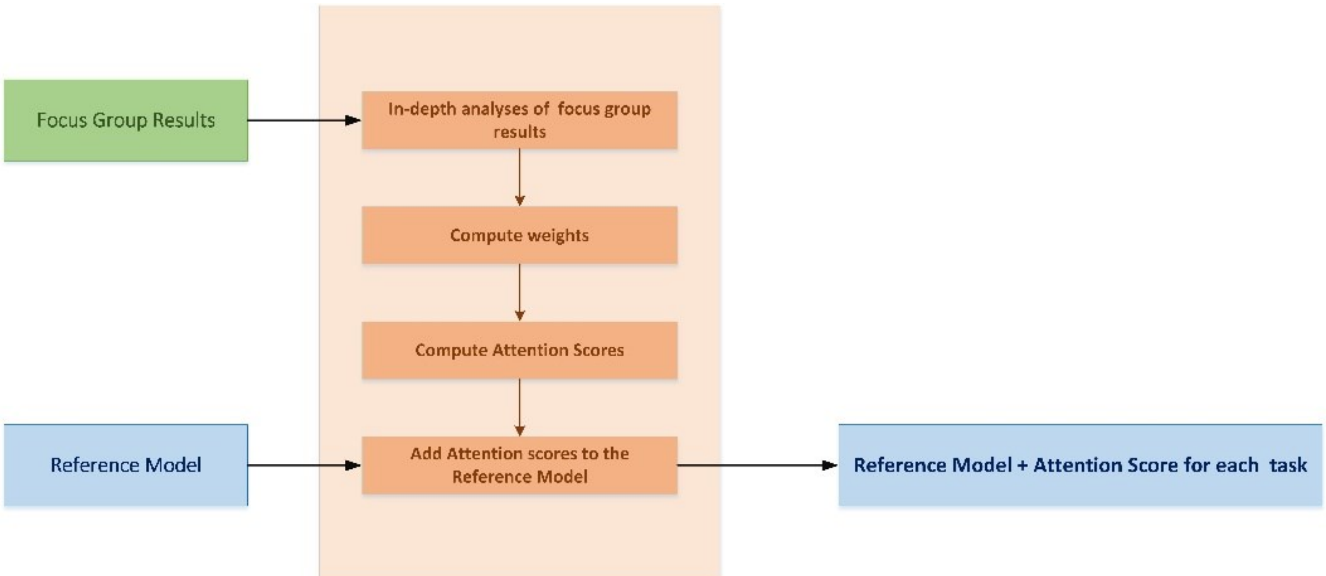


Figure 11. Structure of the Attentional Task Model.

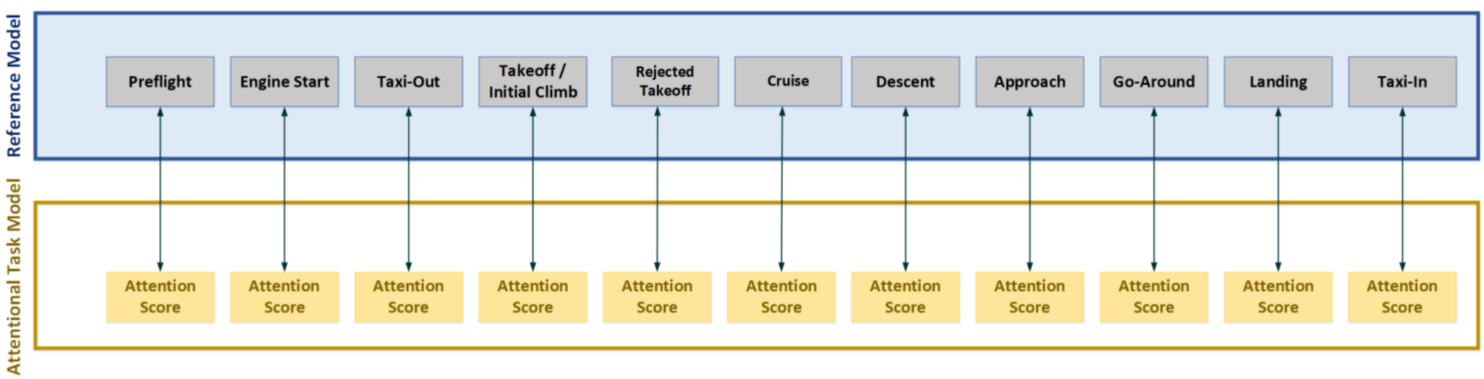


Figure 12. Relation between the Reference model and The Attentional Model.

4.4.2 Reference Model Structure

The reference model is a structure around which the complex task of piloting an aircraft has been by Marc-Antoine , my teammate from the University of UQAM, in the pilot AI project. It contains the domain theory for solving multiple problems in the execution of the task. Since the high level of complexity of the task, the reference model is based on Web Ontology Language (OWL) [61]. The choice of ontology languages for the formalization of the reference model has the advantage of allowing the representation of logical, complex, and efficient relationships between the elements [61, 62]. We are seeing this language as an efficient tool allowing the formalization of a high level of detail by the exploitation of the semantic and explicit description of the knowledge specific to OWL. In other words, this tool is allowing to capture a high level of detail of the task decomposition. For supporting the perspective of task decomposition, there is a short definition of a task ontology: “The term “task ontology” can be interpreted in two ways: (1) Task-subtask decomposition together with task categorization such as diagnosis, scheduling, design, etc. and (2) An ontology for specifying problem-solving process.”(see figure 13, 14) [63].

The link between the Attentional Task Model and the reference model are important. In figure 11, we can see that these two models are highly related. Since the data collected in the focus group is a theoretical reference, the two models are highly related. Our goal is to integrate the Attentional Task Model to the reference model by using the same ontological language. The results of the attentional score for each of the tasks are available in the same OWL language. By using the same formalization format, the reference model is able to manipulate the attentional score of the attentional model. In figure 14, we can see how the Attentional Task Model is integrated in the structure of the reference model. The attentional score is directly attached to the task decomposition.

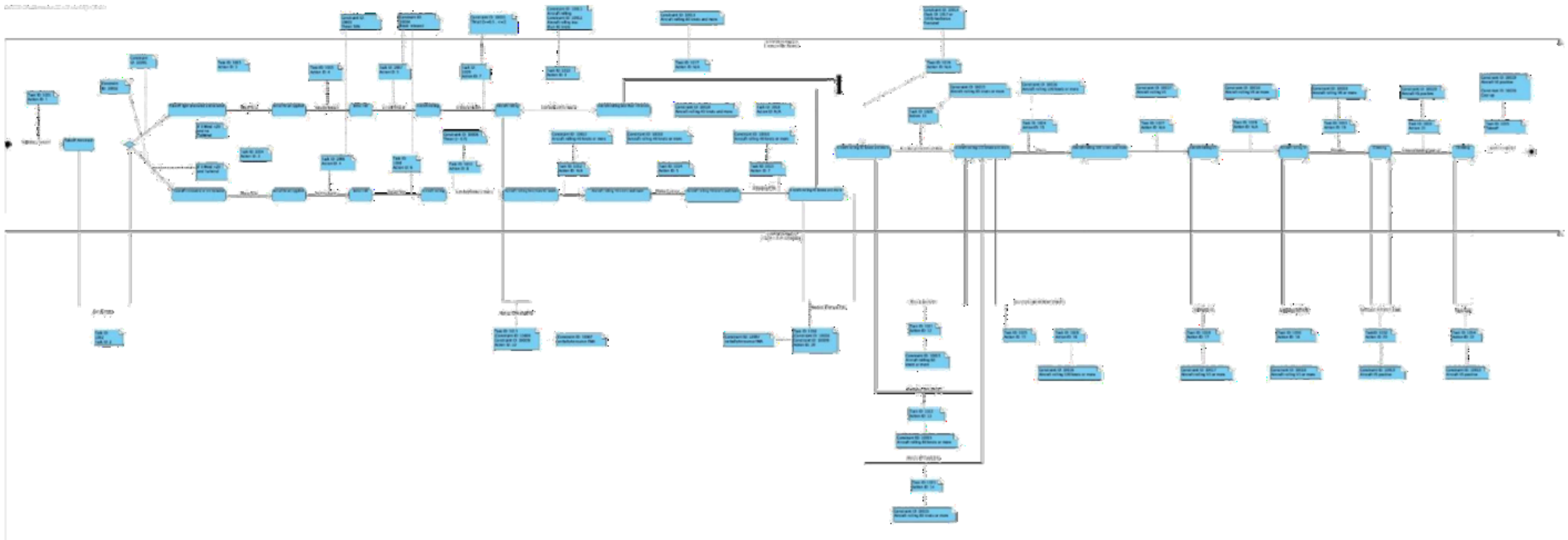


Figure 13. Reference Model

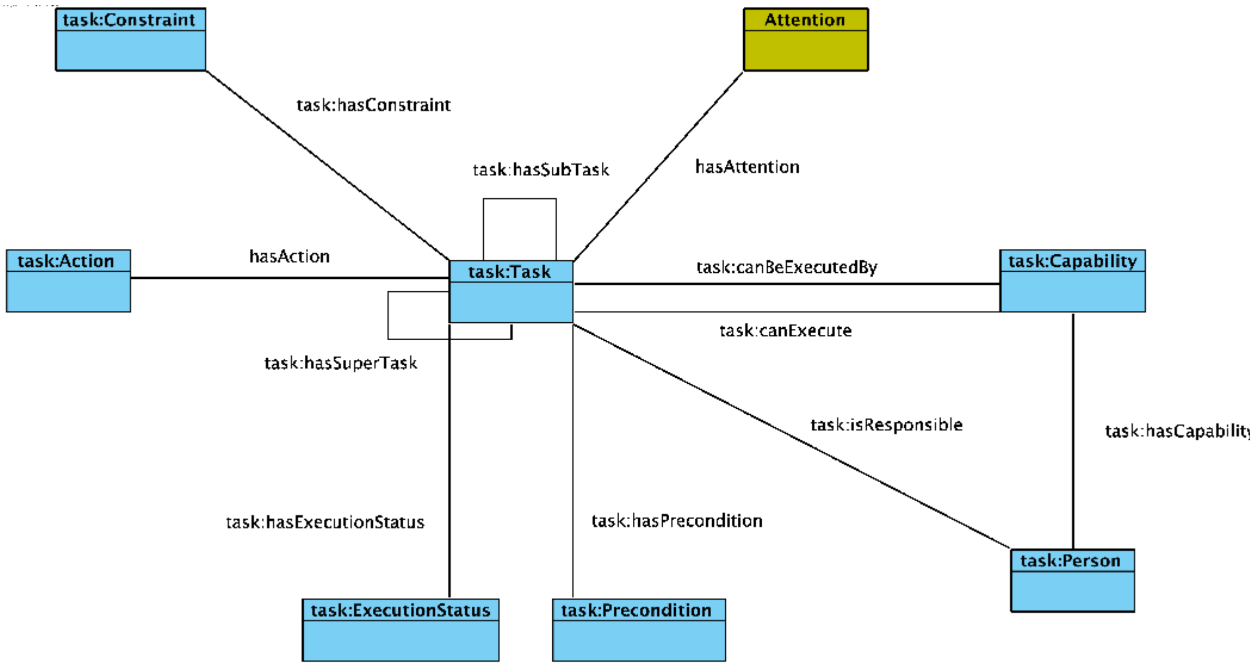


Figure 14. Structure of the reference model.

4.5 Conclusion

The aims of this discussion were to gather some information about the required amount of attention for flight phases from the beginning to the end of the flight. This information is very important to model the pilots' attention and is used to determine a baseline level of workload and required task attention as well as their contributors. Each participant in the focus group had unique experiences and knowledge and made recommendations and gave valuable information about each flight phase. Using this valuable information, the importance and impact of each factor as well as the attentional score for each phase was computed. The attentional scores were added to the reference model as the output of the Attention Task Model. This Model can be used with a workload assessment system.

The results of our analysis show that while the attentional score for all phases is fluctuating between 1 to 6, the "Rejected Takeoff" and "Go Around" are the most strategic phases and have highest attentional scores (9 and 10 respectively). The aims of this discussion were to gather some information about the required amount of attention for flight phases from the beginning to the end of the flight.

Chapter 5 - Experiment

By conducting real-time experiments during actual flights, we can obtain data that reflects the real-world environment and conditions that pilots experience. This allows for a direct comparison with the baseline attention data gathered from the focus group, which provides a comprehensive understanding of pilots' attention levels during takeoff.

This chapter intends to cover the objectives 2 and 3. **Objective 2** and **3** of the study aims to demonstrate the measurement of attention and for that, we will create a controlled environment in a flight simulator that introduces changes in cognitive workload through simulated failures. This allows for the manipulation of workload levels and the measurement of attention in real-time during the takeoff experience using EEG and eye tracker in conjunction with the simulated flight failures.

The approach of conducting real-time experiments during actual flights enables the collection of data that is directly relevant to pilots' attention and workload during takeoff, which aligns with objectives 2 and 3 of the study. This approach also supports hypothesis 2, which posits that it is possible to measure pilots' attention in real-time during takeoff. By identifying any deviations from the baseline attention data, appropriate measures can be taken to address workload and attention-related issues, ultimately improving pilots' performance and safety in aviation operations.

Additionally, taking a proactive approach to managing workload and attention in aviation, including gathering data from expert pilots and conducting real-time experiments, allows for a comprehensive understanding of the unique workload and attention demands of the takeoff phase. This approach aligns with the overall objective of improving aviation human factors management and enhancing flight safety by better understanding and managing pilots' attention and workload during takeoff and other flight phases.

Therefore, an experiment was conducted to gather the cognitive workload (CW), Engagement, and pupil dilation (PD) of pilots during takeoff procedures in an Airbus A320 in real time. The experiment was designed to provide a range of different scenarios, including standard takeoff sessions and failure sessions, in varying weather conditions, times, and conditions. Participants, who were experienced pilots as well as engineers from CAE and Bombardier, were asked to perform the takeoff procedure under each scenario. There was no limit on the number of takeoffs that a participant could take in a single session. The experiment was conducted at the University of Montreal and was closely monitored by an experimenter who acted as a pilot monitor. The study was conducted under an ethical certificate obtained from UdeM, ensuring that the research was conducted in accordance with ethical guidelines and standards (the ethics certificate **F1-CERSES-3849**). To participate, all participants provided informed written consent and were made aware of the potential risks and benefits of the study. The results of this experiment will provide valuable insights into the attention levels of pilots and their cognitive workload during takeoff, and can help improve the safety of air travel by providing a better understanding of how to differentiate expert pilots from novice ones.

5.1 Event generator

Pilot training relies heavily on flight simulators, which provide a secure platform to hone their abilities and ready them for diverse flight circumstances. However, despite their exceptional performance, simulators frequently lack the capacity to initiate or track specific occurrences within a simulation. To address this issue, the primary aim of this study is to establish a system that can launch, record, and document various aircraft procedures, as well as generate malfunctions to assess the pilot's ensuing corrective actions and gauge the variability of their corrective response. Additionally, this software must be capable of real-time data capture.

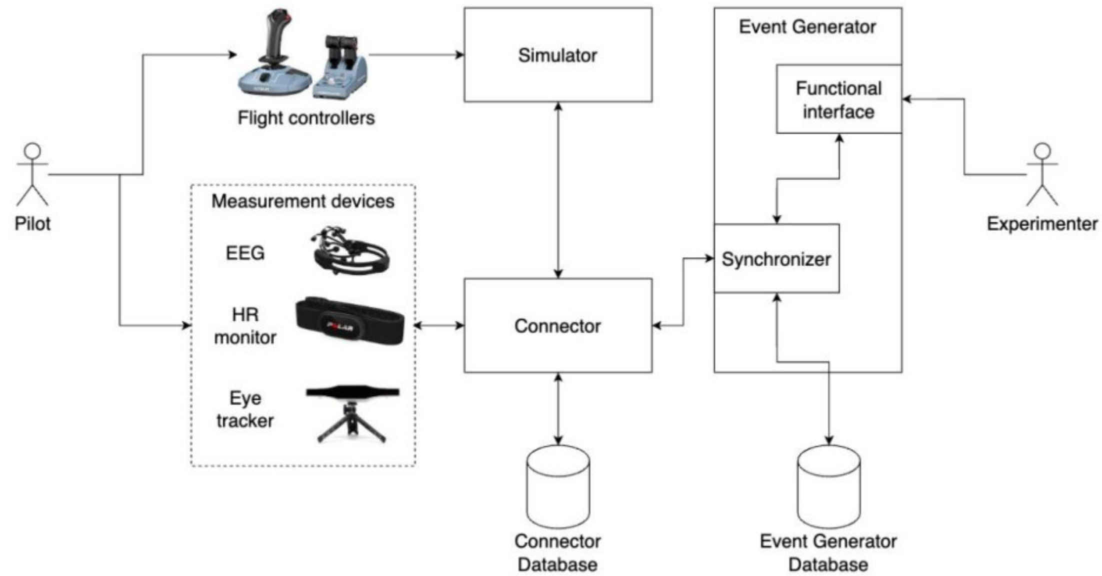


Figure 15- Experiment architecture overview

To accomplish the first objective, in cooperation with Maxime Antoine [64], my teammate in the pilot AI project, we developed the architecture illustrated in Figure 15. This includes the following components:

• **The Event Generator**: A web-based application that allows the experimenter to trigger, monitor, and interact with events in real-time.

• **The Connector**: A multi-threaded Python server that captures data from measurement devices in real-time. It communicates directly with the simulator, sending and receiving requests between the Event Generator and the simulator.

• **Simulator**: The flight simulator, which is connected to a throttle and joystick for pilot interaction.

• **Measurement devices**: Devices used to measure the pilot's CW (corrective workload), HR (heart rate), and PD (pupillary dilation) in real-time. These devices are either attached to the pilot (EEG, HR monitor) or directed towards them (eye tracker).

While several commercial flight simulators are available, this research focused on X-Plane 11, a realistic flight simulator developed by Laminar Research. X-Plane 11 provides a variety of commercial and military aircraft for pilot training and offers the ability to incorporate external plugins to modify its functions. Specific commands, known as Datarefs, can be used to interact with the simulator. In this study, the Airbus A320 aircraft was selected for the experiments, as it is a widely used airplane with many pilots already trained on it. The Flight Factor A320 ultimate pack was chosen as the A320 aircraft plugin, based on the expertise of Bombardier and CAE. While the inner workings of the Datarefs are beyond the scope of this research, they can be compared to HTTP requests sent to a server.

It is worth mentioning that this part (the setup and connection of all the devices and the entire architecture) was realized and implemented by Maxime Antoine [64]. Furthermore, it should be mentioned that the heart rate data was not taken into consideration while calculating attention in our study. However, it was utilized by my other teammates for different analyses.

5.2 Experiment Details

The following chapter requires context in order to be fully understood. The experiment focuses on measuring the cognitive workload (CW), Engagement, and pilot dilation (PD) of pilots during a takeoff procedure on an Airbus A320. The aircraft is positioned on lane 06L at Montréal airport (YUL) and ready for takeoff. The pilot must perform the following tasks:

- Release the parking brake
- Execute the takeoff procedure
- Climb to a height of 3000 feet without using the autopilot

A successful takeoff is determined if these objectives are achieved. However, a takeoff would be deemed unsuccessful if:

- The plane deviates too far from the lane
- The pilot crashes the aircraft

To generate high levels of CW, different scenarios were created with varying procedures, including potential failures and alternate procedures to follow in case of failure. In total, six different scenarios were devised. Each scenario differed in terms of time, weather conditions, and the occurrence of failures. Scenarios 1 to 3 were used for regular takeoff sessions, while scenarios 4 to 6 were used for failure sessions.

The participants were separated into two groups. Group one began with a 20-minute regular takeoff session, followed by a 20-minute failure session, while group two followed the opposite sequence. There was no restriction on the number of takeoffs each participant could perform during a session, and the research found that participants took between 4 to 6 takeoffs per session. This number of takeoffs resulted in some scenarios being repeated during a particular session.

It is important to note that an Airbus A320 requires a pilot and a pilot monitor to operate. During the experiment, the experimenter acted as the pilot monitor. This role involved performing specific actions or making certain calls to assist the participant in taking off the airplane. For instance, the pilot monitor would announce when the aircraft reached 100 knots, or raise the landing gear when the participant said "gear up". These calls and actions were in accordance with the standard A320 takeoff procedure.

5.3 Participants

Participants from CAE and Bombardier participated in the experiment at the University of Montreal. The study included 13 male subjects (all between 24 and 49 years of age) with an average age of 36 years. It was required that participants work in an industry related to aviation. The 13 participants included 7 pilots with piloting experience, piloting license and A320 piloting experience. The other 6 participants were engineers at Bombardier and CAE who were familiar with most aircraft procedures but without holding a piloting license. For these participants, the minimum and maximum flight hours were 1 hour and 3000 hours, respectively.

5.4 Setup

5.4.1 Measurement devices

6.4.1.1 Gazepoint GP3

Measuring PD presents a challenge, as the measurement tool must continuously track the user's eyes and compute the changes in pupil diameter in real-time. Fortunately, eye-tracking devices have become more sophisticated and accurate over the years. This research evaluated various eye-tracking options and selected the Gazepoint GP3 because of its ability to measure pupil dilation and real-time eye gaze. Additionally, the Gazepoint GP3 is well-known and widely used in the research community, and it comes with ready-to-use tools for calibrating and measuring pupils instantly. However, it is crucial to note that this device only functions in a computer screen simulator environment. If these experiments were to be conducted in a real cockpit, a different eye-tracking device would have to be used, as pilots often move their heads around to perform tasks. The Gazepoint GP3's eye-tracking window is too small to accommodate the size of a cockpit. Gazepoint is the most affordable, research-grade eye tracker on the market, used in the experiment to measure pupil dilation [44].

Visual attention can be investigated using the eye-tracking technique. Our attention tends to be drawn to objects that are relevant to the task at hand or objects that have attracted our attention [44]. Seeing only what we're paying attention to is the result of the cognitive system allocating sufficient resources for visual processing. A significant part of visual attention is eye movement, which consists of fixations (stationary phase) and saccades (rapid, ballistic phase) [44]. As well as measuring eye movements and gaze point location, eye tracking is an effective tool for understanding human attention [47].

Pupil dilation: Pupil dilation, or the enlargement of the black circular part of the eye (the pupil), is a physiological response that can provide information about a person's level of attention and engagement.

When a person is paying attention to a visual stimulus, such as a person's face or a computer screen, the dilator muscle contracts, causing the pupil to enlarge. This increase in pupil size is known as pupil dilation and can be measured using specialized equipment, such as a pupilometer. Studies have shown that pupil dilation can be used as a measure of attention and engagement in a variety of contexts, such as during reading, watching movies, or playing video games [7].

5.4.2 NCO EEG Headset

Electroencephalography, is a medical technique used to measure and record the electrical activity of the brain. EEG works by placing electrodes on the scalp to detect the electrical signals generated by the brain, which are then amplified and recorded for analysis. As a result of its high time resolution and broad applicability, electroencephalography (EEG) has been used in numerous research studies to investigate the underlying neural mechanisms. Aside from diagnosing brain disorders, EEG is useful for examining cognitive, memory, and emotional functions related to the brain. more importantly, measuring attention status is also a critical application of EEG [6].

In the traditional EEG analysis method, EEG signals (the brain activity) are divided into the different five wavebands Based on the frequency range, including:

Delta (1–4 Hz), or δ activity is a periodic electric wave that has a frequency ranging from 1 to 3 Hz and an amplitude between 100 and 200 V.

Theta (4–8 Hz), or θ activity is a periodic electric wave that has a frequency ranging from 4 to 7 Hz and an amplitude of under 30 μV. When people are under stress or during a period of profound relaxation, these waves are generated.

Alpha (8–13 Hz), or α activity is a type of periodic electric wave that has a frequency ranging from 8 to 13 Hz and an amplitude between 30 and 50 volts. Whenever a person is conscious, relaxed, or at rest, the brain emits waves in the parietal region and the occipital region.

Beta (13–30 Hz), β activity wave is a periodic electric wave with a frequency between 14 and 30 Hz and an amplitude ranging from 5 to 20 V. During times of thought or sensory stimulation, these waves are especially noticeable.

Gamma (30–60 Hz), or γ activity is a type of periodic electric wave with a frequency of 31-60 Hz and an amplitude of 5-10 volts. γ activity is associated with selective attention, cognition, and perceptual activity [46].

Electroencephalography (EEG) is widely used to investigate neural mechanisms due to its high time-resolution and broad applicability. An EEG is an essential measurement for assessing attention status because it is not just used for diagnosing diseases of the brain, but also for studying cognition, memory, and emotion. An important parameter for determining attention state is band power, which is measured using ratios such as β/θ, β/α, and β/(α+θ). Typically, the power ratios are calculated from the same electrodes on the frontal lobe. For instance, EEG power-based indices like P_β / P_α, $1/P_\alpha$, and $P_\beta / (P_\alpha + P_\theta)$ have been used to assess sustained attention levels in healthy controls and patients with diffuse axonal injury, revealing significant negative correlations between P_β / P_α, 1/ P_α [3]indices and variations in mean reaction time during sustained attention tests [65].

Finally, this experiment uses the BMU9 EEG headset to measure the participant's CW [66]. The headset originates from the company OpenBCI, and the NCO software was utilized on top of it to extract real-time CW. This EEG headset provides the ability to capture real-time brain activity and emotions, without aggregating the brain waves at a specific time t. We opted for the EEG device provided by BMU because it allows us to be independent of the software attached to Emotiv. Unlike Emotiv's EEG, which would require us to purchase additional software, the BMU's EEG does not incur any extra costs for its usage.

5.5 Experiment environment

The experimental setup is depicted in Figure 16. This section provides a detailed description of the configuration used during the experiments. On the left side of the figure is the participant, while the other individuals are experimenters. The participant will be referred to as the flying pilot (PF) and a student(the person in the middle) will act as the copilot or the pilot monitoring (PM) in order to follow the Airbus standard operating procedures as closely as possible. The participant has an EEG headset, a heart rate monitor, and an eye tracker aimed at them while they focus on the screen in front of them. To operate the Airbus A320 simulator in X-Plane, the participant uses a joystick, throttle controls, and pedals like those found in a real Airbus A320. Meanwhile, the experimenters monitor the data coming in real-time through the three other screens, including measurement tools, video recording, and simulator data. The pilot monitor must balance executing the takeoff procedure with monitoring the data.

[3] P β (Power β), P α(Power α), P θ(Power θ)

Figure 16. Experimental setup

5.6 Procedure

The experiment environment was comprised of a participant (for each experiment) as the pilot and the experimenter as the pilot monitor or copilot. Ethics committee and partners' approval were obtained for the experiment's procedure. Participants received a detailed description of the A320 takeoff procedure a week before their experiment to familiarize themselves with its handling characteristics.

The simulator is setup to use a single monitor with the layout shown below (Figure 17). Display Units (DUs) are added at the bottom to avoid changing the pilot's view during the manoeuvres. Each DU contains information that will be required for the tests. From left to right:

- Navigation Display (ND)
- Primary Flight Display (PFD)
- Engine/Warning Display (E/WD)
- System Display (SD)

Figure 17. The Simulator Display Units layout

It also included a rejected takeoff, an engine failure after V1 (the speed beyond which the take-off should no longer be aborted) and a standard takeoff procedure. In order to generate a more cognitive workload for every scenario, participants were not aware of the scenarios beforehand.

Chapter 6 - Visual Attention and Updated Attentional Task Model

Ensuring the steady advancement of the civil aviation sector demands careful attention to numerous crucial elements. Among these, the conduct of aircrews holds significant significance in guaranteeing effective operational procedures and aviation safety, particularly during emergency scenarios [41, 67]. With the ongoing advancement of technology, automation, and advanced sensing in both military and commercial aviation, there have been notable changes in human information processing. For instance, modern pilots do not rely as heavily on processing visual information outside the cockpit compared to earlier years of aviation. Instead, they need to extract information from various sources, including multiple instruments within the cockpit, and integrate it into a coherent understanding to manage the flight effectively [39]. The eye is the primary sensory organ for pilots, responsible for processing approximately 80% of all flight-related information. Thus, it becomes evident that analyzing visual information processing becomes essential when examining potential decrements in flying performance or factors influencing performance, such as attention, fatigue, or stress. A valuable approach to analyze visual information processing is through the examination of eye movement data [39].

In the process of taking off, pilots are required to execute a sequence of intricate operational procedures while simultaneously keeping a close watch on specific flight instruments like the attitude indicator, speed, altimeter, and engine parameters, as well as the external surroundings when the weather is clear. This monitoring task, particularly during dynamic flight phases like takeoff and landing, encompasses interpreting flight path data, the status of aircraft configuration, automation modes, and onboard systems. This demanding and intricate responsibility has the potential to place pilots under significant cognitive strain [41, 68]. Different levels of cognitive load can result in varying visual-motor skills and abilities among pilots, thereby impacting the precision of aircraft control [69]. Elevated cognitive load can potentially give rise to illusions and misjudgments, leading to occurrences such as spatial disorientation.

This chapter explores the possibility of establishing a correlation between attention and measured PD during critical events. Hypotheses 3 and 4 as well as objectives 3 and 4 of the study specifically focus on these aspects.

6.1 Updated Attentional Task Model

The main goal of this section is to update the attentional scores (section 4.3.4) based on the experiment data. Therefore, this model takes the Attentional Task Model, the Reference Model and the Pilot Assessment (real time data from the experiment) as inputs and updates the Attentional Task Model via updating the attentional score for each task (Figure 18). Finally, it will update the Attentional scores in the Reference Model (Figure 19). To this end, as mentioned in section 6, we recorded Pupil Dilation, Heart Rate and EEG signals from 13 subjects during the performance of a sustained attention task (takeoff simulation). These measures were used to compute a final cognitive load assessment of the pilot and also attention levels. The attention levels and cognitive load value are in the scale of zero to 100% of how much mental capacity is occupied by the observed subject. This value is on the same scale representation, as the output received from the Attentional Task Model. It should be noted that the focus of the experiment was only on takeoff and rejected takeoff phase. Thus, for now we just update the attentional score for phase 5 and 6, initial climb and rejected takeoff respectively.

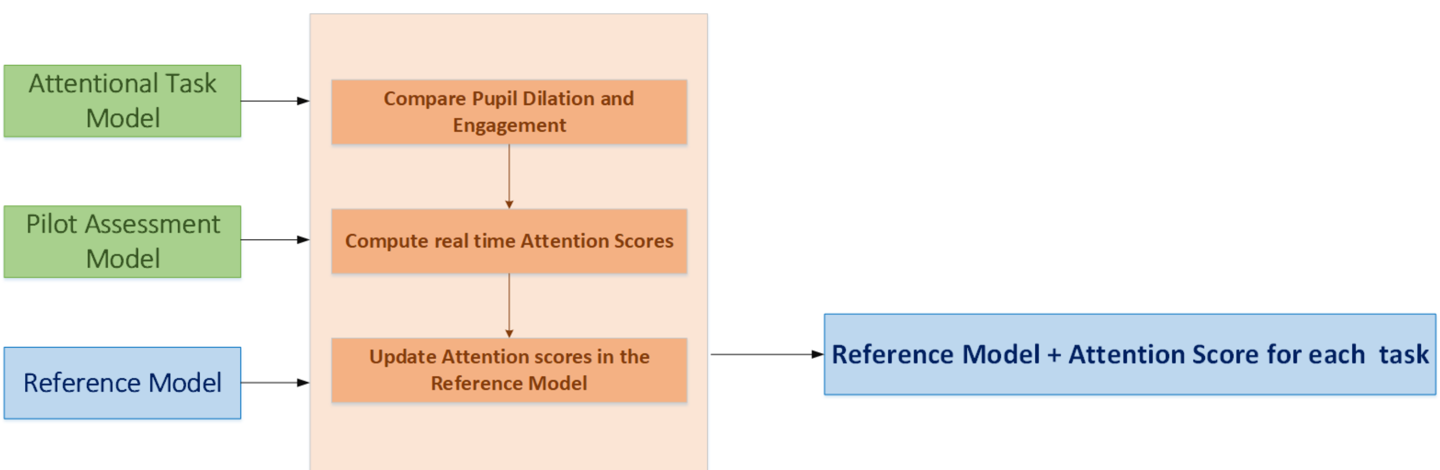


Figure 18. Structure of the Updated Attentional Task Model

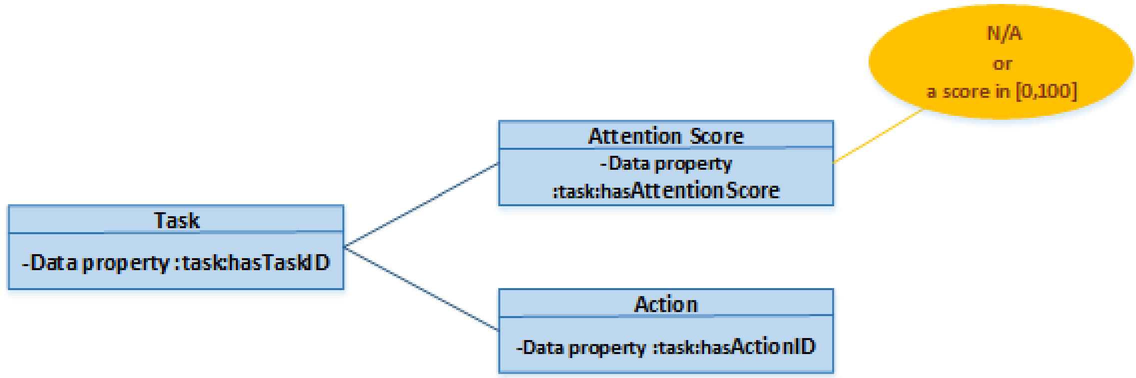


Figure 19. Updating the Attentional scores in the Reference Model

6.2 Attentional scores and reference model

During takeoff, pilots are expected to perform a variety of tasks, according to the Reference Model. In order to perform each task correctly and with high accuracy, we may need a minimum level of attention for tasks involving action.

Furthermore, takeoff may occur in a standard process or with a failure. According to the reference model (Figure 20) from Marc Antoine Courtemanche, the following probable failures are considered: "Dual engine failure with fuel remaining", "engine failure after V1" and "rejected takeoff". It is evident that each failure requires specific actions to be performed, as well as a certain level of attention. In addition, pilots need to keep their eyes on specific visual displays (AOI) during each form of takeoff, especially when a failure occurs.

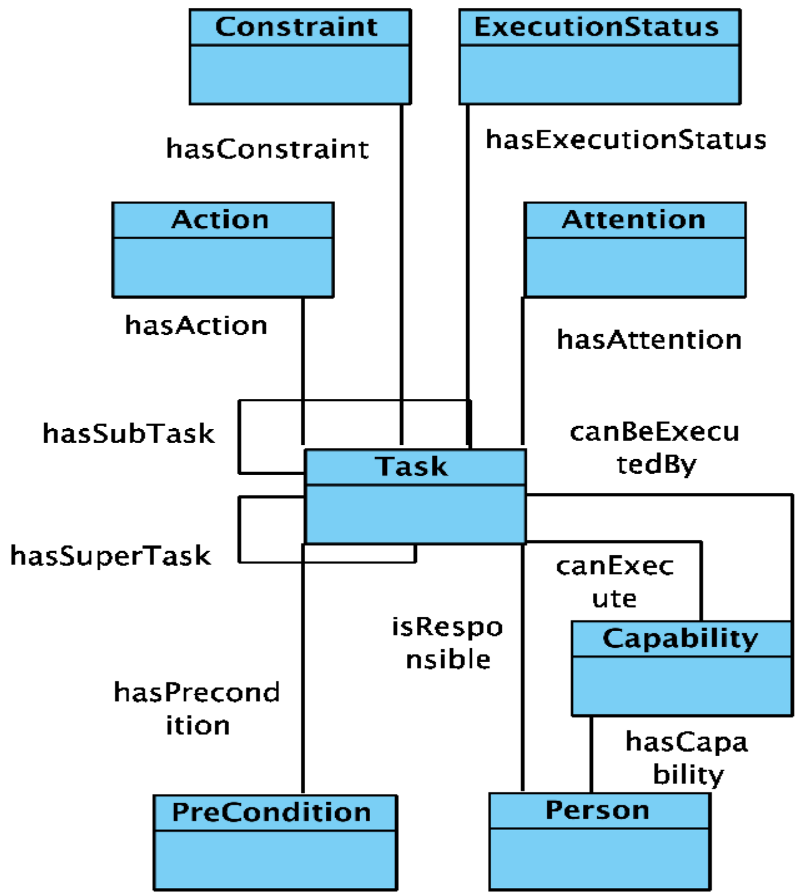


Figure 20. Standard takeoff

6.3 Attention and eye tracking

Two formulas for calculating attention using eye-tracking data are used and introduced in this section[41, 70]. By using these formulas with our experiment-gained insights, we have devised a novel technique for determining visual attention in the A320 Simulator during takeoff phases. Our approach segments the screen viewed by the pilot into several distinct areas (Figure 21), rather than considering it as a unified whole [71].

The acquisition of visual information is mainly through the eyes, and the process of eye movement reflects the process of visual thinking. Therefore, it is feasible to use eye tracking to obtain eye movement data to analyze the distribution rule of observers' visual attention. Based on the studies, area of pixels (pixel as the smallest unit), can be used to divide the target screen into areas of interest (AOI), as shown in Figure 21. There is some areas of Interest (AOI) in the simulator for which their attentional score can be calculated. Based on the experiment that we had done, there are five important areas and dashboards named "Navigation Display (ND)", "Primary Flight Display (PFD)", "Engine/Warning Display (E/WD)", "System Display (SD)", and the "Runway", which were used in the past experiment (Figure 22) [71].

Figure 21. Areas of interest for takeoff

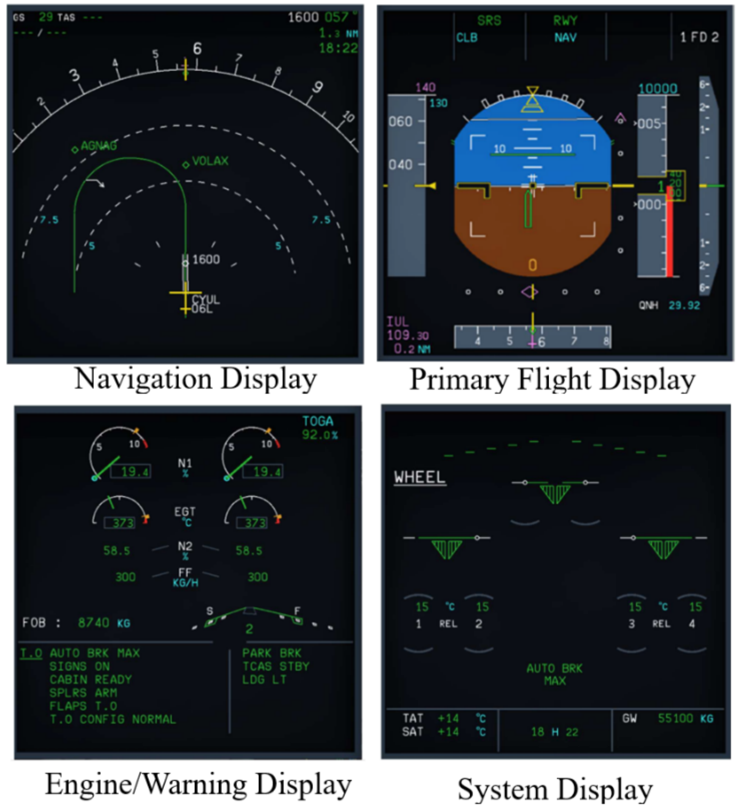


Figure 22. Instruments for takeoff

Visual factors and visual saliency[4] can be studied using eye-tracking technology by researchers and practitioners. When referring to visual saliency, we refer to the extent to which an object or feature in a visual scene attracts attention or catches the eye.

In eye tracking, a person's gaze is tracked as he or she looks at a visual display, such as a computer screen or a poster. Eye tracking records where and how long people look in a scene, giving insight into what they find salient. As a result of this information, it is possible to understand how visual factors in a scene are related to object saliency. Thus, an eye-tracking system can link visual factors and visual saliency. The main eye-tracking indexes which can be used to determine the relationship between the eye tracking index and visual attention [6], and their specific meaning are presented based on the gaze point documentation:

Fixation POG: By using the internal fixation filter, POG (Point of Gaze) data determines the user's point-of-gaze, expressed as FPOGX and FPOGY. In other words, Fixation Point of Gaze (FPOG)

[4] The distinct subjective perceptual quality, which makes some items in the world, stand out from their neighbors and immediately grab our attention.

refers to the specific location where a person's eyes are focused on when they are observing a visual display.

FPOGS: Point of Gaze start times which are expressed in seconds since system initialization Using the start times of Point of Gaze (POG) in eye tracking, insights into the initial focus of attention can be gained. This helps identify the most salient features or noticeable aspects within a visual stimulus or scene.

FPOGD: Fixation Point of Gaze (FPOG) duration in seconds.

FPOGID: The ID Number associated with the Fixation Point of Gaze (FPOG).

As mentioned earlier, pixels (pixel as the smallest unit), can be used to divide the target screen into areas of interest (AOI). We divided the screen into 5 areas of interest based on area of pixels (Figure 21).

A point in a coordinate is named by its ordered pair of the form of (x, y). The first number corresponds to the x-coordinates and the second to the y-coordinate. For screen coordinates, the origin is the upper-left corner of the screen. Usually, the full position of a window is represented as a rectangle with two points defining its upper-left and lower-right corners.

Each window coordinate, which consists of four numbers separated by commas or spaces, defines the boundaries of each area of interest. Two points on the screen are represented by these four numbers. "X" and "Y" coordinates of the first point are indicated by the first two numbers, while "X" and "Y" coordinates of the second point are indicated by the final two numbers. The screen's upper-left corner is marked by "0,0," while its lower-right corner is marked by "1,1." The screen's centre is marked by [0.5,0.5]. By using these two points, we can define the position and size of a window. Specifically, the first point defines the upper-left corner of the window, while the second point defines the lower-right corner. It is possible to define a window's position and size using these two points. The boundaries of each area of interest are as follows:

- Visual Display 1: [0, 0.66] and [0.18, 1]
- Visual Display 2: [0.19, 0.66] and [0.38, 1]
- Visual Display 3: [0.66, 0.66] and [0.84, 1]
- Visual Display 4: [0.85, 0.66] and [1, 1]
- Visual Display 5: Runway
- Visual Display 6: All other coordinates.

Thus, the ***FPOG*** has been used to find the visual display that pilots was looking at each portion of the second. The **FPOGID** has been used a sign indicating a change in the point of view. According to [20], the duration of the FPOG can be used as the only effective factor, which shows the distribution of visual attention during each second of the flight.

$$A = \frac{FPOGD}{\sum FPOGD} \qquad (1)$$

This formula considers the portion of fixation time. The proportion of fixation time on a specified AOI, can be used to measure the distribution of **visual attention** during the flight phase (or any phase segment). The idea of this formula is to divide the duration of the fixation POG during the occurrence of each event by the total time of that event. By doing this, visual attention will be independent of the total duration of the event. In this way, we can see what portion of time the pilot (participant) has looked at each display window. If only one display window was observed for the entire duration of the event, the A will be equal to one (or 100% in scale of 0 to 100), which means that the pilot paid full attention to that display window during the event. Hence, the gaze duration (sum of fixation durations on a specific AOI) was used as the basis for evaluating visual attention distribution. However, we focus only on the distribution of attention during each second in this study. The goal is to find out which display window the participant is looking at each second of the flight [71].

I categorized the tasks associated with each form of takeoff, as well as the visual displays that must be considered (tables 4 to 6).

Table 4. Expected Area of Interest for each phase during a normal takeoff

Takeoff Task	**Area of Interest**
Announce "TAKEOFF"	PFD/ND
Set THRUST LEVERS to 50% N1	E/WD
Crosswind >= 20 kts or a tailwind: APPLY FULL FWD SIDE STICK	PFD
Release BRAKES	-
Crosswind <= 20 kts and no tailwind: Set THRUST LEVERS to TOGA	E/WD
Crosswind >= 20 kts or a tailwind: Set THRUST LEVERS to 70% N1 then progressively forward to reach TOGA by 40 KT ground speed	E/WD
Announce FMA (i.e. MAN TOGA, SRS, RWY, A/THR)	PFD
CHECK	PFD
order "L/G UP"	MIP
Set AP to ON	FCU
Set THRUST LEVERS to CL	Pedestal
Check the target speed change from V2 + 10 to the first CLB speed	PFD
At F speed, order "FLAPS 1" (or CONF 1)	PFD
At S speed, order "FLAPS 0"	PFD

Table 5. Expected AOI for each phase during a takeoff with ENGINE FAILURE after reaching 100 kts.

Takeoff Task	**Area of Interest**
Announce "STOP"	-
Set thrust levers to IDLE, IDLE REV then MAX REV	Pedestal
If AUTO BAKE action is in doubt, apply full BRAKES.	PFD
Use RUDDER PEDALS for DIRECTIONAL CONTROL	-
At 70 KTS, set thrust levers to IDLE	PFD
Set PARKING BRAKE once aircraft has come to a full stop	E/WD

Table 6.Expected Area of Interest for each phase during a takeoff with Engine failure after V1

Takeoff Task	**Area of Interest**
Announce "ENGINE FAILURE"	-
Cancel Master Caution	-
Announce "GO"	-
Announce "ROTATE"	-
Rotate to 15 degrees pitch at a rate of 3 deg/s	PFD
After liftoff, follow SRS pitch commands	PFD
Call to "PULL RWY HEADING"	-
order "L/G UP"	-
Raise L/G	-
Set beta target to zero using rudder pedals	PFD
Set RUDDER TRIM (may have to skip this step)	Pedestal
Call for AP ON when aircraft is stable	PFD
Say "I have control and communication"	-
Call "ECAM ACTIONS"	-
Push FCU V/S to set V/S to 0	FCU/PFD
At F speed, order "CONF 1"	PFD
At S speed, order "FLAPS 0"	PFD
At green dot speed, pull FCU ALT selector to set OP CLB	FCU
Set thrust lever to MCT.	Pedestal

6.4 Attention and Engagement

During a task, engagement refers to a participant's emotional experience resulting from several factors, including focused attention, aesthetic pleasures, novelty perceptions, usability perceptions, and whether the participant feels involved. It has been hypothesized that choice, clear feedback, adaptive difficulty, novelty/exploration, as well as viscerally pleasing stimuli, contribute to engagement [72]. However, engagement is not all about consciously enjoying an experience or being self-motivated to complete a task either. Someone's ability to withdraw their attention can be a legitimate and powerful form of engagement[72]. The automated assessment of pilots' attention levels can be used as an indicator of their active engagement [48].

6.4.1 Engagement & Cognitive Load Extraction

Various sensors that track participants' electro-dermal activity, eye movements, heart rate, posture, facial expressions, or brain activity can be employed individually or in combination to deduce states such as engagement, attention, frustration, flow, boredom, and more [73].

Electroencephalogram (EEG) signals can provide two key mental indicators: cognitive load and mental engagement. These indicators are frequently used to dynamically assess changes in users' states across fields like aviation, robotics, and the military, given their strong correlation with user performance and experience [73, 74].

In contrast to the engagement index, directly assessing mental cognitive load from EEG data lacks a universally established method. Nonetheless, the development of EEG-based indexes for cognitive load evaluation using machine learning algorithms has been a well-explored research area across various applications. Consequently, a cognitive load index can be formulated by training and validating a prediction model using a diverse range of memory and logical tasks [73, 74].

The term mental engagement refers to the level of attentiveness and focus invested in a task, and it is a critical element during the learning process due to its close ties with motivation, memorization, and learning achievement. [74]. The Engagement index can be directly computed from the EEG signal frequency bands. Thus, it is computed using three EEG frequency bands, namely: θ (4-8 Hz), α (8-13 Hz) and β (13-22 Hz) as follows:

$$E = \beta / \theta + \alpha \quad (2)$$

The engagement index is computed each second from the EEG signal [73, 75].

6.5 Conclusion

The purpose of this section was to present a method for updating the Attentional Task Model and Attentional scores in the Reference Model using data from the experiment. We proposed two techniques for accurately determining the pilot's attention state. The first approach uses eye tracking data (total gaze duration) to calculate visual attention, while the second involves comparing pupil dilation curves with curves of engagement and workload obtained from EEG.

This will result in an attentional score between 0 and 10 for each task performed during takeoff or rejected takeoff. It is expected that the average attentional score for the entire phase (takeoff or rejected takeoff) will be similar to what was obtained from the focus group. Additionally, it is crucial to consider parallel tasks and their sources when evaluating the level of attention given to each task. The presence of two or more parallel tasks originating from a common source increases workload and demands a higher degree of attention.

Chapter 7 - Data Analysis and Results

In this study, detailed information was presented in previous chapters on the extraction, interpretation, and recording of various data types using a specific architecture and a strict procedure. This chapter builds upon that foundation by focusing on the merging of all the data logs and highlighting the data points that are present. The first objective of this chapter is to provide a comprehensive overview of the data, including its sources, format, and characteristics. The second objective of this chapter is to showcase the power of combining eye tracking and EEG data to gain a deeper understanding of the attention levels of pilots and distinguish expert pilots from novice ones**. This chapter also focuses on hypotheses 3 and 4 of the study, as well as objectives 3 and 4. The chapter aims to analyze these hypotheses and objectives, providing insights into the potential relationships between attention, PD, and EEG measurements during critical events.**

In particular, the chapter will explore the relationship between eye tracking data, such as fixation duration, and EEG data, such as engagement and workload levels. The results of this analysis will reveal patterns in the attention of pilots during critical phases of flight and provide valuable insights into how attention levels can impact performance and safety. Additionally, the study will demonstrate how these data points can be used to differentiate expert pilots from novice pilots and inform the development of training programs aimed at enhancing the safety of air travel.

This chapter will be an important contribution to the growing body of research on the relationship between attention and performance in complex tasks, and it will provide valuable insights into the use of physiological measures for understanding engagement and workload in pilots. Ultimately, this research will have practical implications for the aviation industry, providing a foundation for future research aimed at improving the safety of air travel. Two publications on this topic have been authored by me [71, 76].

7.1 Overview of Data Features

In this section, we present a brief summary of the various data points collected during the experiments. Some of the data points collected by the measurement tools may not be relevant to this research and will not be discussed in detail. Table 9 provides a comprehensive list of the data gathered, along with its abbreviations and a concise description of each data point.

Table 7.An overview of the captured data with its corresponding description.

#	**Attribute**	**Description**	**Type**
1	Time	The time at which the data was recorded in milliseconds since the epoch	float
2	LPD	The diameter of the left eye pupil in pixels	float
3	RPD	The diameter of the right eye pupil in pixels	float
4	Fixation POG	The Fixation POG data provides the user's point-of-gaze as determined by the internal fixation filter	float
5	FPOGX, FPOGY	The X- and Y-coordinates of the fixation POG, as a fraction of the screen size. (0,0) is top left, (0.5,0.5) is the screen center, and (1.0,1.0) is bottom right	float
6	FPOGS	The starting time of the fixation POG in seconds since the system initialization or calibration	float
7	FPOGD	The duration of the fixation POG in seconds	float
8	FPOGID	The fixation POG ID number	integer
9	Alpha	Brain waves with a frequency range of 8-13 Hz and are typically associated with a relaxed and awake	float
10	Beta	Brain waves with a frequency range of 13-30 Hz and are generally associated with a state of alertness, focus, and increased mental activity	float
11	Theta	Brain waves with a frequency range of 4-7 Hz and are associated with a state of deep relaxation or meditation, as well as with sleep	float
12	Workload	Percentage of workload	integer
13	Engagement	Percentage of engagement	integer
14	Status	Video recording status events(Start, Stop)	
15	Event type	Events during the experiment(start scenario, Stop scenario, Speed, Engine failure)	
16	Flight	The current flight number	
17	Pilot	The pilot number which uniquely identifies a participant	
18	Scenario	The scenario that currently being played	

7.2 Fixation Duration and Attention

A participant may gaze at one or more visual displays per second, as explained in the previous sections. Knowing what visual displays the participant was looking at, at every second of a flight is crucial to determining his correct and proper performance. Each period of the flight includes special tasks, so the participant is expected to pay attention to special visual displays at those times. Consequently, comparing the areas that the participant looked at every second with the areas that he was supposed to look at gives us valuable information about the participant's ability to control the flight and his level of performance.

Two participants' data output examples are shown here. As shown in Figure 23, the first one exhibits the data output of an official A320 pilot with over 250 formal flight hours and eight years of experience during a rejected takeoff (sixth pilot). In addition, the second one shows the output of a non-licensed pilot for the same scenario. This pilot has flown in the simulator with the A320 for testing purposes but is not a licensed pilot. He is an A320 engineer who knows the ins and outs of the aircraft (fifth pilot). In figures 23 and 24, we can see which screen participants 5 and 6 were watching throughout the flight.

Figure 23 gives us the information about participant 6 and 5, flight 6 and scenario 4. As you can see participants' fractions of a second spent on each visual display are displayed in different colors. For example, a participant's attention was diverted to three areas of one, two, and three in the 2th second, but in the 10th second, the participant focused entirely on the runway. It should be noted that, for different windows, the sum of fractions of seconds is the maximum one since our measurement standard is one second.

During a flight, the visual displays a participant looks at can provide valuable information about their ability to control the flight. Checking whether they looked at the appropriate displays can be determined by comparing where they looked with where they were supposed to look (tables 5 to 7). Pilots with licenses (participant 6) demonstrated better focus during a rejected takeoff scenario than non-licensed engineers with no licenses (participant 5). Thus, monitoring a pilot's visual attention during critical scenarios can enhance pilot training and flight safety [71].

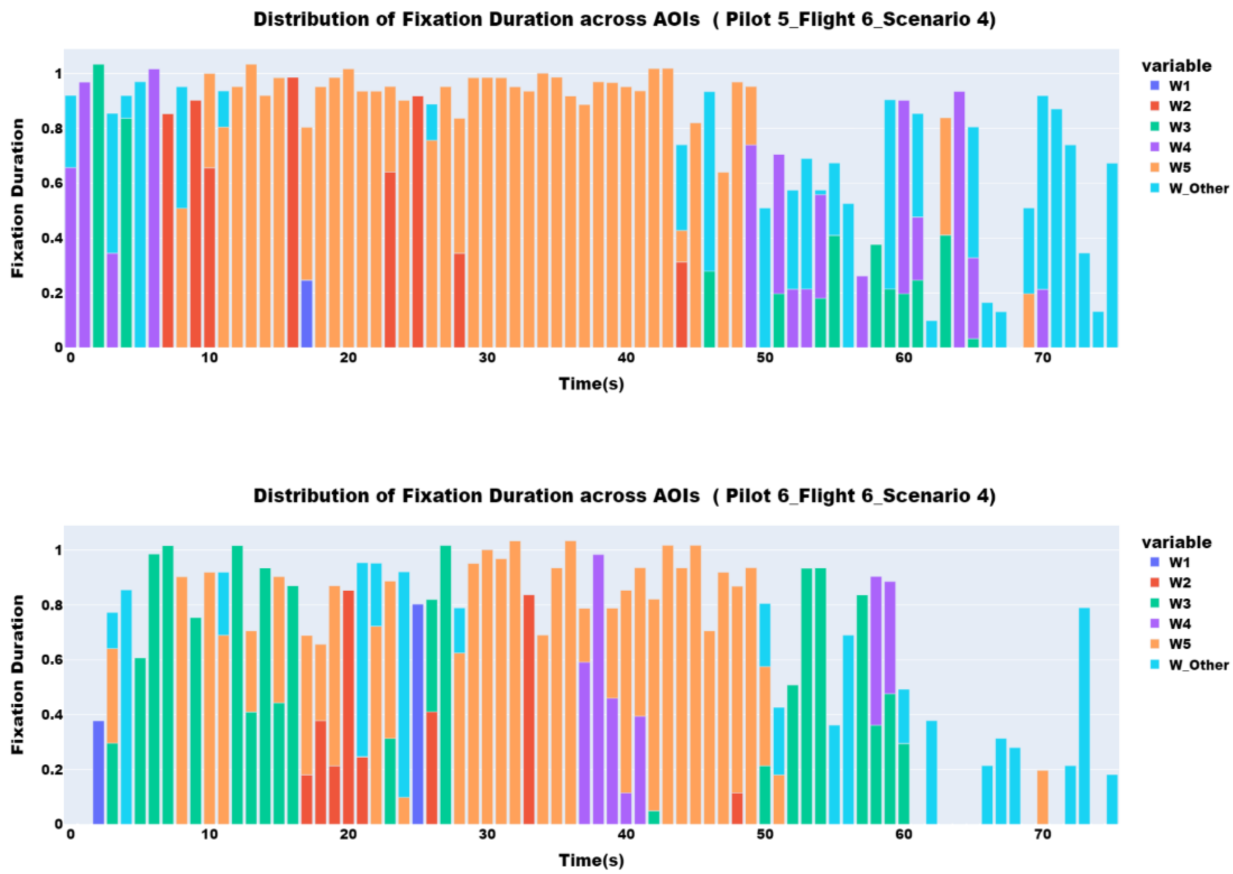


Figure 23. Distribution of fixation duration across AOIs Related to Pilot 6 and 5

As shown in figure 24, the duration of the fixation POG at each Area of Interest is shown in seconds, 3 seconds before and after the engine failure. The figure on the down represents the 6th participant, and the figure on the top represents the 5th participant. In the 3 seconds leading up to the engine failure, the 6th participant looked at the primary flight display and the most at the runway and had everything under control. The pilot's attention was only focused on the front window (Runway) once the engine failed, so he could keep the plane on its course by controlling the pedals.

However, the figure on the top shows that before the engine failure, the 5th participant mostly looked at the primary flight display and the front window (Runway), failing to pay attention enough to the other runway, which is very critical at the time of failure. Additionally, he was not only focused on the runway at the time of the engine failure but was also looking around. He randomly looked at visual display 2 (primary flight display), the runway and around, indicating a lack of control of the aircraft and the fact that he does not know where to look at.

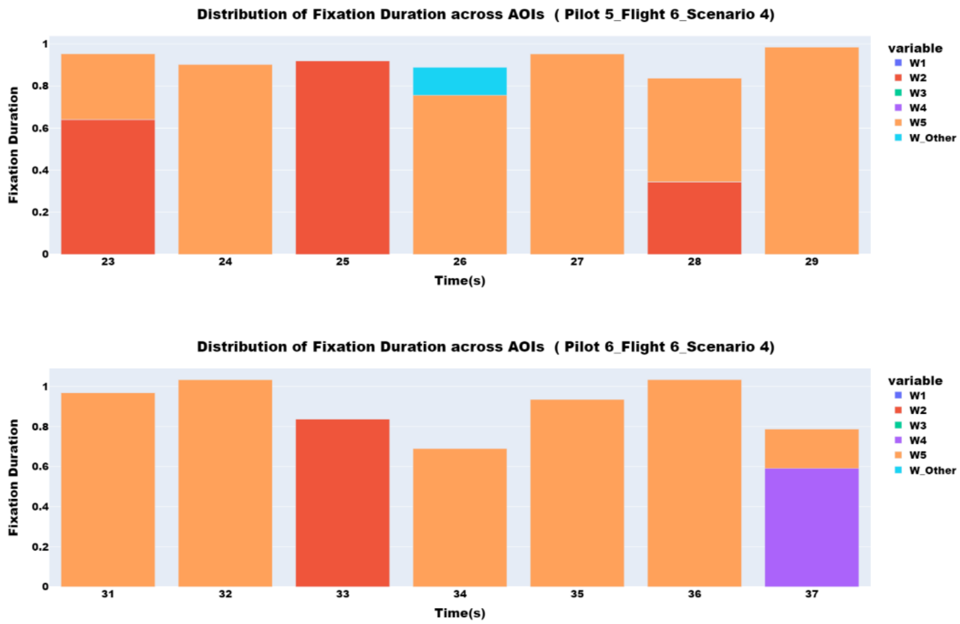


Figure 24.Distribution of fixation duration across AOIs 3 sec before and after engine failure (Related to Pilot 6 and 5)

Based on the pie chart (figure 25), we can see how pilots' attention is divided between different visual displays (AOIs) throughout the whole flight. Visual displays are represented by slices of the circle. Based on the size of each slice, we can determine how much attention the pilot paid to each visual display during the flight. The figure on the left represents the 6th participant, and the figure on the right represents the 5th participant. As you can see, both participants looked at the runway for almost half of the flight (this is not unexpected since the pilot's primary goal is to keep the plane on course, so spending so much time in the front window (runway) makes sense). However, it is the amount of time participants spend looking at different dashboards that distinguishes the experienced pilot participant from the non-pilot participant. As it is shown, participant 6, who was an expert pilot, spent more than a quarter of the flight looking at dashboard 3 (Engine/Warning Display), which is quite reasonable given the engine failure and shows he has control of the flight. He looked at the dashboard 2 (Primary Flight Display) and 4 (System Display) for about 6% of the total flight time (6.2% and 6.71% respectively).

However, despite the importance of dashboard 3(Engine/Warning Display), only 7% of the 5th pilot's attention was focused on this dashboard. A greater amount of attention was paid to dashboard 2 (Primary Flight Display) and dashboard 4(System Display). It shows he had no control over the flight, as he looked at different dashboards at random and was not aware of where to look at all times

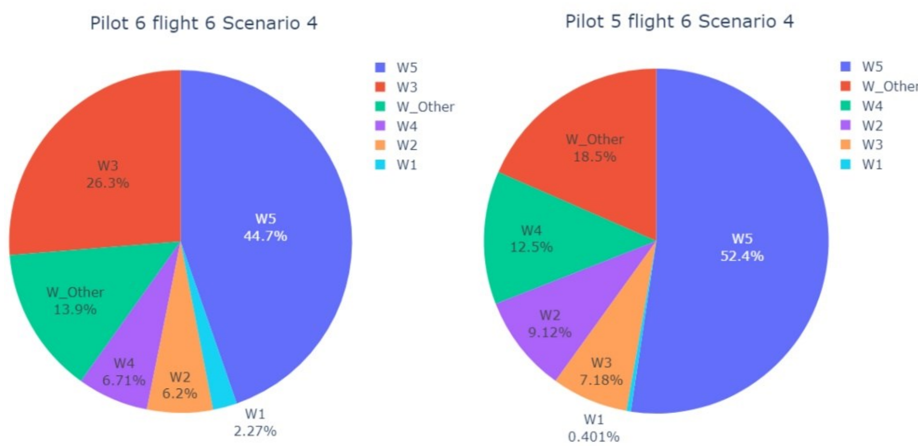


Figure 25. Pilot attention distribution across areas of interest (AOIs) during flight.

7.3 Pupil Dilation and Attention

One of the hypotheses that this research tries to answer is: "Is it possible to measure pilot attention during a takeoff flight?", hypotheses 1.

Here we show the data output examples of two participants. The first one (Figure 26) shows the data output of an official A320 pilot with eight years of experience and more than 250 official flight hours during a rejected takeoff. The other figure (Figure 27) is related to output of a non-licensed pilot for the same scenario. This pilot is an A320 engineer who knows the ins and outs of the A320 and has flown on the simulator with it for testing purposes but is not a licensed pilot.

The figures include:

- The Engagement, Pupil Dilation, and Cognitive Workload of the pilot at a time t.
- Important events, which resulted in a Cognitive Workload increase.

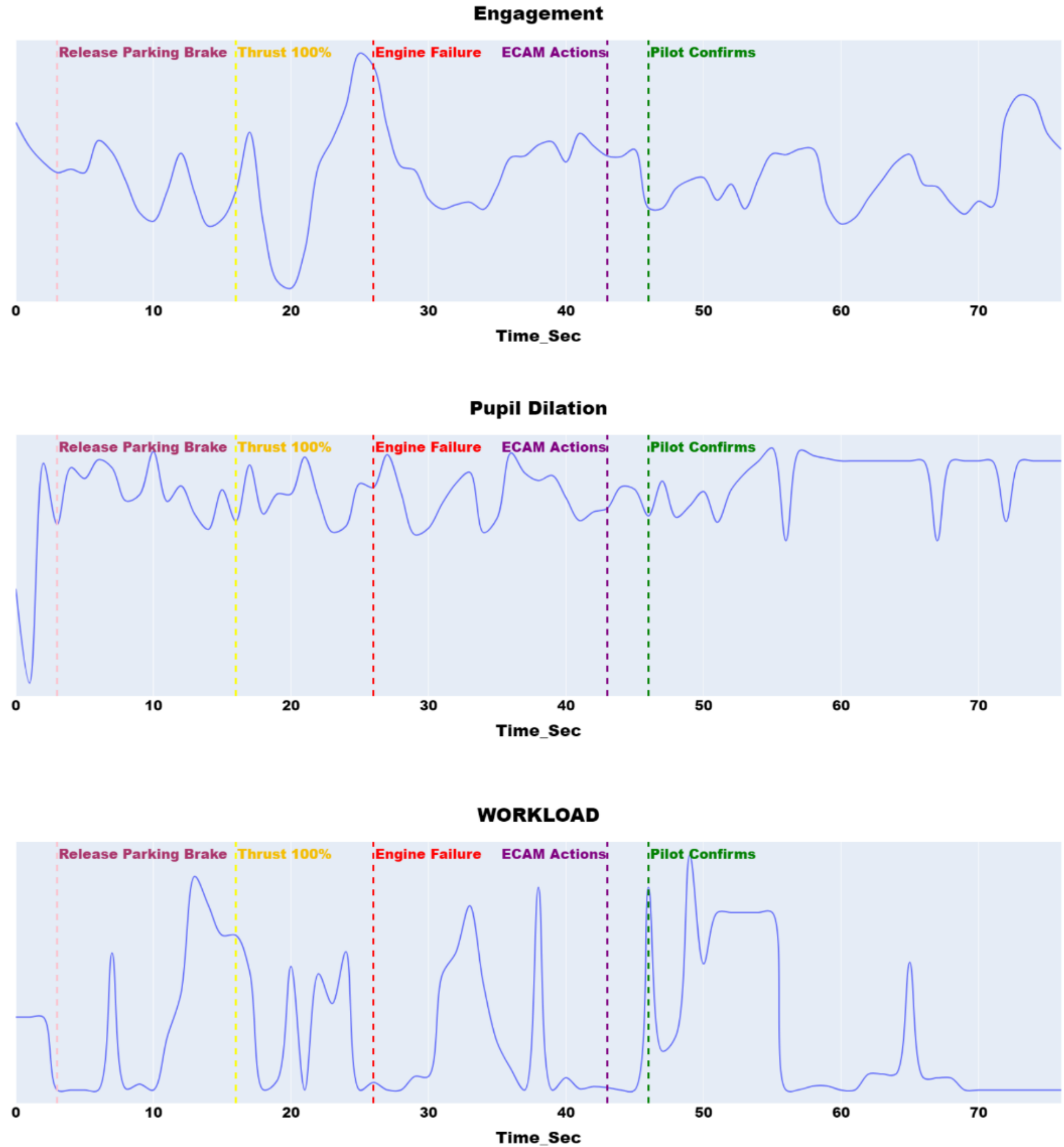


Figure 26. Data output of an official A320 pilot with eight years of experience and more than 250 official flight hours.

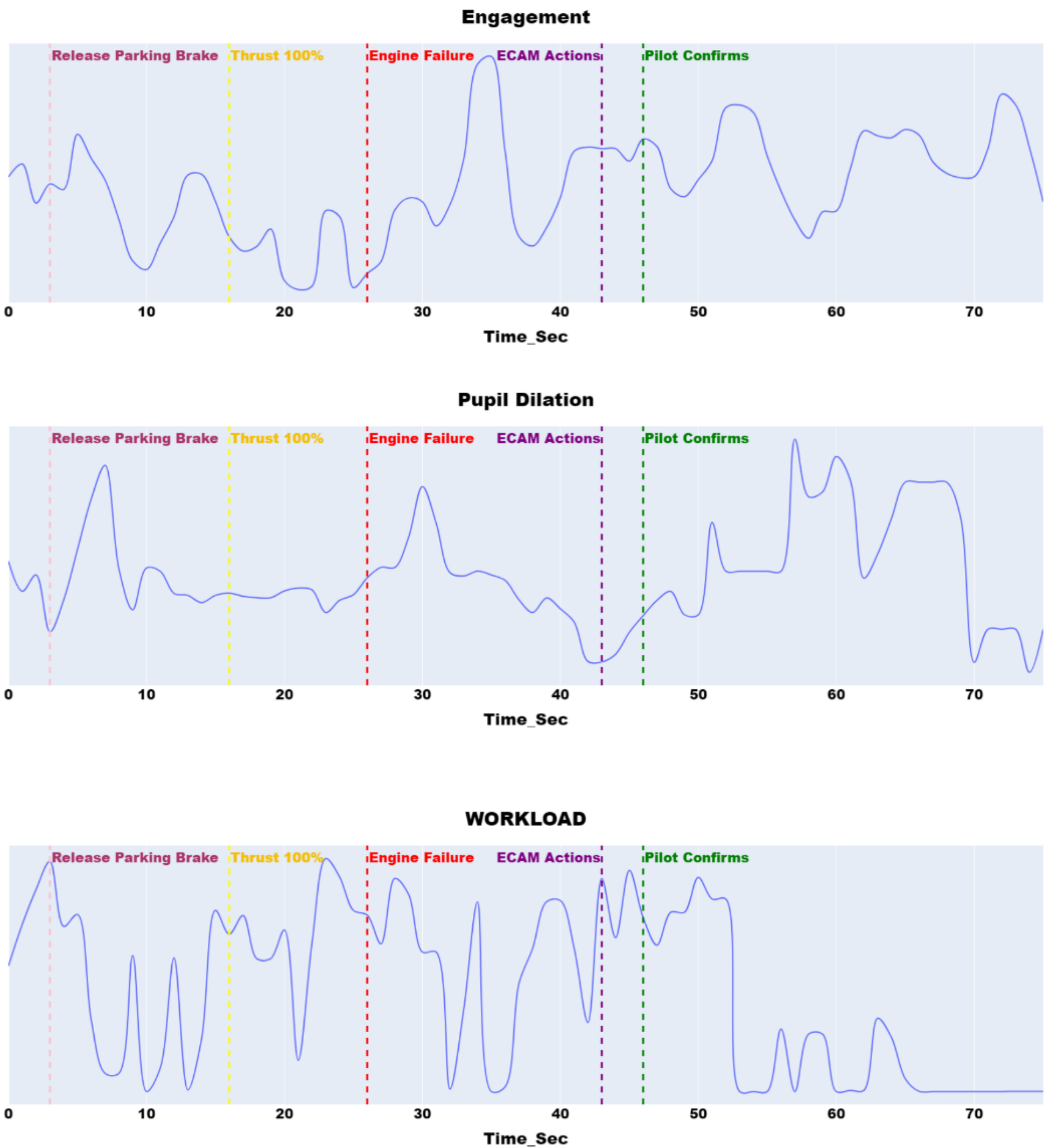


Figure 27. The data output of a non-licensed pilot (an A320 engineer).

In each Figure, the three plots are aligned vertically based on time. Time 05^{th} Sec is the start of this scenario when the parking brake is released (first vertical line) and 50^{th} sec is almost the end of scenario, ECAM action and when the pilot confirms the engine must be turned off (last two vertical lines).

As pupil dilation directly relates to someone's attention and is often used as a physiological measure of cognitive load, attention, and engagement, our main focus will be on the dilation directly and its relation with cognitive workload. As we can see in the figure 26, from time zero to 05^{th} Sec, which is the start of this scenario when the parking brake is released (first vertical line), the workload is low due to the fact that the flight is a regular operation and does not require excessive resources. The pupil dilation is high from the beginning until 15^{th} sec, because the plane is about to take off and the participant wants to maintain it in the middle of the runway. There is a medium to high level of engagement during this period of time. This is the first reaction of pilots and shows that attention is triggered before the workload. The workload increased noticeable after a short delay because the brain energy was mobilized. What we see before reaching 15^{th} sec, is the peak of workload and we see that the engagement and pupil dilation has been reduced a little and then maintained at a medium to high level.

Although there is some peak in workload between 15^{th} and 33^{th} seconds, in general the workload is low. At the time of peaks in workload (which are mainly a search), we see a decrease in engagement and pupil dilation (20^{th} sec after the plane leaves the ground), but shortly thereafter, both engagement and pupil dilation increase as the pilot realizes its normal occurrence. Which means that the pilot has identified the problem, knows what to do and has applied the right task (The pilot is in full control of the problem).

Again, at 30^{th} , there is a search and the workload increase again in parallel until 34^{th} sec. There is an engine failure at 34^{th} sec. Thus, after the pilot discovered the engine failure at 33^{th} and 34^{th} seconds (when it was announced by the copilot), there was a considerable workload at first, but it decreased rapidly at 35^{th}, which indicates that the pilot was not surprised, knows the problem and has applied the right task. The pupil dilation changed quickly because of the urgency of the situation, and he knew he was going to need to be very careful. At this time, engagement also increased somewhat, but not too much because as we mentioned, he was a master pilot and had flight under control even during a failure. Again, at 50^{th} sec we see a considerable increase of workload which is almost the end of scenario(takeoff), ECAM action and when the pilot confirms the engine must be turned off (last vertical line). The workload increased because it is the end of takeoff and pilot had to think about the next action and to see what to do. Then, as we progressed from 50^{th} to the end of the flight, after making the correct action, when arriving at 52^{th} sec, the workload decreased and was low in general since he has done the correct action.

In this period, we see that the engagement was medium which means that in pilots mind, he has completed the takeoff and now he is entering to navigate. However, the pupil dilation was high due to his concern for maintaining the plane's course.

We should take into account the fact that participants know that a failure may occur during takeoff. The PD and CW curves show that despite the fact that the workload decreased and increased at different points (each CW increase was due to a specific action the pilot needed to perform), the pilot continued to be engaged even when a failure occurred, which proves that the pilot has identified the problem and knows what to do about it.

On the other hand, for the other participant (pilot 5) who was a non-licensed pilot (Figure 27), everything was completely different. At the beginning of the flight, he has a high workload since it is not a normal operation and will require a lot of energy consumption. He is unfamiliar with the procedure, and this is why the engagement and pupil dilation are low (decreased). In general, even though there are two peaks in workload, we have seen a decrease in workload until the 10^{th} sec. This is while both engagement and pupil dilation decreased and maintained a medium level after a sharp increase at around 4^{th} sec. which is not normal because the pilot has decreased the workload and not fully mobilized on the task and the workload is decreased while the attention remains medium to high.

From the 10^{th} sec to the 26^{th}-sec pilot realized that he has to face over steps of tasks that is why workload increased. At this point, the workload is maximum and in parallel, the pilot’s Engagement and pupil dilation increased slowly. This means that the capability of pilot is fully mobilized. The engine failure was announced in Sec 26. Pilots, however, did not realize this before announcing it as we see that the workload increased following the announcement of engine failure. Engagement and pupil dilation increased at first, but not much (just a small amount) and then decreased, showing he was not engaged and unsure of what to do.

From 35th sec to 43th sec, the workload increased while both engagement and pupil dilation decreased which is not good and he should be fully attended, because he did not know what to do and looking for what to do. After that, we see a sharp increase in workload ((very high workload)) during the ECAM action period, which is between 43th and 50th sec, whereas engagement and pupil dilation are low or medium. Which is again not good and normal.

The graph shows that most of the time when the workload is high, engagement is low or average. When the workload is low, engagement is high, but that is no sign of flight control. When the engagement is increase while the workload is low, means that the pilot has not enough resources and look around to see what to do [76].

7.4 Conclusion

In conclusion, this study aimed to investigate the relationship between physiological measures and cognitive processing in pilots. The study focused on two physiological measures: pupil dilation and engagement measured by EEG, and evaluated their relationship with the workload and attention. The results showed a strong correlation between **pupil dilation and engagement** measured by EEG, indicating that these two physiological measures are related and follow the same pattern. Additionally, the study found that both pupil dilation and engagement measured by EEG were positively correlated with the workload as measured by EEG, further emphasizing the utility of **pupil dilation as an indicator of cognitive processing**. These findings demonstrate the usefulness of combining these two physiological measures to understand engagement levels and cognitive workload in pilots.

Additionally, the study investigated the attention distribution of expert and novice pilots during takeoff, using fixation duration as a measure of attention. Fixation duration can help to measure attention because it reflects the amount of time that a person spends looking at a particular location. In general, longer fixation durations are associated with higher levels of attention, as the longer someone looks at a particular location, the more information they are likely to extract from it. In the other word, Fixation duration can be used to determine the relative amount of attention paid to different locations or objects in a scene. Locations or objects with longer fixation durations are likely to have received more attention. The results showed a clear difference in fixation duration between the two groups, with the expert pilot maintaining a consistent focus on the relevant display window, while the novice pilot's attention was less targeted.

The findings of this study have practical implications for aviation, as they can be used to differentiate expert pilots from novice pilots and improve pilot training programs. They also contribute to the advancement of research in this field, open up new avenues for future research in this field, aimed at enhancing the safety of air travel. Overall, this study highlights the importance of physiological measures in understanding engagement, workload, and attention distribution in pilots, and demonstrates the potential of combining these measures to gain a more comprehensive understanding.

Chapter 8 – Conclusion

In this research, the focus was on investigating the real-time attention of airline pilots during takeoff and understanding the relationship between physiological measures and cognitive processing in pilots. Two physiological measures, pupil dilation and engagement measured by EEG, were used to evaluate their relationship with workload and attention. The study classified flight tasks based on their attentional scores, which were obtained through a focus group, and found that the required level of attention for each phase was directly related to the presence of important factors, contributing factors, and types of tasks involved in each phase.

Real-time experiments were conducted during actual flights to obtain data that reflects the real-world environment and conditions that pilots experience. The study used a controlled environment in a flight simulator that introduced changes in cognitive workload through simulated failures, allowing for the manipulation of workload levels and the measurement of attention in real-time during takeoff using EEG, heart rate monitor, and eye tracker in conjunction with simulated flight failures.

The study found a strong correlation between pupil dilation and engagement measured by EEG, indicating that these two physiological measures are related and follow the same pattern. Both pupil dilation and engagement measured by EEG were positively correlated with the workload as measured by EEG, further emphasizing the utility of pupil dilation as an indicator of cognitive processing.

Additionally, the study investigated the attention distribution of expert and novice pilots during takeoff using fixation duration as a measure of attention. The results showed a clear difference in fixation duration between the two groups, with the expert pilot maintaining a consistent focus on the relevant display window, while the novice pilot's attention was less targeted.

It is worth noting that I have authored four papers:

- Paper 1 titled "An Analysis of Mental Workload Involved in Piloting Tasks"[30]
- Paper 2 titled "Attentional Tasks Model: A Focus Group Approach" [59]
- Paper 3 titled "Attention Assessment of Aircraft Pilots Using Eye Tracking"[71]

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- Paper 4 titled "Estimation of Piloting Attention Level Based on the Correlation of Pupil Dilation and EEG"[76]

I have also received the third-best project in the field of aviation at the CRIAQ Forum 2023.

Overall, the study highlights the importance of physiological measures in understanding engagement, workload, and attention distribution in pilots, and demonstrates the potential of combining these measures to gain a more comprehensive understanding. The findings have practical implications for aviation, as they can be used to differentiate expert pilots from novice pilots and improve pilot training programs. This research advances the field and opens up new avenues for future research aimed at enhancing the safety of air travel.

8.1 Limitations

It is important to acknowledge that this study has its own limitations, and future research could build upon these findings to provide a more complete understanding of the factors that influence pilot attention. The first limitation is the use of a flight simulator rather than real-world flight conditions. While using a simulator allows for greater control over the experimental conditions, it may not fully replicate the complexity of real-world flight scenarios. Therefore, the findings may not fully apply to actual flight conditions.

Additionally, the study only measured attention and workload during the takeoff phase of flight. Other phases of flight, such as cruising and landing, may involve different levels of attention and workload. Future research could investigate attention and workload levels throughout the entire flight experience to provide a more comprehensive understanding.

Finally, the study only focused on the relationship between physiological measures and cognitive processing. Other factors, such as environmental and situational factors, could also impact attention and workload levels in pilots. Future research could explore the influence of these other factors on pilot performance.

8.2 Future work

The Pilot AI project includes this research as a foundational element for future investigations. The data collected and experimental setup will be utilized in upcoming research and modeling endeavors. This setup may also be implemented in a real simulator for future investigations, and the resulting model could serve as a basis for more complex machine learning models.

In future experiments, additional measurement tools in conjunction with cognitive workload and attention could be employed to determine if it is feasible to forecast a pilot's attention without utilizing any EEG headset. Additionally, to obtain a more comprehensive data range in a realistic setting, new failures could be introduced and monitored in an actual A320 cockpit.

In recent discussions, the limitations of using the gaze point as the only representation of the locus of attention have been raised and suggests combining it with other measurement tools for a better understanding of human attention. In recent studies, thermal imaging and temperature sensors have been used as a means of understanding users' mental states. These tools, when combined with eye-tracking, can help classify attention based on the detection of overt attention. The use of thermal imaging and temperature sensors can add a new dimension to the study of human attention, and this could be a valuable addition to future experiments.

It should be noted that for the second experiment, which is set to take place in mid-May 2023, the thermal camera has already been integrated with other sensors to collect relevant data. Furthermore, the Xplane logger has been included to record all aircraft movements and related data, providing insight into the exact timing of events.

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